Annual Report on:

EXPLORATION ACTIVITIES

And

PROPOSAL FOR FUTURE EXPLORATION

On

EXPLORATION LICENCE 9434
HARTS RANGE, NORTHERN TERRITORY

JULY 1977

Barfuss Corporation Pty. Ltd.
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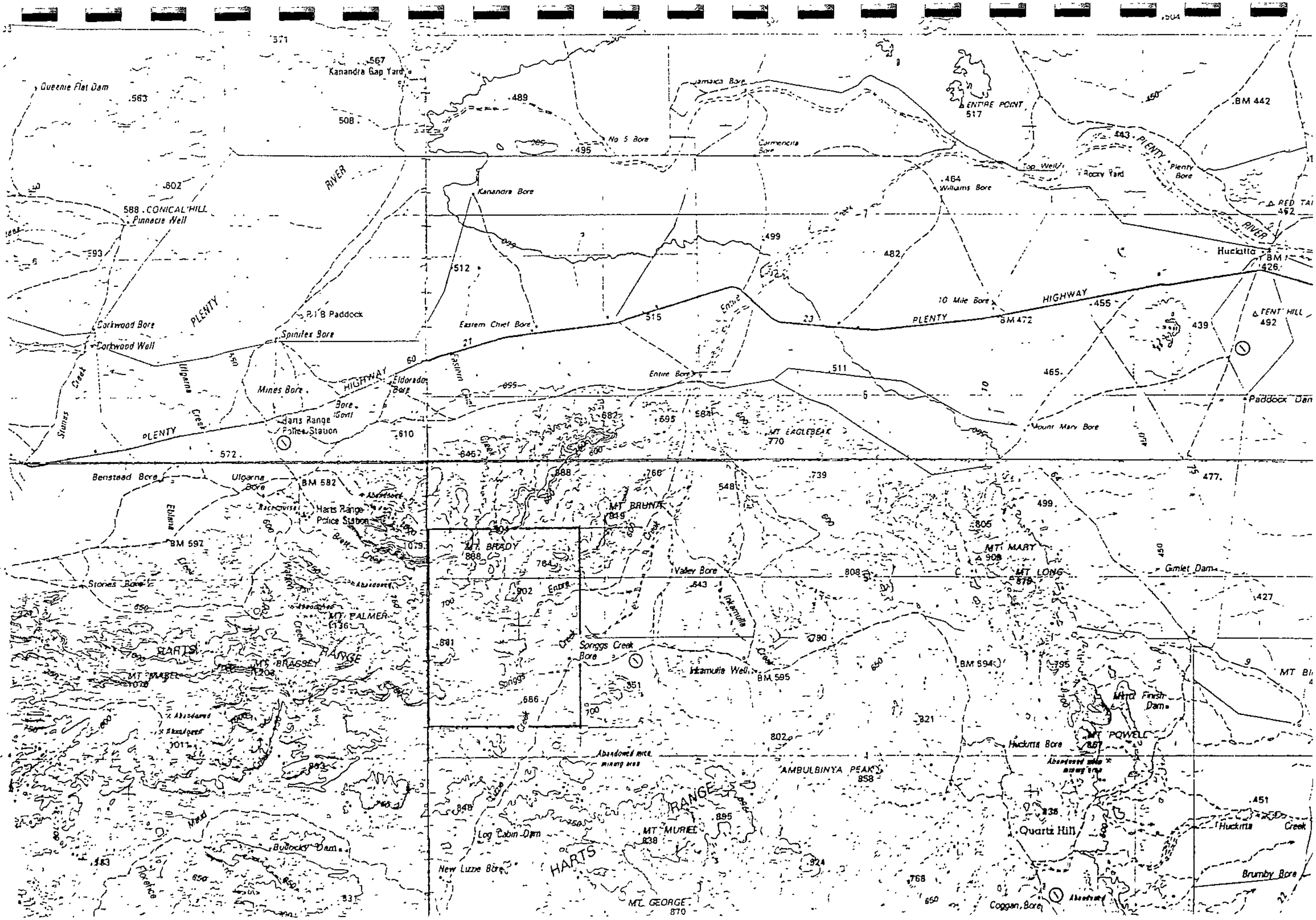
Table of Contents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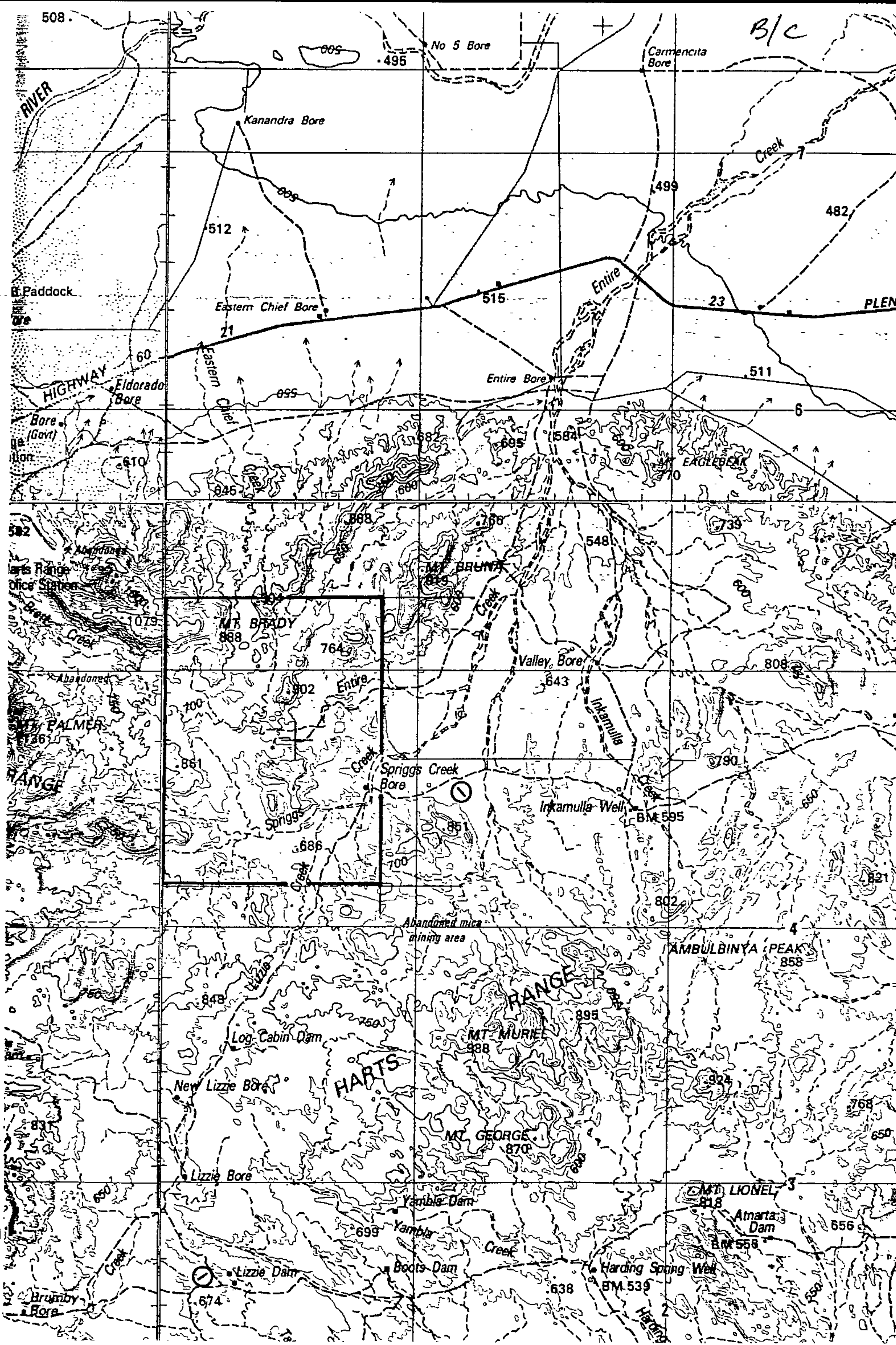
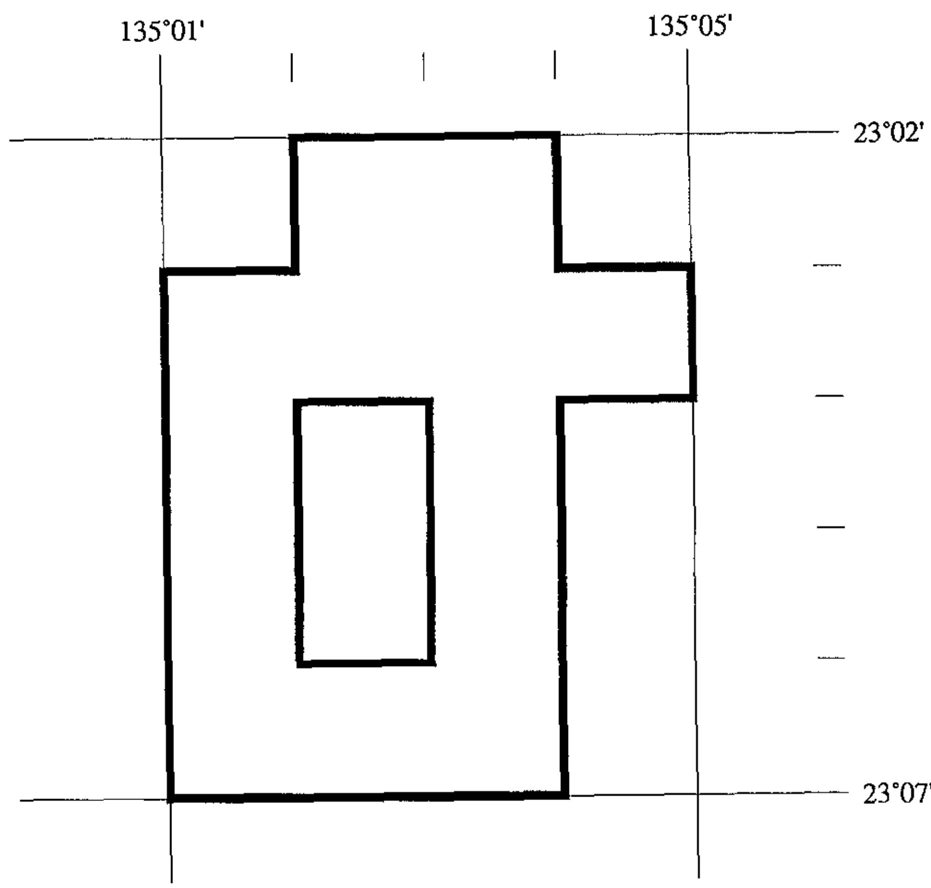
Kanandra Gap Yard
Jamaica Bore
ENTIRE POINT
517
BM 442
No 5 Bore
Carmencita Bore
PLENTY
Plenty Bore
Top Well
Rocky Yard
RED TAIL
462
RIVER
CONICAL HILL
Pinnacle Well
Kanandra Bore
Williams Bore
Huckitta
BM 426
P.I B Paddock
Corkwood Bore
Corkwood Well
Spinifex Bore
Eastern Chief Bore
Entire
10 Mile Bore
HIGHWAY
BM 472
TENT HILL
492
Mines Bore
Eldorado Bore
Entire Bore
Paddock Dam
Harts Range Police Station
Mount Mary Bore
MT EAGLEBEAK
770
Stanes Creek
Ulgarna Creek
Eastern Chief
Benstead Bore
Ulgarna Bore
BM 582
Harts Range Police Station
Brett Creek
MT BRUNA
MT BRADY
Valley Bore
Inkamulla Creek
MT MARY
MT LONG
Gimlet Dam
Eblana
BM 597
Stones Bore
MT PALMER
Watson Creek
Spriggs Creek Bore
Inkamulla Well
BM 595
BM 594
HARTS
RANGE
MT BRASSEY
MT MABEL
Spriggs
Mud Finch Dam
MT POWELL
MT BI
Abandoned mica mining area
AMBULBINYA PEAKS
858
Huckitta Bore
Quartz Hill
Huckitta Creek
Log Cabin Dam
MT MURIEL
Bullocky Dam
Floretice
New Lizzie Bore
MT GEORGE
870
Coggan Bore
Brumby Bore



B/C
508
No 5 Bore
495
Carmencita Bore
RIVER
Kanandra Bore
Creek
499
482
512
Entire
B Paddock
Eastern Chief Bore
515
23
PLEN
21
60
HIGHWAY
Eldorado Bore
Eastern Chief
Entire Bore
511
6
Bore (Govt)
610
682
695
584
MT EAGLEBEAK
770
645
600
888
766
739
548
Abandoned
Harts Range Police Station
MT BRUNA
1079
MT BRADY
888
764
Valley Bore
643
808
902
Entire
Inkamulla
Abandoned
MT PALMER
1136
861
Creek
Spriggs Creek Bore
790
RANGE
Inkamulla Well
BM 595
650
Spriggs
851
686
Creek
700
821
802
Abandoned mica mining area
4
AMBULBINYA PEAK
858
Lizzie
848
RANGE
895
750
Log Cabin Dam
MT MURIEL
988
HARTS
New Lizzie Bore
924
768
831
MT GEORGE
870
650
Lizzie Bore
MT LIONEL
818
3
650
Yambla Dam
Atnarta Dam
699
Yambla
656
Creek
BM 558
Creek
Lizzie Dam
Boots Dam
Harding Spring Well
638
BM 539
Brumby Bore
674
2

SECOND SCHEDULE
(Plan of Area)



EL9434
13 BLOCKS
42 sq kms

POSSIBLE EXPENDITURE REPORTING FORMAT *1996/1997*

Major Activity	Staff Salaries	Staff Wages	Consultants/ Contractors Fees	Vehicles	Travel Other	Accom	Field Accom	Field Equipment	Office Equipment	Other	Sub Totals
Geology	$1200			$500	$1000		$500				
Geochemistry			$400								
Geophysics	$800		$2000	$1500	$1200	$600	$1000				
Access	$1600							$1200			
Gridding											
Drilling: - Diamond - Other											
Drafting	$2400										
Mettallurgy	$6500		$4000	$500	$1400	$800	$500				
Engineering	$4900				$1000				$350		
Environmental	$										
Other Sampling	$2200			Bush Surplus $4000				Bulk Sample $4500			
Sub Totals	$19000		$6400	$6500	$4600	$1400	$2000	5700	$350		

TOTAL	$46,550
LOCAL OFFICE OVERHEADS	$
HEAD OFFICE OVERHEADS	$3,500
GF ID TOTAL	$450,050

WIK

Exploration work has been hampered by the effect of the WIK decision and the uncertainty of title position. Reference is made to the letter attached to the Licence, written by the Principal Registrar Mr. C.P. Smith and dated 10th July 1966, which made reference to the grant of the Licence having been made on the assumption that native title had been extinguished by the past grant of pastoral leases – (see copy of letter attached). The uncertainty caused by the Wik decision has impeded the speed of the exploration and it is hoped that this matter will be clarified shortly and taken into account by the Department.

The original application for the Exploration Licence was for an area covering 15 blocks, but for reasons still unknown to the applicant, despite having made inquiries in relation thereto of the Department, the licence was granted for an area covering only 13 blocks. The 2 blocks, which were excised by the Department, were of real significance to the total area applied for by the Applicant and upon which a good deal of exploration work had been carried out in the past.

Department of Mines and Energy

CENTREPOINT TOWERS BUILDING, THE MALL, DARWIN N T 0800
G P O BOX 2901, DARWIN, N T 0801, AUSTRALIA

NORTHERN TERRITORY — DEPARTMENT OF MINES AND ENERGY —

PROMOTING GROWTH THROUGH RESOURCE

TITLES ADMINISTRATION BRANCH

TELEPHONE: (08) 89 997368
FACSIMILE: (08) 89 817106

Our Ref: EL 9434

Mr Uwe Barfuss
Barfuss Corporation Pty Ltd
Suite 102, 17 Heatherdale Road
RINGWOOD VIC 3134

Dear Mr Barfuss

I am pleased to advise that I, as Delegate of the Minister for Mines and Energy, have granted Exploration Licence 9434 for a period of one (1) year over an area of thirteen (13) blocks only. The remaining two (2) blocks fall within Reservation from Occupation 1357, consequently, this area is not available for Exploration Licences. In addition, the NT Government has identified fossicking as a significant tourism industry and this area has been identified as such an area.

The relevant licence document is enclosed. This licence is granted subject to the Mining Act 1980 (as amended), the Regulations thereunder and all other laws of the Northern Territory as are applicable. *In particular, your attention is drawn to the Aboriginal Sacred Sites Act. This Act may require you to consult with the Aboriginal Areas Protection Authority prior to any ground disturbance.*

I advise that enquiries have been made in an endeavour to ascertain whether any native title subsisted and still subsists over any of the land which is the subject of this grant. Because of legal uncertainty beyond the Northern Territory Government's control as to the effect on native title (if any) of the past grant of pastoral lease(s) over the land, it is not presently possible to form a definitive view on this matter.

This grant is made on the assumption that any native title has been extinguished by the past grant of pastoral lease(s). This assumption has yet to be tested in the High Court. You should therefore be aware that if this assumption proves to be legally incorrect in this case, it may be necessary for you to reapply for the grant of the tenure held at the time such invalidity is determined. You may have to comply with the procedures in the Native Title Act 1993 before grant of that tenure can be made.

It is the intention of the Northern Territory Government to amend the Mining Act to confer priority in the event that grants are invalidated because of the continued existence of native title, and where as a result the grantee seeks a further grant. The exact terms of this amending legislation have not yet been settled.

In addition you may be required to comply with the procedures in the Native Title Act 1993 should you seek the grant of subsequent tenure over any of the land. This is a matter for separate consideration at that time.

The licence is granted with the expectation that the annual expenditure commitments will be met. Failure to do so will result in the initiation of the cancellation process. *I also wish to advise, if there is no real progression during this year of the licence, renewal will not be supported.*

Before any field work is commenced, it is important that the conditions applying to this licence are checked and understood; some are included in the licence document, and others will be found in section 24 of the Mining Act. All persons employed on the licence area should be fully conversant with those conditions.

Your attention is drawn to the requirement for written notification and prior approval for substantial disturbance. In this regard, details of the proposed activities and plans depicting their precise locations must accompany the advice required to be submitted by section 24(e) of the Act. Environmental Guideline No. 1 on this subject is enclosed for your assistance.

Pursuant to sections 32 and 34 of the Act, there are statutory requirements for a licensee to lodge reports. Explanatory notes for the submission of these reports are attached. Should you transfer the licence, you are to ensure that the transferee is provided with a report on your activities such that the new licensee will be able to comply with those requirements. Please note item 3 in the Explanatory Notes on Reporting, whereby transparencies must be provided for any plans larger than A3 size. Transparencies are less susceptible to damage or fading and are easier to reproduce for future records.

You should also be aware that, should any portion of this licence be taken up in any form of mining tenure and subsequently transferred, all geological information in relation to these areas must also be passed on to the transferee.

Under the Mineral Royalty Act, expenditure in the Northern Territory on exploration work carried out may be claimable as eligible exploration expenditure for the issue of Exploration Expenditure Certificates. These may be sold or used to reduce royalty payable on exploration or mining titles. Guidelines with respect to these Certificates are available from the Royalty Branch (telephone 89 5444).

If you have further concerns about any of these matters, I advise you to seek your own independent legal advice.

I wish you well with your exploration.

Yours sincerely

10/7/96

C P SMITH
Principal Registrar

enc

cc: Mr John George
Cridlands
PO Box 1302
DARWIN NT 0801

Report on the feasibility of garnet mining, Harts Range , Northern Territory.

GARNETS

As previously reported Almardine Garnet are extensively distributed in the entire valley and all its tributaries. The percentage varies from 10% to 55% course grained Garnets and of particular interest is the 4 to 12 Tyler Mesh sizes.

Extensive prospecting and visual examination has revealed that the distribution of commercially viable deposits of Garnets Sands could be proven to exist, and further work is planned to prove and define high grade deposits.

Prior to this work bulk samples at random were collected from the valleys in the E/L to give a representative particle size distribution and general Garnet quality.

The bulk samples were extensively studied and valuable metallurgical work carried out by gravity separation, heavy media and spiral separation. Various techniques were employed (see report) and the work conducted by various laboratories.

This work has been very encouraging and has resulted in the design of Wet Exploration pilot Plant.

A dry method, its force magnetic separator recovering high grade Garnet product, has also been examined and bulk tests carried out in the United Sates by "Inprosys".

It has been concluded that a Dry Method of recovering clean Garnet Sands is possible, and obviously a feasible alternative.

If there is insufficient water available, then this technology is only 5 years old and is also of interest for recovering clean vermiculite.

Future Exploration.

Detailed mapping of high grade Garnet Reserves and systematic sampling/ evaluation.

Exploration Pilot Plant.

Establish a small pilot plant to process bulk samples from the identified reserves able to be mined and to define particle sizes and distribution. This study is necessary before any establishment of a mining production plant.

Garnets (additional information)

Bulksamples were collected at random all along the valleys east and west, some north and south of the ruby mine camp. All samples selected are from areas of significant availability of sand. All samples were made up to make a bulk composite.

The purpose of this work was to obtain a preliminary representation samples of particle size and average quality - and to test recovery methods.
This has also provided us with commercial samples to research the marketability of the product and study the commercial viability of the project.

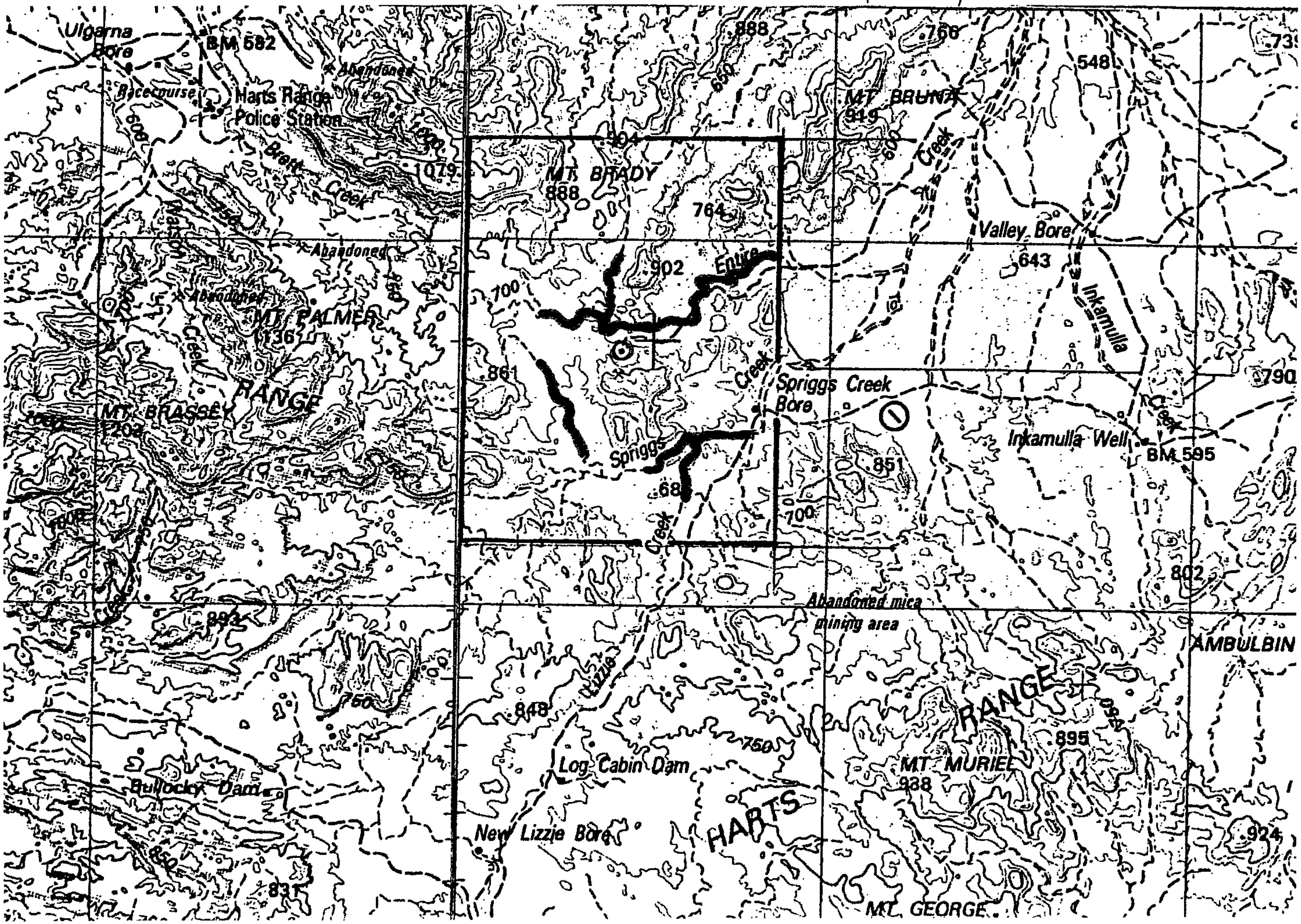
See **Future Exploration** (as noted in the report).

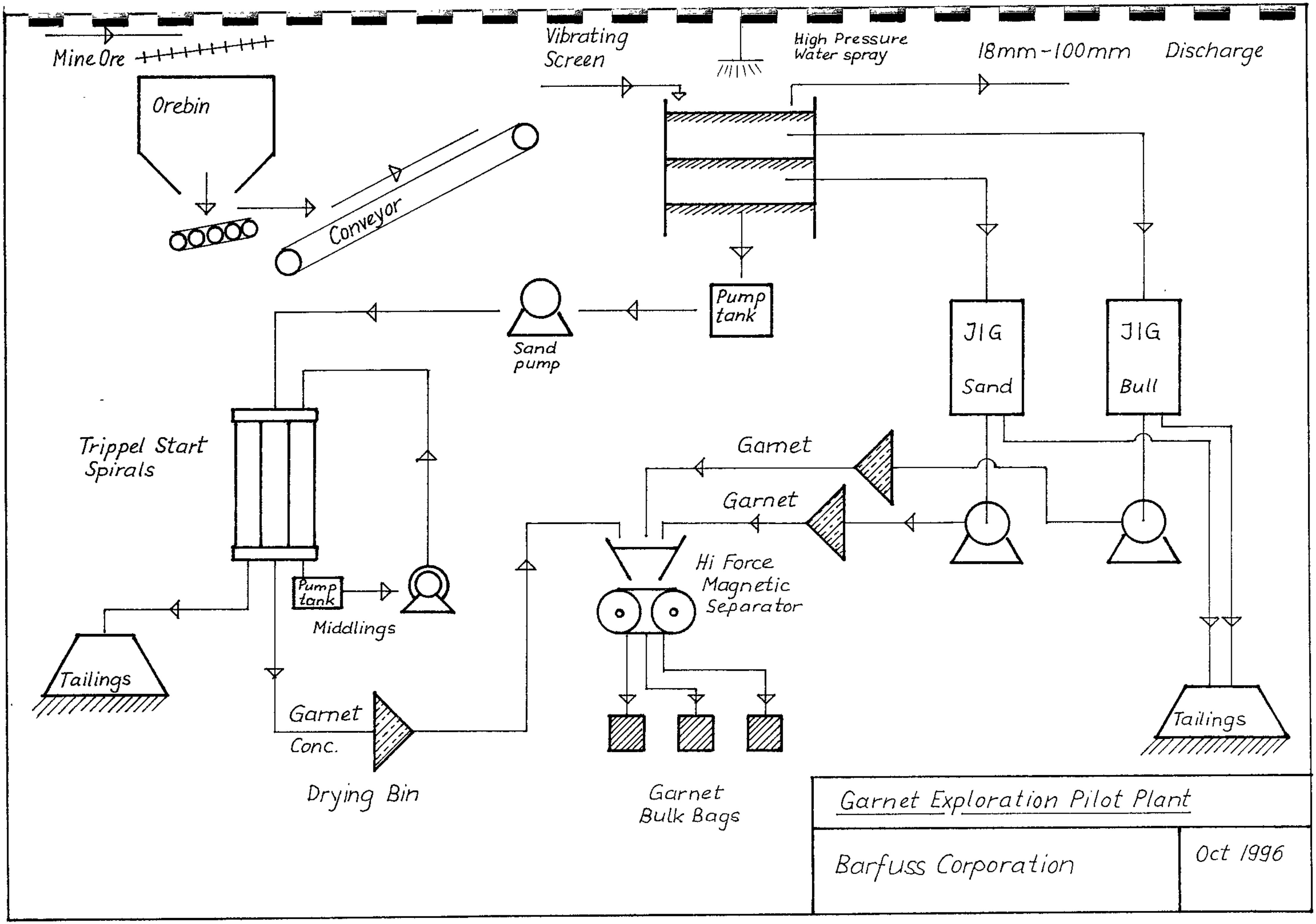
I am attaching a map showing areas of sampling in red and latitudinal and longitudinal positions of sampling.

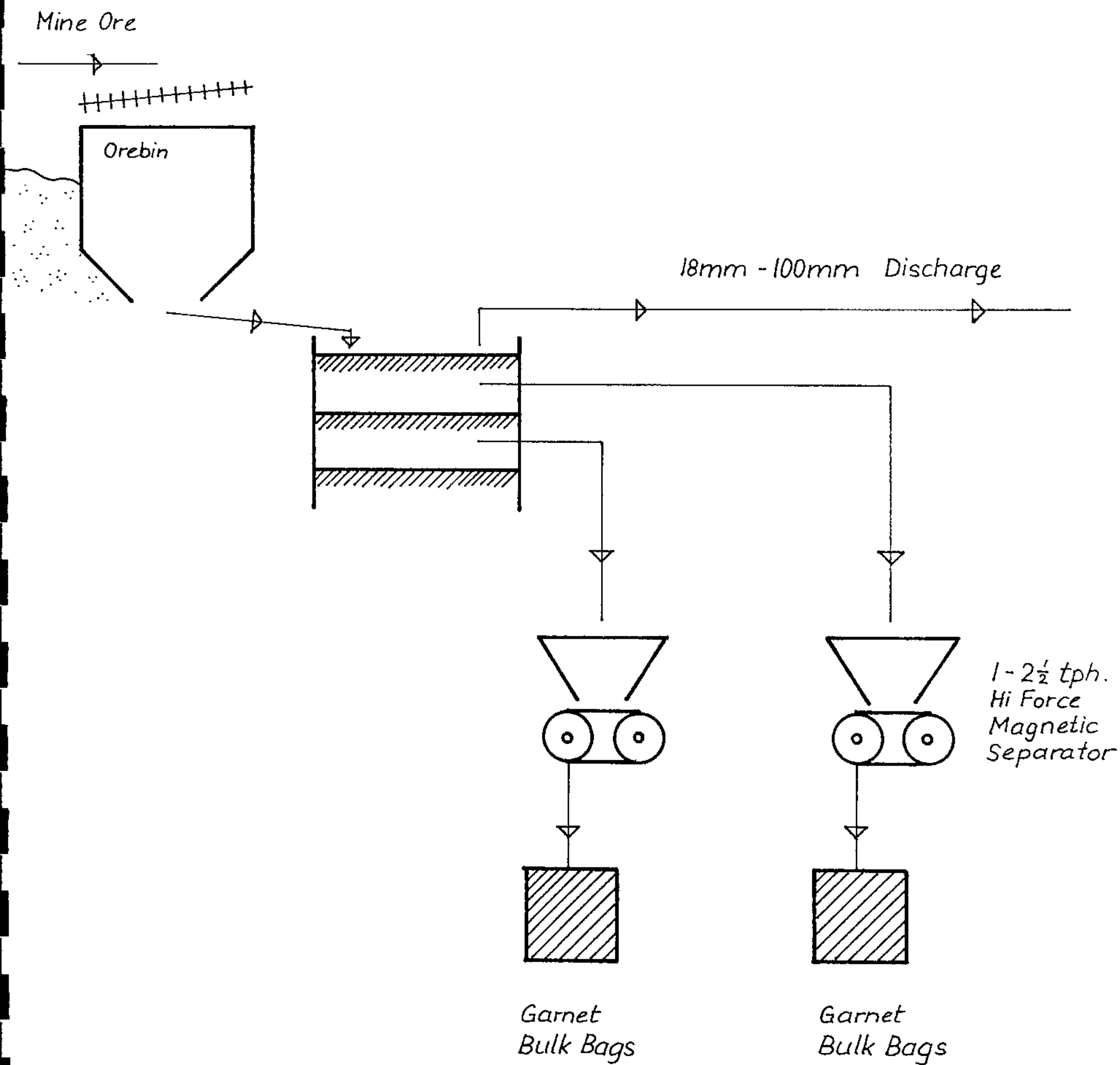
Positions:

135o01'800 / 23o04'790
135o02'260 / 23o04'650
135o02'480 / 23o04'820
135o03'600 / 23o04'750
135o04'700 / 23o03'780

135o01'740 / 23o05'630
135o03'250 / 23o06'700
135o03'690 / 23o06'300
135o03'560 / 23o06'680


Ulgarna Bore
BM 582
Abandoned
Racecourse
Harts Range Police Station
Brant Creek
1079
MT. BRADY
888
764
904
888
650
760
548
MT. BRUNA
949
Creek
Valley Bore
643
Inkamulla
Abandoned
Abandoned
MT. PALMER
1136
Watson Creek
RANGE
MT. BRASSEY
1203
902
Entire
Creek
861
Spriggs Creek Bore
Spriggs
68
Creek
Inkamulla Well
BM 595
851
790
739
802
Abandoned mica mining area
AMBULBIN
893
760
848
Lizzie
750
Log Cabin Dam
RANGE
895
MT. MURIEL
938
HARTS
New Lizzie Bore
Bullocky Dam
850
831
MT. GEORGE
924


Mine Ore
Orebin
Conveyor
Vibrating Screen
High Pressure Water spray
18mm-100mm
Discharge
Pump tank
Sand pump
JIG Sand
JIG Bull
Trippel Start Spirals
Garnet
Garnet
Hi Force Magnetic Separator
Pump tank
Middlings
Tailings
Garnet Conc.
Drying Bin
Garnet Bulk Bags
Tailings
Garnet Exploration Pilot Plant
Barfuss Corporation
Oct 1996



Dry Separation

Garnet Exploration Pilot Plant

Barfuss Corporation P/L.

Nov. 1996

SM755

METALLURGY PROJECT

Gravity Separation of Garnet.

NAME: Andrew Jones.

STUDENT NO.: 941684.

SUPERVISOR: W. Jay.

MODERATOR: K. Brady.

DUE DATE: Week 13.

GRAVITY SEPARATION OF GARNET.

Introduction:

In this project, garnet was separated from its ore by utilising the shaking table and spiral separator. Before the separation occurred, however, a screen analysis was conducted to give an overview of the ore and to ascertain if size fractions of low garnet concentrations could be rejected in order to increase the overall concentration before separation proceeded using the shaking table and spiral separator.

Almandine, or iron garnet, is comparatively widespread in occurrence and are used in the manufacture of abrasives such as coated garnet paper, cloth and discs glued with sodium silicate and other binding material like sorel cement. Garnet abrasives are widely used in wood finishing although finer garnet particles are used as tumbling chemicals and grits for ceramics, glass, leather and optical polishing. About 90% of garnet used in industry is employed for the use of garnet paper and cloth, the remainder being used in the form of loose grains. Garnet is usually offered for sale in a range of sizes between 20 and 200 mesh. Garnet sand in a paste form is also available for a variety of polishing purposes. Granular garnet is of no great valve because it often breaks into rounded fragments.

A recent development is 'electro-coated' garnet paper which is said to be more efficient. This type of abrasive paper is made by dropping the crushed garnet through an electrostatic field in which the wet paper acts as an electrode. This treatment allows the grains to orientate themselves with their points towards a highly charged electrode which is suspended above the paper. This is an ingenious way of making the sharp splinter ends of the garnet turn into the best position possible for its task as an abrasive.

Another important application of garnet is in metal polishing, commonly known as 'bead or sand blasting'. This process is generally used in the aircraft and transportation industry for quick and efficient removal of paint and rust. Water filtration is another large use of garnet. Used as a filtering media, it is said that garnet's high specific gravity and resistance to abrasion and corrosion provide better filtration efficiency compared to sand which is more commonly used for this purpose.

The spiral design of the device causes not only the flowing film velocity gradient as mentioned above, but, a centrifugal velocity gradient in the horizontal plane. These two phenomena together, cause a cross-sectional rotation to develop. This cross-sectional rotation of the stream is utilised to shift the heavy minerals inwards towards the collecting zone or outlet. The lighter, faster flowing (but slower settling) minerals shift outward, away from the outlet. The heavier and lighter particles are therefore shifted laterally in opposite directions so that one is separated from the other. Some spiral separators have the added feature of having a series of points which discharge wash water in an effort to assist in washing the lighter particles from the surface of the stratified bed at the inner radius, back into the stream.

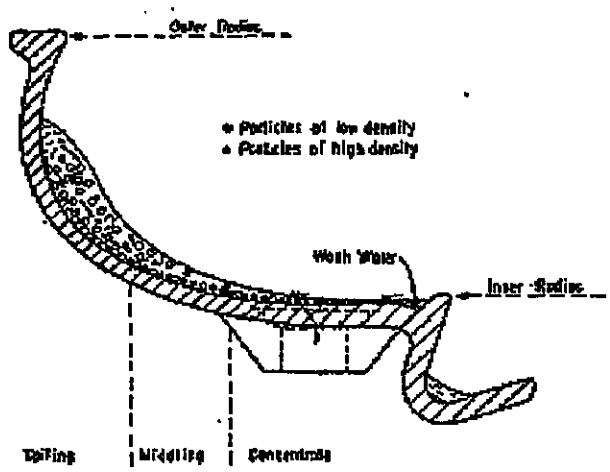


Fig. 1. Cross Section of spiral trough.

The upper size limit for good separation of ores is 1mm, however, gangue particles as coarse as 3mm can be handled. Oversized particles will not normally remain in suspension in the pulp flow but will settle out and form sand bars. While early spirals were inefficient when particles are coarser than 75 micrometers, more modern spirals can achieve separation when particles are as fine as 50 micrometers.

Shaking Tables.

Provided there is a significant difference in the specific gravity of minerals, shaking tables are effective. This also depends on the size and shape range of the particles in the table feed and on the magnitude of difference in size of the specific gravity of the individual particles. A

In the mineral processing industry, garnet particles are pre-heated to a temperature of between 700°C and 1000°C before crushing, normally for a period of about 12 hours before quenching. Heating and quenching improve toughness, fracture and colour. The degree of heat treatment is judged by the colour of the garnet, which, at high temperatures turns a silver dark ruby colour from a colour or ruby red at low temperatures. A better adhesive property to the grains is also experienced after heat treatment.

GARNET	VARIETY OF GARNET	SPECIFIC GRAVITY	HARDNESS	REFRACTIVE INDEX
Almandine	Iron-Aluminium, $3FeO.Al_2O_3.3SiO_2$	3.9-4.2	7-7.5	1.830
Pyrope	Magnesium-aluminium, $3MgO.Al_2O_3.3SiO_2$	3.7	7	1.705
Rhodonite	Magnesuim-iron-aluminuim	3.8-3.9	7-7.5	1.760
Andradite	Calcium-Iron, $3CaO.Fe_2O_3.3SiO_2$	3.8-4.1	7	1.895
Spessartite	Manganese-aluminium, $3MnO.Al_2O_3.3SiO_2$	3.8	7.5	1.810
Uvarovite	Lime-chromium, $3CaO.Cr_2O_3.3SiO_2$	3.4	7.5	1.860
Grossularite	Lime-alumina, $3CaO.Al_2O_3.3SiO_2$	3.5	7.5	1.735

Table 1. Properties of Garnet.

Spiral Separators.

Spiral separators, since being introduced more than 50 years ago, have proved to be cost effective and metallurgically efficient in the treatment of various ores. There is a minimum height requirement because of their vertical orientation and the use of gravity feed in most cases. It is important, therefore, to design the spiral separator to incorporate a minimum number of turns to achieve the required separation. It has been claimed that effective separation is achieved after 2 turns on a mineral spiral. However most modern spirals use 4 to 5 turns, with mineral processing plants thirty years ago using spirals of 2 to 3.5 turns.

After the feed is introduced as an almost homogeneous slurry to the spiral separator, stratification occurs in a vertical plane. This is the result of a combination of hindered settling and interstitial trickling. The result is that the heavier particles proceed to the lower velocity zones near the trough surface whilst the lighter particles stratify above them in the higher velocity zones.

difference of at least one specific gravity unit between concentrate and tailing particles is needed if separation is to quick and efficient.

To maximise the performance of a shaking table, it is necessary to carefully consider the various operating parameters. These include the feed rate of both water and solids, size of the feed, and the mechanical settings of the table itself.

The largest particle size that can be effectively treated on a shaking table is 10 mesh (in the case of ores). Ores that are larger than this size are more effectively treated in jigs or heavy media separation. The presence of fines below 325 mesh increases the viscosity of the pooled beds of pulp on the table and slows the specific gravity stratification action and sizing.

As flowing water flows over a flat inclined surface, the water closest to the surface is retarded by the friction of the water absorbed on the surface and the velocity increases towards the water surface. When mineral particles are introduced, small particles will not move as fast as the larger particles because they will be submerged in the slower moving part of the water film. A lateral displacement of minerals of a high specific gravity will be produced because they move slower than lighter particles.

Superimposed onto the flowing film of the shaking table is an asymmetric recipitation motion along the long axis of the table. This motion, which is produced by the mechanical headmotion, induces the deck and the layers of particles to become momentarily at rest at the end of the reverse stroke. The table is then moved forward and the particles move toward the discharge end of the table.

Ideally, film concentrates require a single layer of feed but in practice multi-layered feed is introduced to the table, meaning that more ore can be processed. Vertical stratification due to the shaking action takes place behind the riffles which run parallel to the long axis of the table. Particles stratify in the protected pockets behind the riffles so that the lightest and heaviest particles are at the bottom and the coarsest and lightest particles are at the top. Layers of particles are moved across the riffles by the crowding action of the introduced feed coming down the table and also by the flowing wash water. Because of the taper of the riffles, finer and denser particles are continually being bought into contact with the flowing film of water that washes over the riffles. Final concentration is achieved at the unrifled area at the end of the deck. At this stage the layer of concentrate is usually only one or two particles deep.

Discussion \ Results.

A screen analysis was conducted in an effort to ascertain if the garnet was specific to a certain size ranges. It was hoped that certain sizes of the ore containing low grades of garnet could be efficiently screened off, providing feed to the shaking table and spiral separator of a higher grade concentrate.

After screening and weighing, an effort was made to get an accurate count of the actual percentage of garnet contained in each individual size fraction. This was attempted by shining a light from below a glass table and individually separating each particle within a certain size range. After many tedious hours and with only 4 size fractions being able to be analysed accurately (the four largest screen sizes), this method was rejected in favour of a more general analysis described below.

Each size fraction of the ore was placed on the glass table, and, using a magnifying glass, it was concluded that all size fractions contained a significant amount of garnet and therefore it was decided that no prescreening would be done before the garnet is separated. (Note: records of sizes 48 mesh and below are only estimates of garnet concentration, using the above method.)

It was disappointing to find after the analysis that the garnet was not specific to a certain size range with all size ranges (8 mesh to <270 mesh) containing a significant amount of the mineral. Percentages of up to 45 (14 mesh) were found with the lowest percentage recorded at 15%(100 to 270 mesh).

scrn size	aperture (mm)	sample 1 weight (g)	sample 2 weight (g)	sample 3 weight (g)	Average weight(g)	% Garnet
8	2.38	64.5	84	61	69.83	22
14	1.16	321	390	342	351	43
20	0.84	134.5	133	132.5	133.33	33
35	0.5	342	308.5	337.5	329.33	18
48	0.35	74	52	69.5	65.17	14*
65	0.212	22	15	23	20	11*
100	0.15	1	2.5	4.5	2.67	15*
150	0.105	17	8	11	12	20*
200	0.074	4	2.5	3	3.17	20*
270	0.053	1.5	2	3	2.17	20*
<270	-0.053	3	1.5	2	2.17	20*

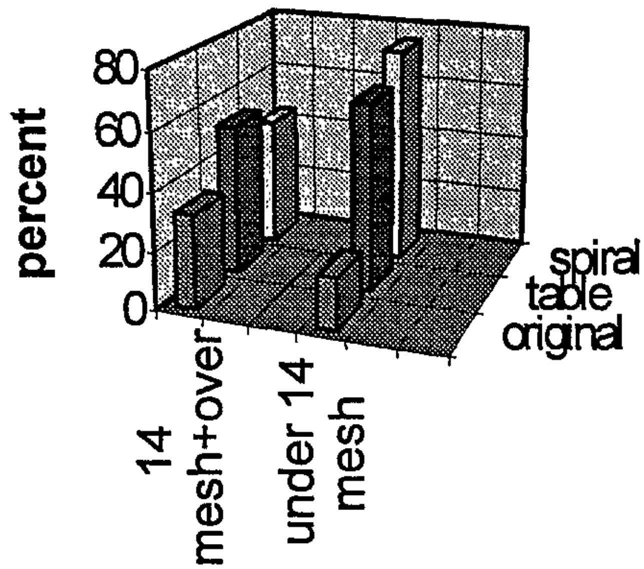
Table 2. Initial screen analysis. *Estimates only

It was decided that the garnet should be attempted to be separated using two methods namely using the shaking table and spiral separator, both of which are located in the Mineral Industries Shed on the campus of The University of Ballarat.

The shaking table was used first with the ore being broken into two size fractions, 14 mesh and over and under 14 mesh. Mixed results were achieved as the slope of the table could not be set at a different level, speed and stroke as it was set up specifically for first year metallurgy practical sessions. An increase in slope (cross tilt) was really needed to compensate for the thick bed and sluggish action of the mineral flow. Ideally, the table should be set to a minimum at which it is possible to achieve a good distribution of the ore on the table deck. Also needing an adjustment, but unable to be was the stroke and speed. For coarse material, a long stroke and slow speed should ideally be used, and with finer material short strokes and high speeds are needed. When the specific gravity between the particles are small, the stroke length needs to be shortened.

Spiral separation was then used in an effort to obtain better results than those recorded on the shaking table. Results for the 14 mesh and over seemed to be worse than those obtained on the shaking table. This result was predicted as feed size for spiral separation is normally between 1.16mm and 74 µm (14 and 200 mesh). Concentrate on the spiral was 44% garnet, compared to 52% garnet on the shaking table.

Garnet Percentages.



Results for the under 14 mesh showed improvement over the shaking table. Even better results were obtained when the feed was reduced in volume, as the sluggish flow of the water caused a sand bar formation to form. Concentrate on the spiral for the under 14 mesh sample was recorded at 75% which was the best test result produced. This result compared closely to that recorded for the shaking table concentrate containing 65% garnet).

Excessive volumes of feed cause the high specific gravity mineral to be swept wide, resulting in sand bar formations in the lower turns which was observed during testing. The coarser the feed, the higher the optimal feed rate, because a high pulp density is needed to crowd the high specific gravity particles into the concentrate.

Conclusion:

Whilst results show a marked improvement over original garnet concentrations, it was disappointing to find concentrations lower than expected, especially in respect to the larger particle size range (14 mesh and over). As mentioned in the discussion, parameters such as wash water volumes and feed pulp need to be tightly scrutinised in order to produce maximum concentrations. During the experimental phase of the project, it was brought to light that extensive testing needs to be conducted in order to balance all variables so that concentrations are at a maximum. Also, a heavy liquid analysis of the sample should have been performed to determine the washability of the ore. This analysis establishes the size of separation of the ore and the specific gravity of separation. However, with this in mind the experiment can be seen to be a success with much being learnt about the process of gravity separation.

References

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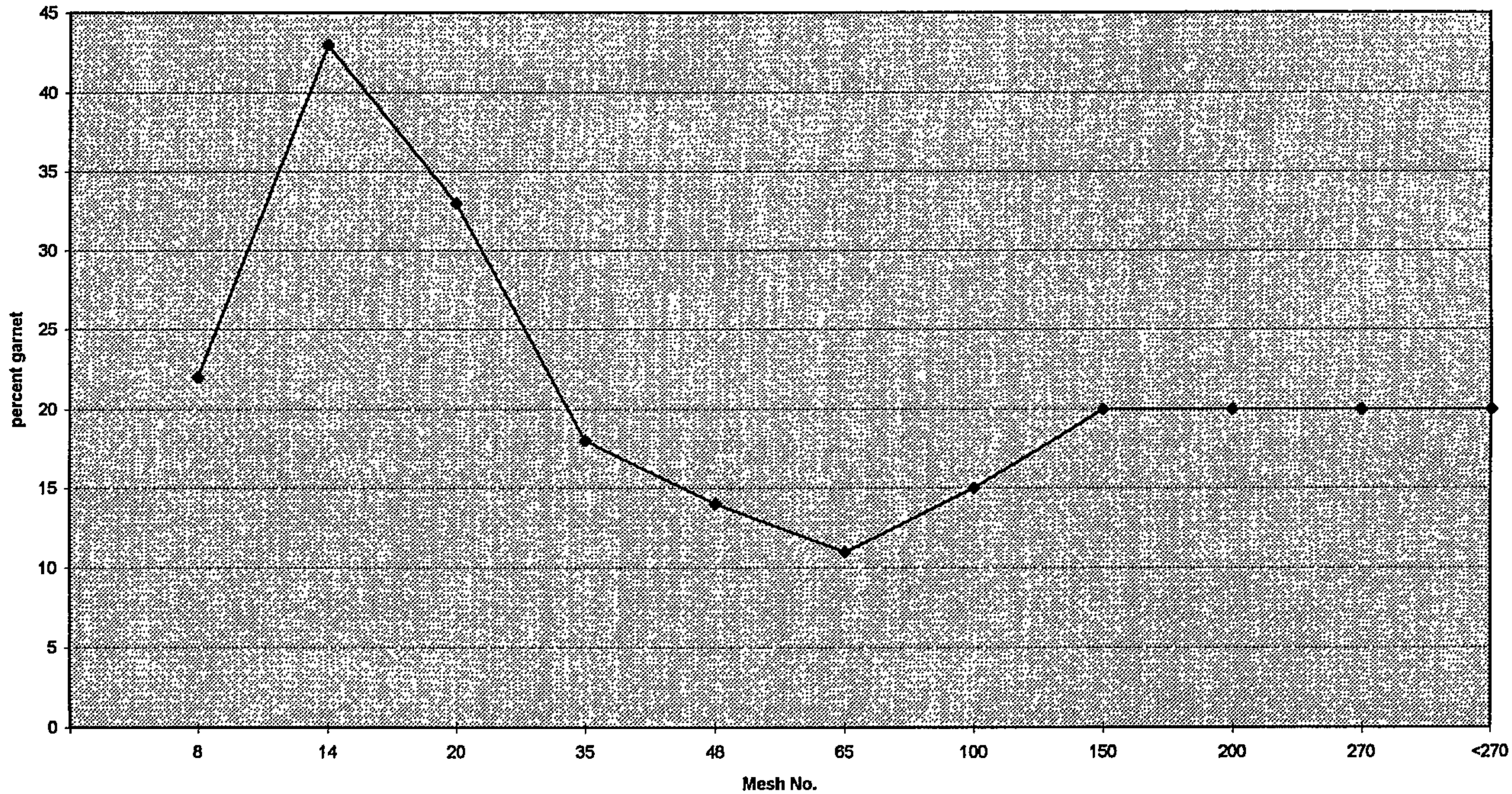
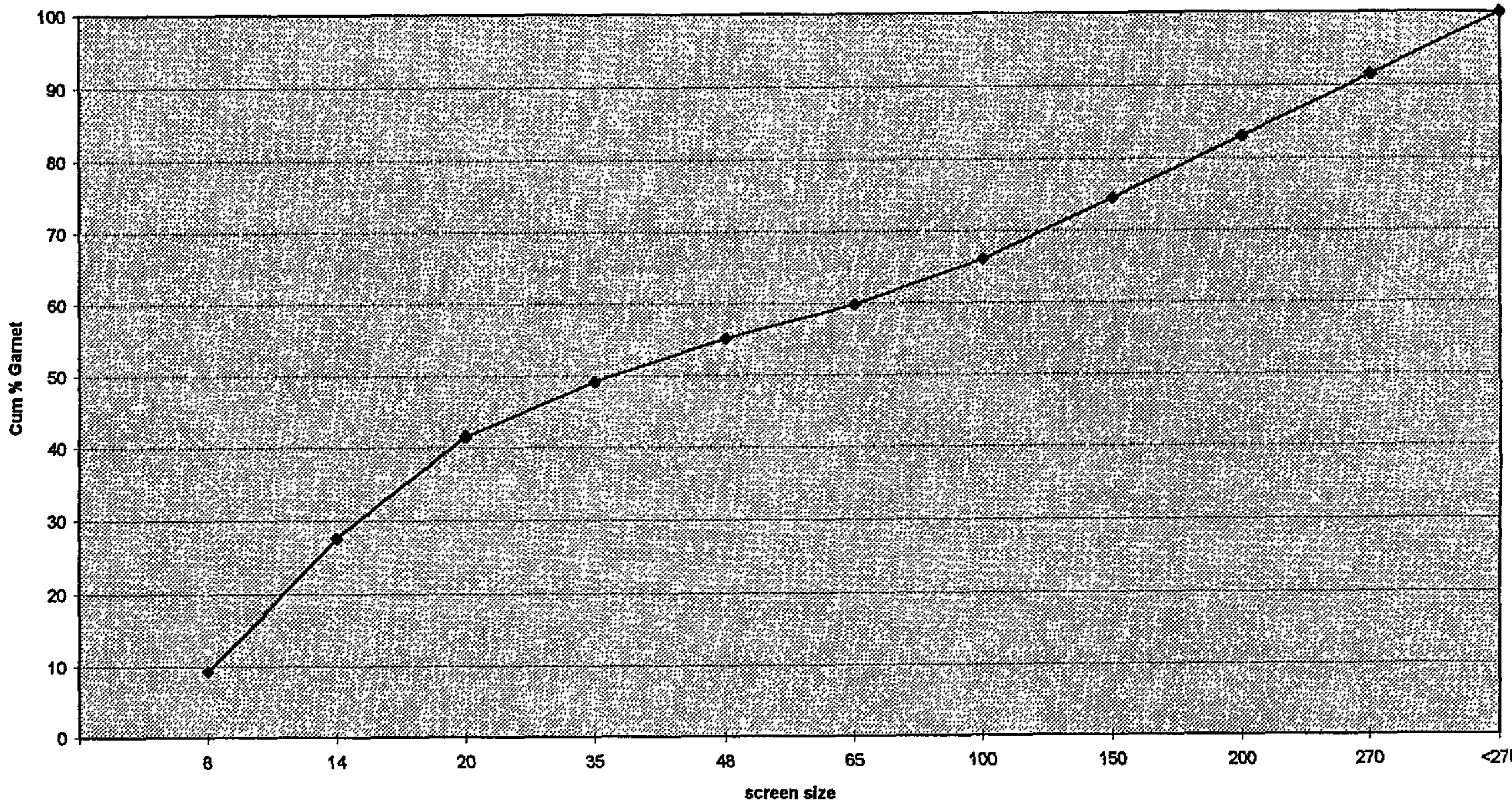
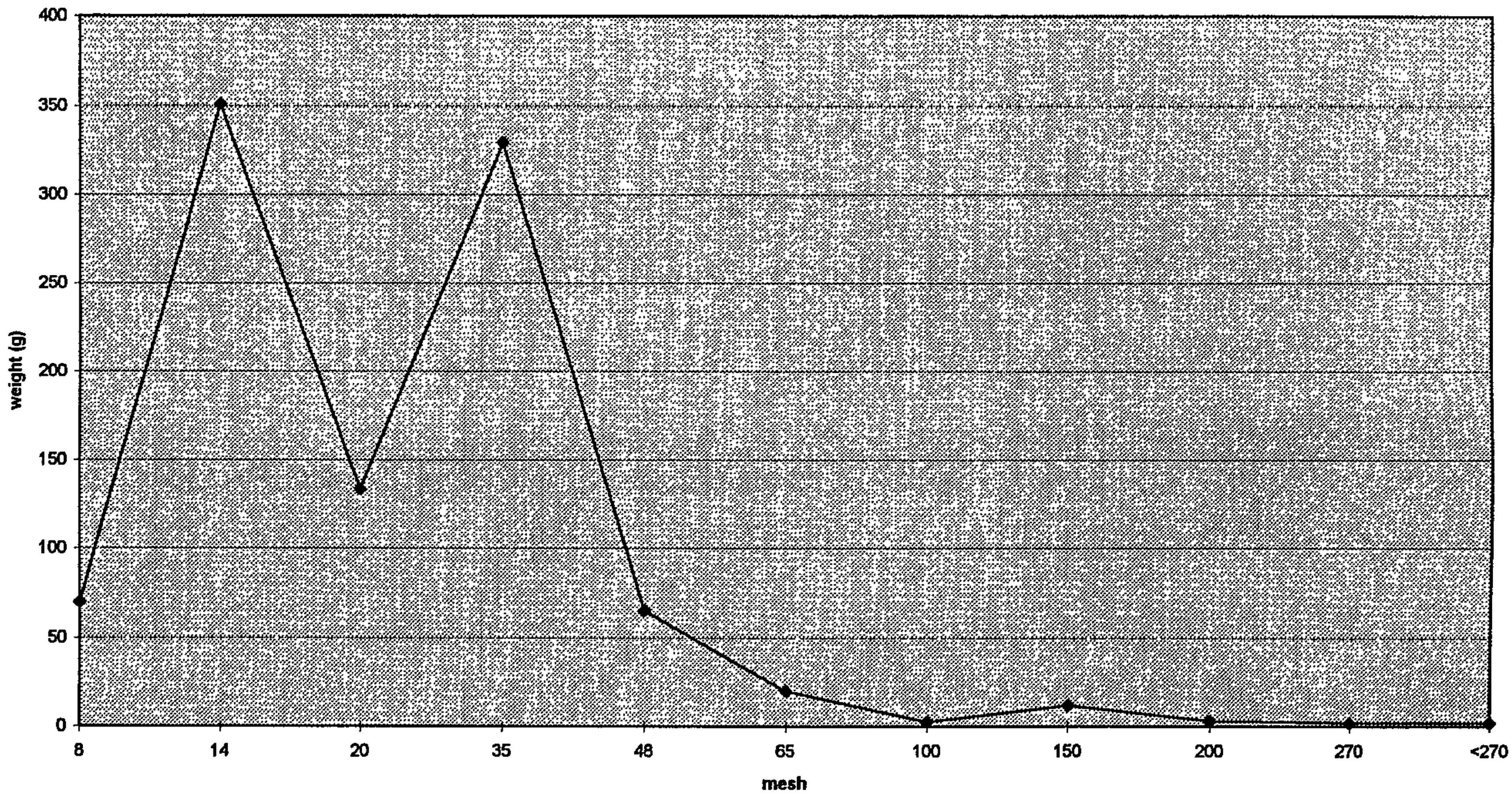
Percent of garnet per screen size



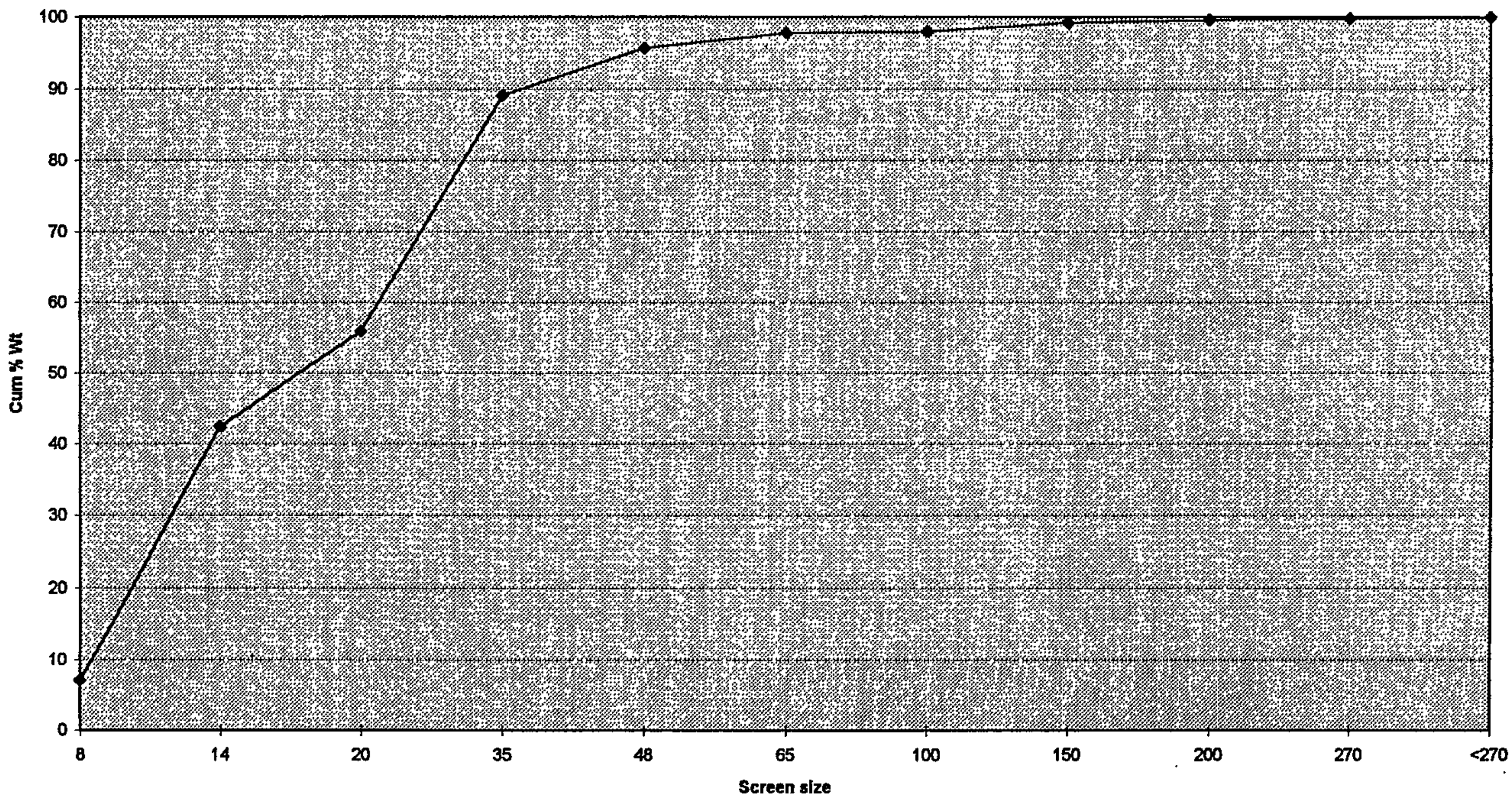
Cum % Garnet v's Screen size



Average weight per mesh.



Cum % Weight v's Screen size



SM765 MATERIALS APPLICATION PROJECT

SUPERVISOR: *Dr. W. JAY*
MODERATOR: *Mr. K. BRADY*

TOPIC:

Investigation into the potential use of gravity concentration techniques as a separation method for obtaining concentrated Garnet mineral sands.

BRENDAN DORRICOTT
&
STEPHAN VAN DER LIT

MARCH 1997

Executive Summary.

Testwork evaluating the effectiveness of two gravity concentration techniques for the separation of valuable mineral garnet was initiated. Samples were obtained from a deposit in the Hart's Ranges, Northern Territory, and testwork was to be analysed with respect to the potential use of these gravity concentration techniques as separating techniques for future commercial use.

The size of the mineral particle was cited early as a potential problem, thus the bulk sample was sized into three separate fractions; coarse $d = 6.7 \times 10^3 - 1.18 \times 10^3$ μm ,medium $d = 1.18 \times 10^3 - 425$ μm, and fine $d < 425$ μm. However a unsized sample was also taken from the bulk sample to contrast these results.

Several static heavy media separation cells were trialed with the size fractions mentioned above. Use of these size fractions over both the heavy media vessels and the spirals allowed a comparison between both gravity concentration techniques. The expectations were that these would work more effectively for the coarser sizes rather then the fine sized fractions. However, this could not be confirmed as three attempts at modeling this separation behavior failed. The reasons for these failures included the instability of the suspension, turbulence resulting from excessive agitating speeds, and being able to obtain collection of the separate constituents once the separation appeared to be effective. Each of these attempts were discussed in relation to their separating techniques and the reasons for each cells inability to work effectively.

Metallurgical results on the spirals were found to be profoundly affected by the particle size of the minerals in the feed, specifically the coarse and medium size fractions. This conferred with the observations of **Hubbard et al. (1950).** The feed to the spirals at these large size fractions tended to result in a concentrate and tail containing similar sized particles. That is, the spiral acted as a size classifier and not a gravity concentrator. The best metallurgical results were obtained for the fine size fraction with a Recovery of almost 90 % resulting from the roughing stage. However potential further upgrading of this concentrate did not result, because of an *"over-zealous"* cleaning stage.

TABLE OF CONTENTS.

TABLE OF CONTENTS. (con't)

Section **Page Number**

TABLE OF CONTENTS. (con't)

Section **Page Number**

LIST OF ILLUSTRATIONS.

Illustration **Page Number**

LIST OF ILLUSTRATIONS. (con't)

Illustration **Page Number**

DEFINITION OF SYMBOLS.

v = Terminal velocity of particle (ms^{-1})

d = Particle diameter (m)

g = Acceleration due to gravity (ms^{-2})

Ds = Particle density (kgm^{-3})

Df = Fluid density (kgm^{-3})

η = Fluid viscosity (Nsm^{-2}) (water = 0.001 Nsm^{-2})

E_P = Probable Error of Separation

P_{25} = Probability @ 25 %

P_{75} = Probability @ 75 %

= Tyler Mesh Number

rpm = Revolutions Per Minute

d = Particle Size

t/hr = tonnes per hour

µm = micro meters

c = concentrate assay, (% valuable mineral)

t = tailing assay, (% valuable mineral)

f = feed assay, (% valuable mineral)

C = mass of concentrate, (kg)

T = mass of tailings, (kg)

F = mass of feed, (kg)

Rec. = recovery of valuable mineral

1.0 AIM:

To investigate the effectiveness of using two different gravity concentration techniques including Heavy Media Separation and Spiral Separation as methods of separating the commercially valuable mineral garnet from its gangue constituents mainly quartz. Hence evaluate the potential use of these techniques in a commercial recovery operation. The garnet mineral sample that was used throughout this investigation was obtained from a deposit in the Hart's Ranges in the Northern Territory.

To achieve this aim, testwork sought the best combination of size, methodology and density which resulted in the best recovery and grade of garnet from the ore used. Because the testwork used the same ore over rougher and cleaner spirals and heavy media apparatus, it was possible to directly compare the results from the individual testwork. Upon completion of the testwork a preferred technique, or combination of techniques can be recommended as the means for concentrating the sample supplied.

2.0 INTRODUCTION:

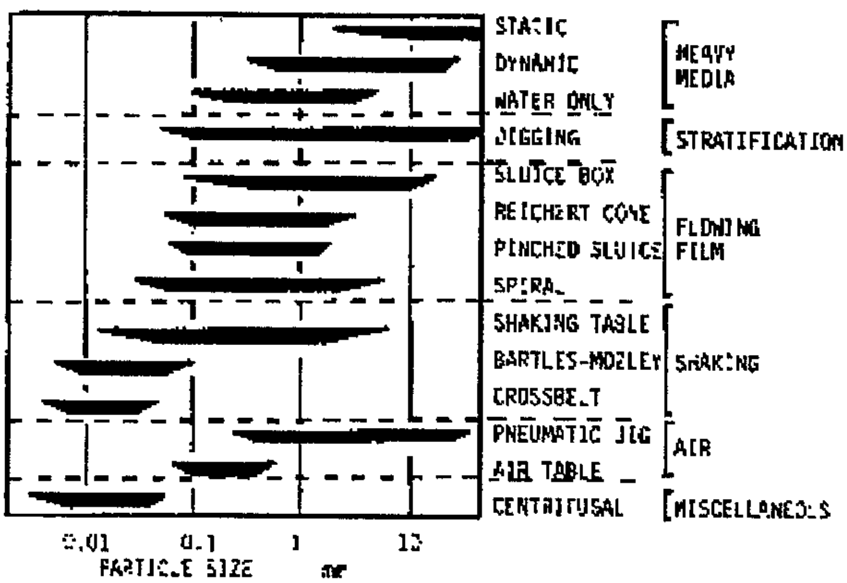


Figure 1:- ***Types of gravity concentration processes and the size range over which they operate.***
Source:- ***Burt. R.O., (1984), p 114.***

There are a large range of gravity separation techniques which implement and manipulate different aspects of the mineral's shape and properties, a number of which are included in the diagram above. The two techniques used in this experiment are thought to be effective over different size fractions. Spirals are supposedly more effective for small to medium size fractions and heavy media separation being more effective for medium to larger size fractions. This experiment will investigate these effects and compare the results obtained to those published by **Hubbard et al. (1950)**.

3.0. GARNET BACKGROUND:

3.1. GARNET.

Garnet is the term used to describe a specific family of alumino-silicate minerals. The chemical composition of individual garnets may differ, however they have very similar physical properties as shown in Table 1. below. Colours of individual garnets do however vary, ranging from white/yellow with the Grossular-Andradite to emerald green with Uvarovite through to a clear deep red for Pyrope.

Garnet	Variety of Alumino-Silicates	Specific Gravity	Hardness	Refractive Index
Almandine	Iron-Aluminium $3FeO.Al_2O_3.SiO_2$	3.9 - 4.2	7 - 7.5	1.830
Pyrope	Magnesium-Aluminium $3MgO.Al_2O_3.3SiO_2$	3.7	7	1.705
Rhodonite	Magnesium-Iron-Aluminium	3.8 - 3.9	7 - 7.5	1.760
Andradite	Calcium-Iron $3CaO.Fe_2O_3.3SiO_2$	3.8 - 4.1	7	1.895
Speassarite	Manganese-Aluminium $3MnO.Al_2O_3.SiO_2$	3.8	7.5	1.810
Uvarovite	Lime-Chromium $3CaO.Cr_2O_3.3SiO_2$	3.8	7.5	1.860
Grossularite	Lime Alumina $3CaO.Al_2O_3.SiO_2$	3.8	7	1.735

Table 1 :- Properties of some select garnets.
Source :- Johnstone, S.J.,(1961) p 209.

3.2. Applications of Garnet.

Technical grade industrial garnet is a mixture of almandine and pyrope garnets, the remaining garnets are classified into those of gemstone quality and a mixed gangue. Up to 1980 the chief use of this industrial grade was as loose grain abrasives for spectacle grinding and plate glass grinding. However, in more recent years the uses of industrial garnet has increased, with applications in many areas including the scratch free lapping of semiconductor and other materials. Garnet is also used in abrasive papers for the finishing of wood, leather, hard rubber, felt and plastics, as garnet is much cheaper than synthetic abrasives such as silicon carbide and fused alumina. Low quality industrial garnets have been used primarily as airblasting and hydroblasting media in a variety of applications, and have become the abrasive media of choice for the aircraft and shipbuilding industries.

Abrasive papers with superior performance characteristics are made by the selective attachment of garnet grains under the influence of an applied electrical field. The paper is made one of the electrodes and the garnet introduced into the system. The influence of the electrical field causes the sharpest edge of the garnet grain to align with the higher potential of the two electrodes. The higher potential electrode is positioned above the papers surface ensuring that the garnet splinter ends point outwards in the optimum direction for abrasive work. This type of abrasive paper is known as *electrocoated garnet papers*. Another application of low quality industrial garnets is in mixed media filtration systems, which combines industrial garnet with anthracite to give superior results in terms of water quality and reliability when compared to the use of older filtration methods.

3.3. Occurrence of Garnet.

Garnets are relatively widespread throughout the earth's surface particularly in the rocks which have formed at high temperatures. Most garnets may be found as detrital minerals in sediments. Almandine is commonly found in schists, gniesses and amphiboles. Pyrope is typical of mafic and ultramafic igneous rocks. Spessartine is found in low grade schists, metamorphosed magniferous sediments rhyholites and pegmatitites. Grossular occurs in metamorphosed calcerous rocks. Andarite is typical of contact metamorphosed skarns. Uvarotite is mainly found as serpentines and chromium rich metamorphic rocks.

The composition of garnet depends of the conditions under which it formed. This is indicated in the chart below, where it can be seen that the garnets that are formed at the lowest grade of metamorphism are relatively rich in calcium and magnesium. The colour, hardness and toughness are significant properties and can be improved when heated to 800°C for 12 hours then quenched.

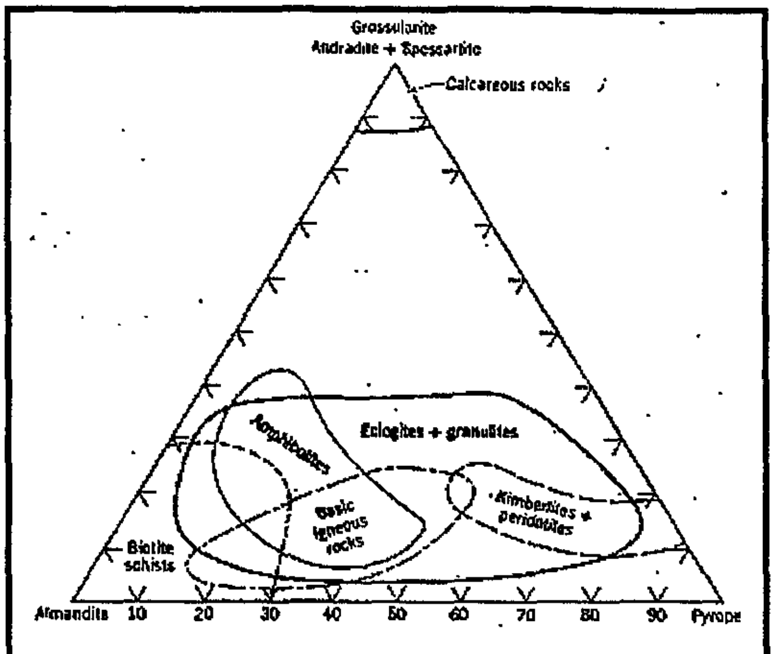


Figure 2 :- Petrographic Affinities of Garnets
Source :- Frost. M. J., (1981) p.166.

3.4. Garnet Deposits.

Garnet is typically found in deposits with metamorphic rocks, commonly mica schists and gneisss. Garnet can also be found as alluvial deposits due to weathering of the parent rock, but these are usually too small to be used as an industrial mineral. However, they are generally not worth treating if it contains <10% garnet. Alluvial deposits can also be mined such as the Garnet Miller sands north of Geraldton WA, which mine beach sands incorporating a very large alluvial garnet deposit. Sizes of alluvial garnet can range from microscopic crystals to masses weighing up to 100 lb. and are generally round in shape due to weathering and are tough and hard to fracture.

3.5. Industrial Use of Garnet.

Approximately 90% of the industrially used garnet is consumed in the manufacture of garnet paper and cloth abrasives. It is desirable that these grains have high capillary attraction so the glue or bonding material can readily attach them to the paper or cloth. The rest are used as loose grains, i.e. for sandblasting, or polishing marble, slate and soapstone. Garnet is positioned on the paper by using electrodes to orientate the garnet with the sharp sides up. The size ranges of garnet that are sold are between 20 # - 200 # with only a small portion of fines, the colour of these garnets tend to be a deep red. These abrasive papers are often used for finishing and polishing surfaces of hard rubber, celluloid, plastics, brass and metal furniture, and for grinding valves and castings.

4.0 HEAVY MEDIA SEPARATION:

Heavy media, also known as Dense media separation, is essentially one of the simplest forms of separation and concentration for a variety of minerals, the words medium and media can and are also commonly used interchangeably. This is a practical and efficient application of sink/float testing which manipulates differences in specific gravity of the minerals in a liquid or a stable suspension. The aim of heavy media separation is to produce two products, a float product (lower density material) and a sink product (higher density material).

The heavy media separation process is not highly efficient in the separation of fine particles, therefore this technique is used for the separation of ores where either the valuable or the gangue materials liberate at a reasonably large size. The upper size limit of the heavy media processes effectiveness is related to the liberation of the constituents. The lower size limit is accepted to be about 0.5 mm. The separation takes place in a medium that has a density higher then that of water and in-between that of the valuable and gangue minerals. The medium can be a dense liquid, salts dissolved in water or more commonly a suspension in water of finely divided high density particles. This technique is commonly used in the cleaning of coal, where the coal is separated from its impurities such as slate.

The different types of heavy media separation can be classified by the specific mechanisms that are used for mineral separation. The main classification of heavy media separation cells are; static separation and dynamic separation cells.

4.1. Static separators.

In a static or otherwise known as gravity type separator, the essential concentrating force is gravity. The liberated and sized ore is fed into a fully static vessel where the density of the liquid or suspension is in between that of the minerals to be separated. The rate of sinking or floating can be determined by Stoke's law which is displayed in Equation 1 following. This considers variables such as particle size, fluid viscosity, density of particles and suspension. The counter force is an important variable which is essentially the *resistance to viscous shear that is produced between the mineral and the suspension.* This shear force is dependent on a number of variables including particle size. If the sinking force (i.e. mass by gravity) is less then this viscous shear force then the mineral will float, but if the sinking force is greater, then the mineral will sink. However, if the sinking force is equal to the shear force then the mineral particles will appear to hover in the suspension, this can be called a middling. This is more evident for finer sized particles. A typical example of a commonly used static / gravity type separator is a drum separator, of which there are many variations, one of which is shown in Figure 3.

Equation -1:- Stokes Law.

$$v = \frac{d^2 g(D_s - D_f)}{18\eta}$$

Where		
v	**= Terminal velocity of particle (ms^{-1})**
d	**= Particle diameter (m)**
g	**= Acceleration due to gravity (ms^{-2})**
Ds	**= Particle density (kgm^{-3})**
Df	**= Fluid density (kgm^{-3})**
η	**= Fluid viscosity (Nsm^{-2}) (water = 0.001 Nsm^{-2})**

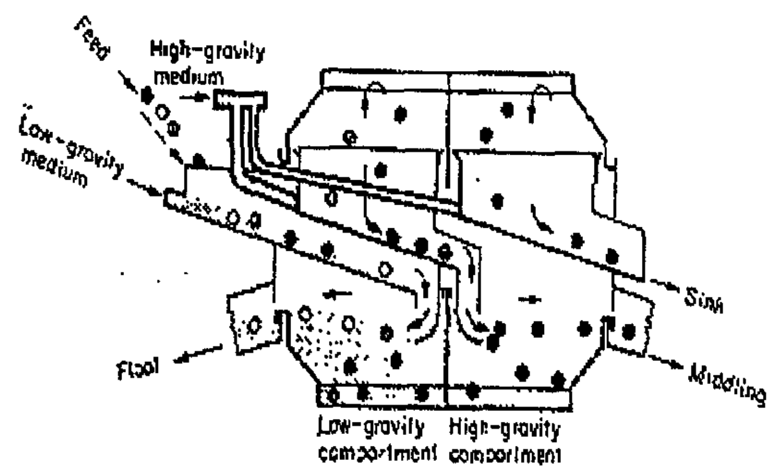


Figure 3.:- Double compartment drum separator
Source:- Wills, B. A. (1988) p. 459

4.2. Dynamic Separators.

Dynamic separators or centrifugal separators, as they are also known, are more commonly used and more effective for smaller particle sizes than the static type separators. When concerned with the finer sized particles a greater acceleration force (more than just the sinking force) needs to be acting on the minerals otherwise the minerals will be suspended due to their size and no separation will occur. Thus, mechanical forces such as centrifugal forces need to be applied for separation to occur. Equipment including hydrocyclones are modified to enable them to do this job. The separation achieved by these methods tend to be much more effective, as there is a significant increase in the separating force on the minerals. With the use of cyclones the force applied can be as great as twenty times the gravitational force that separates in a static separator. This force also applies to the medium in the dynamic heavy media separator, thus the density of this must also be sufficiently high to maintain effective separation.

In the hydrocyclone separator, the light float fraction is entrained in the vortex and discharged, whilst the heavy, sink fraction is discharged through a tangential outlet. The autogenous (water only) hydrocyclone is different to the usual hydrocyclone, in that it allows the separation to occur without any added medium, that is it just uses water. As shown in the diagram below, this separator has different stages in this cone. Other differences include a longer vortex and conical region. The fine particles are considered to accumulate in the conical region and create a barrier against particles of lighter density, i.e. only denser particles will pass through. The main advantage with this type of separator over conventional cyclones is the cheaper operating costs and lower capital investment. Other types of dynamic separators include: The Dyna Whirlpool Separator, The Tri-Flo Separator, The Hirst Washer and many others.

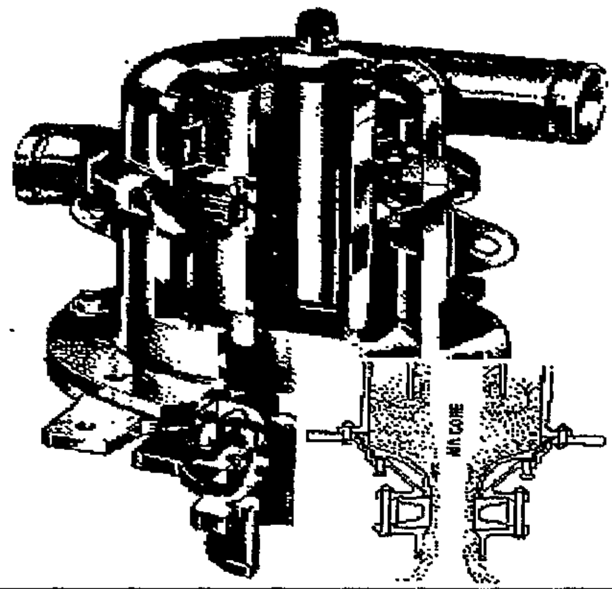


***Figure 4.** :- Autogenous (water only) hydrocyclone - Dynamic heavy media separation cell*
***Source :-** Kelly, E. G., Spotiswood, D. J., (1989), p. 246.*

A major part of any heavy media separation operation is the control and recovery of the medium, i.e. the suspended particles. A suspension is defined as *any liquid in which solids that are insoluble in the liquid are dispersed and kept in a state of fluid energy*. Commercially suspensions are generally employed, rather then dense liquids or dissolved salts, even though they tend to have a low settling rate. The most common medium that is used in suspension for separation is fine magnetite and/or ferrosilicon (FeSi). Magnetite is used to create a suspension of densities between 2200 - 2900 kg/m^3, and ferrosilicon creates densities in a range of 2900 - 3400 kg/m^3. Higher densities are possible when spherical ferrosilicon is used. These two mediums are commonly used as they are both physically stable, chemically inert, easily recovered from the sink by magnetic separation and form a low viscosity fluid of the prescribed density range.

Suspension stability is an important requirement for efficient separation, especially in static separators. i.e., a more stable suspension requires less agitation to keep it in suspension then less stable suspensions. With high agitation the probability of fine particle misplacement increases, due to the secondary currents and turbulence. The stability of heavy media separation is dependent on many aspects including: density of suspension, type of suspension and shape of the medium particles.

Heavy media separation when effectively controlled can provide sharp separations within the limits selected and at very high efficiency. They can also be easily modified and monitored if the head feed to the separator changes. The efficiency of the separation can be measured by a partition or Tromp curve, as shown in Figure 5. below. The curve in this diagram shows the ideal separation curve, which is almost impossible to achieve.

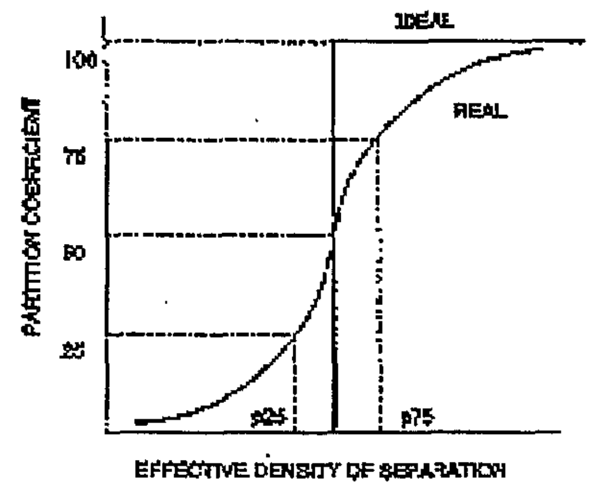


Figure 5. :- Partition or Tromp Curve
Source :-. Burt, R.O.,(1984) p.175

The probable error of separation is given by E_p, where $\mathbf{E_p = (P_{75}-P_{25}) / 2}$. Where P is the probability at that percentage. If the separation is ideal the $E_p = 0$. Typically for real situations E_p is between 0.01 and 0.1. These curves can also be used for other separation processes including shaking tables and spirals.

5.0. SPIRAL SEPARATION.

5.1. Gravity Concentration.

This is the term given to the *separation of two or more minerals, usually of different specific gravities, by their relative movement in response to the force of gravity and one or more other forces, typically resistance to motion in a viscous fluid such as water.*

The principle of gravity concentration has been known for over two thousand years, with its early uses being documented by **Pilny (circa 70AD)** and later by **Agricola (1556)**. It has only been in this century, with an increased understanding of physics and chemistry that has lead to the development of separation technologies such as flotation, leaching and magnetic separation, that the use of gravity concentration has been on the decline.

The use of gravity concentration technology has many advantages when compared to other concentration techniques, however since flotation is the major separation technique employed for the concentration of most minerals, including coal and iron ore, the best comparison is based on a comparison between these two methods.

Gravity separation has a lower installed cost per tonne of throughput than flotation, lower power requirements, uses no expensive reagents, and the waste and effluent generated is more environmentally friendly when compared to the use of flotation systems.

Not only does it economically make sense to use gravity concentration, but it can make even more sense from a metallurgical standpoint, as often the use of gravity concentration offers superior recovery without the use of chemicals. This was demonstrated by **Bath, Duncan, and Rudolph (1973)**, who showed that with the recovery of fine gold that the use of gravity concentration as the major separation technique, followed by cyanidation as a scavenging stage yielded a significant improvement in the recovery of gold. The chief disadvantage of gravity separation is its ability to handle fines, as the lower limit that it is possible to treat is around 10 microns.

5.2. Spirals.

The spiral is a helical flowing film concentration device, originally developed for the recovery of gold. The spiral can be described a follows: *"a multi-turn helical sluice of modified semi-circular cross section, for pulp flow, with a wash water channel and a series of concentrate take off ports at regular intervals."* **Burt (1984).**

Spirals were invented by I.B. Humphreys, who used old car tyres and sheets of lead to experiment with different spiral configurations, specifically, varying pitch, diameter, and cross sections. The first use of spirals on a commercial basis was in the concentration of chromite bearing sands in 1943 in Coos County

Oregon USA. This was followed by the introduction of the spiral to the mineral sands industry in Florida USA in 1944, and the iron ore / wolframite industry in 1964. The growing minerals sands industry in Australia in the 1950's led to the introduction of the spiral there, and subsequently most of the recent development work has been carried out there.

5.3. Principles of Spiral Concentration.

The feed is introduced to the spirals feed box, which has the function of regulating the fluid flow so that the correct pattern of flow is established at the top of the spiral. Attempts to mathematically describe the mechanism of spiral separation have been made in the Soviet Union, **(Anekin et al. 1970, Sukhanova et al. 1972)**, however these investigations failed. Nonetheless the mechanism of spiral separation is known to consist of two components;

(i) vertical stratification

(ii) horizontal stratification.

(i) Vertical Stratification.

The combined actions of hindered settling, interstitial trickling, and the Bagnold shear force **(Burt (1984))** will cause stratification of particles in the vertical plane. The heavy minerals will proceed to the lower velocity zones near the surface, whilst the light particles will report to the high velocity zones above them.

(ii) Horizontal Stratification.

Due to a difference in the centrifugal forces acting upon the varying stream components cross rotation may develop. The portion of the stream nearest the surface moves outward to the point of maximum stream velocity, from here it moves down into the stream to near the surface of the spiral. It then follows the spiral surface inward to the inner margin of the stream. This causes the heavy mineral to report to the inner margin of the stream towards the collection ports, and the lighter particles to be forced outward away from the collection ports.

Addition of Wash Water.

Many spirals have the facility to add wash water after removal of heavy mineral at each of the splitters. This assists the washing of light particles from the surface of the stratified bed at the inner radius, back toward the outer radius of the channel. Therefore it can be seen that the operation of the spiral is a complex blend of a variety of forces, specifically; interstitial trickling, hindered settling, Bagnold shear, and cross sectional rotation.

However, because there is no definite mathematical model of the interplay between these forces, spiral concentration operation continues to be based on empirical data rather than theoretical reasoning.

5.4. Types of Spirals.

With the recent developments in spiral technology spirals have been subdivided into two categories: (i) multi-off take, traditional spirals based on Humphreys original design, and (ii) limited-offtake, incorporating the more recent trends in spiral design.

5.4.1. Multi-Offtake Spirals.

Humphreys Spiral.

This spiral is essentially the same as its original design; 5-6 helical turns wrapped around a central support column which acts as a discharge, a internal washwater channel which introduces wash water periodically through notches in its wall, offtake ports in the bottom of the channel at various stages down the spiral length, and adjustable splitters adjacent to every offtake port to regulate the discharge of the heavy mineral. A full turn of the spiral is made up of three identical 120 ° segments that are joined together, typically made from cast iron or fiberglass. To make optimum use of floor space the capacity of the spiral can be increased by the introduction of another start 180 ° out of phase with the first.

GEC Spiral.

This spiral was originally made under license for Humphreys, and as such are essentially the same of the Humphreys spiral. The main difference between the two being the cross section where the GEC tends to have a steeper pitch and therefore requires less wash water.

Riechert Spiral.

There are numerous types of spirals manufactured by Riechert, both multi-offtake and limited off-take. They are characterised by their twin start continuous fiberglass helix, which whilst reducing the maximum number of turns, gives great improvements in flow. The table below shows the difference between the multi-offtake Riechert spirals.

Model	*Pitch (mm)*	*Splitter Dist.(mm)*	*Height (mm)*	*Diameter (mm)*	*Capacity (t/hr)*	*Feed Density (%)*
2A	387	298	2370	590	1.0 - 1.5	15 - 35
2B	387	324	2370	590	1.0 - 1.5	15 - 35
3	387	348	2370	640	2.0 - 2.5	25 - 45
6	367	254	2054	610	1.0 - 1.5	25 - 45

Table 2 :- Riechert spiral specifications.
Source :- Burt, R.O., (1984) p.265.

Vickers Spiral.

The spirals made by this company are also similar to the Humphreys spiral, however like the Riechert is manufactured from fiberglass in a continuous helix. The Vickers XVS model spiral has a reservoir after each take-off port facilitating the addition of wash water. Whilst the Vickers CC model spiral has a separate wash water trough wound around the supporting column. Water addition is via a stainless steel value, which eliminates washwater blockage.

5.4.2. Limited-Offtake Spirals.

The current trend in spiral design is to reduce the number of outlet ports. Many designs in which the only split is made at the end of the helix have been released onto the market.

Riechert.

Riechert have released many limited offtake spirals. The Mark 7 series incorporating triple starts and consisting of the Mark 7A and 7B, for the treatment of low grade and high grade feed respectively. Both have a helix in which the inner section has a lower slope than the outer rather than a curve. The Mark 7A has a single set of splitters and offtake port, whilst the Mark 7B has three sets of splitters and offtake ports. Mark 9 and Mark 10 series have been developed for the reduction of ash levels in coal. The Mark 9 spiral has increased diameter and decreased pitch with one set of splitters. Whilst the Mark 10 has a diameter similar to that from the Mark 7 series but with slightly decreased pitch and also has one set of splitters.

Vickers.

This company have developed the Feed Grade Low, LGL, and the Feed Grade High, FGH, spirals, for use in situations where the feed grade, density and size are variable. They incorporate a separating trough profile which allows the mineral path to remain constant regardless of these fluctuations. Therefore once these spirals are set they do not require adjustment.

Cyclo- Spiral.

The Mark I spiral was developed for low grade ores. The velocity of the heavy minerals in the pulp stream is decreased down the length of the helix to improve the recovery taken from the single set of splitters at the bottom of the spiral. This is achieved by the use of a channel in which the pitch of the floor gradually decreases down the length of the helix. The Mark V is for the treatment of higher grade ore. It uses a channel with constant pitch throughout the length of the helix, and has four offtake ports built into the floor of the channel at 180 ° intervals on the last two turns of the spiral. An adjustable cover over the offtake ports determines the amount of heavy mineral that is removed from the pulp stream.

5.4.3. Russian Spiral Technology.

A thorough review of spiral concentration techniques and apparatus looked not only into the effects of variable pitch and geometry, but also the effects of increasing the spiral diameter, as increased diameter leads to the acceptance of greater volume feeds. Incorporating the information gathered the SVM range of spirals were developed. They are characterised by their elliptical helix, and their 180° rubber lined aluminium segments. The table following outlines each spirals specifications.

Model	*Diameter (mm)*	*Starts*	*Capacity (t/hr)*	*Feed Density (%)*
SV2 - 750	750	2	1 - 5	15 - 40
SV2 - 1000	1000	2	3 - 8	15 - 40
SV2 - 1500	1500	2	20 - 30	15 - 40
SV3 - 1500	1500	3	10 - 30	15 - 40
SV4 - 1500	1500	4	15 - 40	15 - 40
SV2 - 2000A	2000	2	25 - 60	15 - 40
SV3 - 2000A	2000	3	30 - 75	15 - 40

Table 3:- SVM spiral specifications.
Source :- Burt, R.O., (1984) p. 269.

In addition to those spirals that are listed above, researchers in the former Soviet Union have also developed a spiral which maximises the use of the major settling zone of a spiral. Exposure of the pulp stream to the bottom portion of the channel is increased by incorporating two additional helixes inside the main helix, in effect giving three spirals in one as shown below.

5.4.4. Other Spirals.

Wyong Spiral.

Designed, built and used in the minerals sands industry in Australia, this spiral incorporates four channels side by side. Pulp is introduced at the top of the outer spiral, heavy mineral being forced inward and then onto the next spiral. Unfortunately this spiral is unable to produce finished concentrates therefore never gained widespread use.

Budin Spiral.

Originating in Austria, this spiral is similar to the Wyong spiral in that it incorporates more than one collection channel. This spiral involves three internal channels inside the main helix. Heavy mineral report to the inside channel whilst lighter mineral will migrate outward, the respective fractions are then removed at the bottom of the spiral.

Revolving Spiral.

A revolving spiral has been developed in China for the treatment of iron ore and tailings. It is constructed from fiberglass, has a 2 m diameter, typically has 4-6 turns, a pitch of inclination of 15 - 20° , and rotates at 10 - 15 rpm. **Robinson (1983)**

5.5. Operating Parameters of Spirals.

5.5.1. Helix Shape and Size.

Investigative work in the former Soviet Union by **Anekin et al. (1970)**, and more recently **Boganov (1983)** have investigated the effect of helix shape. It was found that the optimum shape for a helical cross section was an ellipse with an aspect ratio of 2:1, shown as Cross Section 1 in Figure 6 below.

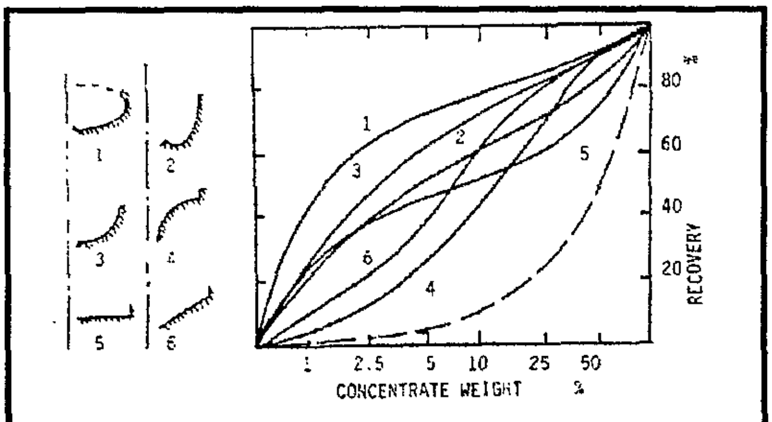


Figure 6.:- Effect of helical cross section on efficiency of separation, Cross Section are shown on the LHS. Source:- Burt , R.O., (1984) p.273.

In addition to the work done on the shape of the helix by Anekin, the effect of the helix diameter was carried out by another Russian investigator, **Sukhanova et al. (1972)**. This work revealed that the helix diameter was related to the particle size of the feed, suggested sizes from this work are:-

Fine particle size	0.05 - 0.20 mm	Helix Diameter	400 - 500 mm
Coarse particle sizes	1.00 - 2.00 mm	Helix Diameter	1000 - 1500 mm

However it is noteworthy that these recommendations are not generally accepted by the western manufacture of spirals.

5.5.2. Concentrate Removal.

Efficient concentration depends on the correct setting of the splitters. Whilst there are an infinite number of combinations for these settings, correct setting of the splitters is best done visually. Visual inspection of the pulp flow characteristics will be a guide to where the splitters should be set. Extending the distance between the splitters permits stratification and separation to occur. Thus extending this distance to a maximum increases the grade of the concentrate able to be removed. This was the logic behind the development of the limited take off spiral.

Work by **Snedden (1956)** showed that if the optimal spiral performance is desired then the splitters must be adjusted to give a constant grade through each offtake port, rather than constant volume. This is summarised by the results in the table below comparing constant volume to constant grade.

	Const. Volume			Const. Grade		
	Wt.%	*% H.M*	*Rec. HM*	*Wt.%*	*% H.M*	*Rec. HM*
Concentrate	56.0	9.94	91.7	53.80	9.85	94.3
Tails	44.0	1.10	8.30	46.20	0.70	5.70
Head	100.0	5.80	100.00	100.00	5.60	100.00

Table 4:- Effect of splitter opening on spiral performance.
Source :- Burt,R.O., (1984) p. 275.

Observation of the table reveals that by setting the splitters for constant grade rather than constant volume, an increase in concentrate recovery of almost 3 % results, with only a very small decrease in the grade of the concentrate. This fact is also apparent in the results for the tails, which is especially beneficial because of the decreased loss of valuable heavy mineral in the tails.

An additional concern when positioning the splitters is the cut between heavy and light mineral. As seen in the diagram below, the lighter mineral tends to ride up on the tail of the heavy mineral. Therefore the splitter position will depend on the intended function of the spiral, i.e. optimum grade or recovery. The rougher and scavenger spirals will be set well beyond the apparent edge as recovery is the primary objective. Conversely a cleaner spiral will have the splitter set inside the apparent edge as obtaining a high grade is its primary objective.

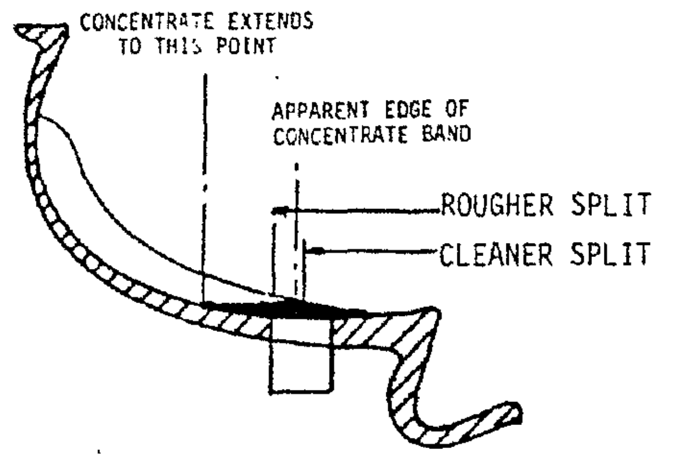


Figure 7:- Contour of heavy mineral band.
Source:- Burt, R.O., (1984) p.275.

5.5.3. Particle Size.

Coarse Particles.

The work of **Hubbard et al. (1950)** found the upper limit for good separation of most ores was approximately 1 mm, however gangue up to 3 mm and coal up to 6 mm can be tolerated. Therefore the size of the feed entering the spiral should be controlled. The presence of oversize in the flow will cause "sand bars" in the channel hindering stratification and separation, thus effecting the performance of the spiral and subsequent recovery of the heavy mineral.

Fine Particles.

As the coarse particles have an upper limit the fine particles have a lower limit. This is thought to be between 50 - 75 microns, depending of the type of ore being used. This is clearly demonstrated in the graph below. Based on investigations by **Chong (1978)** into spiral performance of iron ore, **Guest (1975)** into spiral performance of pyrite, **Weston (1978)** into spiral performance of scheelite, **Burt (1979)** into spiral performance of tantalite, and **Balderson (1982)** into spiral performance of cassiterite. Results obtained have been plotted on the same graph to allow a comparison between recoveries and particle size.

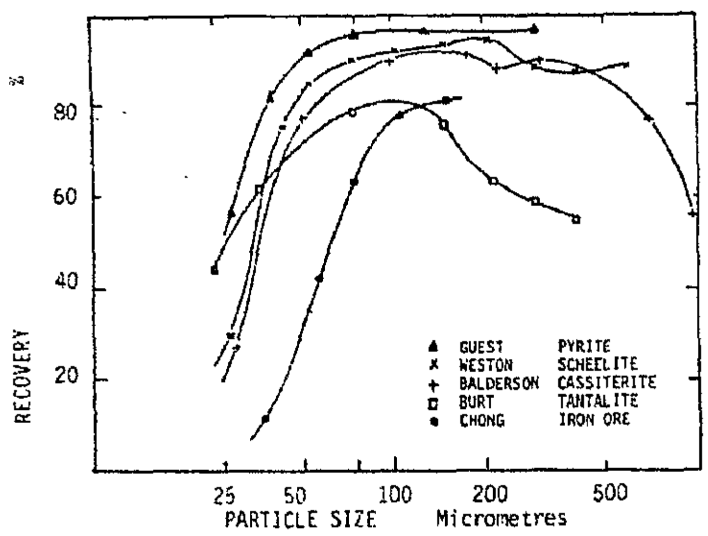


Figure 8:- Performance of spiral concentrators on various feed materials over a large size range. Source :- Burt, R.O., (1984) p. 277.

5.5.4. Particle Shape.

A marked difference in particle shape between two materials will allow efficient separation by a spiral concentrator. An example of this is the separation of mica from quartz and feldspar. The flaky mica is swept outwards into the region of fast flowing water predominantly because of the shape of the mica, and not the density of the mica.

5.5.5. Feed Grade.

Once the splitters are set for the optimum grade any fluctuations will have an adverse effect of the grade of the concentrate recovered. For example, an increase in the grade of the feed will result in a decreased recovery, because the extra heavy minerals present will be missed by the splitters. Alternatively if the grade is decreased then the recovery will be good at the expense of grade of the heavy mineral.

Dallaire et al (1978) discovered that fluctuations such as those discussed above can be combated by the control of spiral variables. For example, a lower pulp density and a smaller feed tonnage will tolerate such fluctuations. In fact some rougher / scavenger spirals are set for fluctuating loads because they have the function of optimum recovery.

5.5.6. Fluid Flow.

Dallaire et al (1978) discovered that a flow rate of between 1.0 - 1.5 L/s in a 600 mm spiral will result in laminar flow, whilst over this flow rate turbulent flow will result. Laminar flow is desired for optimal conditions as increasing the flow rate to turbulent velocities causes the fine heavy mineral and more of the middling to be forced into the tailing band, thus decreasing the recovery. However, it is also undesirable to have a low flow rate because it fails to provide sufficient centrifugal force necessary to force the light minerals out of the concentrate stream and into the tails at the periphery.

Further reduction in the flow rate will cause the coarser particles to settle out of the flow creating sand bars, thus hindering stratification and separation. Thus the flow rate of the pulp stream is very important to the efficient operation of the spiral. As mentioned above, this should be set at 1.0 - 1.5 L/s, however it can be optimised visually by regulating the flow rate so the pulp stream is 25-30 mm below the rim of the spiral.

5.5.7. Pulp Density.

Maximum pulp density is a function of the type of spiral that is being used. For example, the Riechert Mark 2 is rated at a pulp density of 15 - 35 % whilst the Mark 6 is rated at 25 - 45 % solids. In general, the higher the spiral pitch, the great the pulp density it can handle and consequently the greater its capacity. Excessive pulp density must be avoided as it results in reverse classification occurring which causes recoveries to decrease rapidly.

5.5.8. Solids Load.

Work by **Dalliare et al (1978)** compared the difference in the recovery obtained with constant solids load and increased solids load. Increasing the solids load, by an increase in the pulp density whilst maintaining a constant pulp flow yielded a small decrease in recovery and negligible effect on grade line (AB on the graph in Figure 9). Conversely maintaining a constant solids load, by increasing the pulp density and decreasing the pulp flow, yielded a significant increase in recovery with only a small decrease in the grade (line CB on the graph in Figure 9).

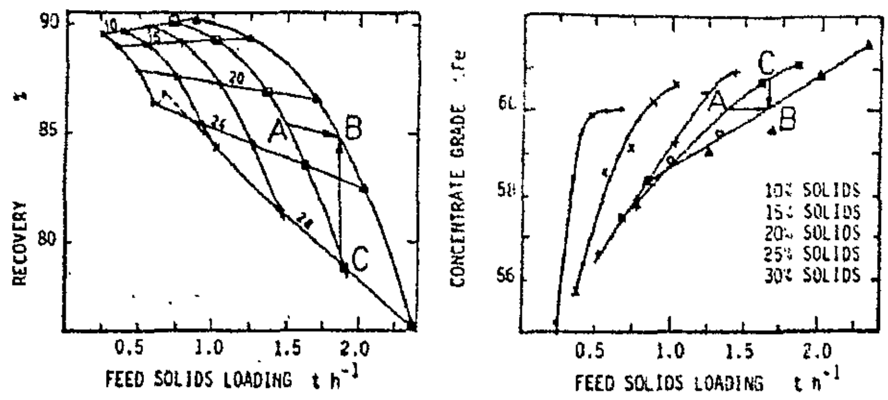


Figure 9:- Effect of solids load at different pulp densities on recovery (LHS) and grade (RHS).
Source:- Burt, R.O., (1980) p. 280.

5.5.9. Wash Water Flow.

Wash water is used in multi-offtake spirals, its function is to clean the heavy mineral band before offtake by washing the light mineral out to the tailing stream. The amount of wash water required will depend on the type of mineral being treated, spiral load, and the size of the mineral in the pulp stream. Typically coarser particles require greater additions of wash water. The conditions of wash water addition are displayed in the diagram below. The correct amount of wash water is displayed in part (A) the heavy mineral band filling the offtake port entirely; too much wash water is displayed in part (B) whereby the concentrate is being forced out towards the tailing band of the pulp stream; too little is displayed in part (C) whereby only a small amount of the heavy mineral band is extracted and the gangue is entering the takeoff port. It is also noteworthy that the use of reclaimed water is only possible on rougher / scavenger spirals, as dirty water will be split into fractions in the cleaner spiral thus decreasing the grade. Use of reclaimed water can also cause the build up of scale which alters the effective surface of the spiral thus effecting its operation.

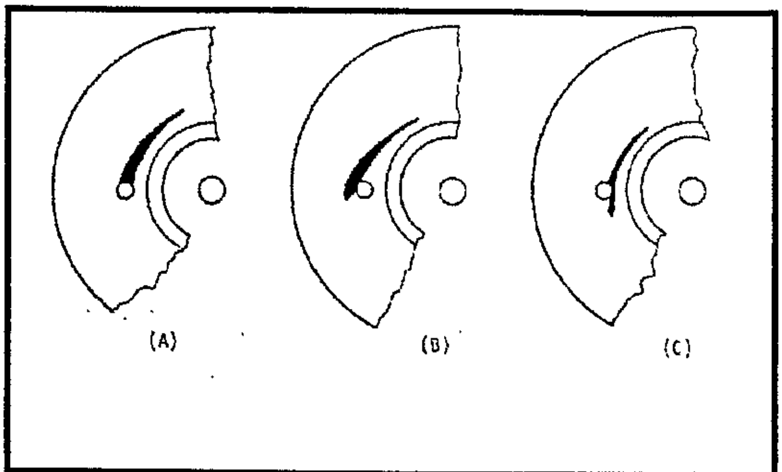


Figure 10:- Levels of wash water addition.
Source:- Burt, R.O., (1984) p.282.

5.6. Application of Spiral Concentrators.

Spirals can be employed in the separation of two minerals providing certain criteria are met;

(i) minerals are essentially liberated,

(ii) there is reasonable difference in the specific gravity or particle shape

(iii) where the heavy minerals are between 2 mm and 30 microns.

They have four primary uses:-

- a single roughing stage producing a concentrate and a tailing.
- a roughing stage producing a bulk concentrate of several heavy minerals for additional processing and a finished tailing.
- a cleaning stage producing a finished concentrate and tails reporting to an additional process.
- scavenging stage processing the tailings from other processes returning a rough concentrate for re-processing.

Spirals are used in the iron ore, mineral sands, metal oxide, and coal preparation industries, some typical examples are.

Iron Ore.

Generally spirals are used in the one rougher, two cleaner configuration. This typically results in a recovery of 80 - 85 % of iron at the specified grade.

Canada	Quebec Cartier Mine 2300 spiral units
	Mount Wright Mine 4330 double start units
Liberia	Bong Mine 2700 units

Mineral Sands.

Mineral sands by their very nature make an ideal feed to a spiral. That is, they are fully liberated, natural sized ore body with minerals with differing densities.

Australia	Eneabba Processing Plant 1000+ spirals
USA	Manchester Mine 1500 spirals

Metal Oxide.

South Africa	Winterveld Mines (Cr_2O_3) 168 spirals
USA	Wheal Jane Processing Plant Ta spirals

Desulphurisation of Coal.

Riechert has designed, built and manufacture spirals specifically for the cleaning of coal, namely the Mark 9 and 10 series spirals.

6.0. EXPERIMENTAL:

6.1. Experimental Procedure:- Sizing.

A bulk sample of garnet mineral sand was obtained from a deposit in the Hart's Ranges, Northern Territory. Preliminary investigations were aimed at classifying the bulk sample into three or four specific size fractions. A random 5 kg sample was taken from the bulk sample and screened over a large range of screens. This screening produced a wide range of size fractions, these fractions were then analysed and split into four separate fractions of similar size. These fractions were called oversize, coarse, medium and fine. The Tyler Mesh Numbers of the screens used to obtain these fractions were noted. Another 5 kg random sample was taken from the bulk and reserved for unsized trials, whilst the remainder of the bulk was screened according to the Tyler Mesh Numbers in the sizing regime mentioned above. The oversize was placed in the treated ore bin and the resultant coarse, medium and fine size fractions were stored for use as a feed material for this investigation.

6.2. Experimental Procedure:- Heavy Media Separation.

Heavy media separation techniques were used to separate the valuable garnet from the gangue minerals in each of the size fractions mentioned in the sizing regime above. The testwork employed ferrosilicon powder as the media added to the heavy media separation cell. The ferrosilicon was added to obtain a suspension with a range of densities between that of the gangue constituent (quartz, SG=2.65) and that of the valuable heavy mineral (garnet, SG=3.7-4.2). The testing regime involved adding each of the different size fractions separately to a static type heavy media cell. The density of the suspension would be varied between tests, with subsequent analysis of results revealing the optimum density and size fraction for the recovery of garnet in this type of heavy media separation. The static type heavy media cell initially involved a flotation cell and a variable speed impeller to keep the ferrosilicon in suspension. However, due to unexpected circumstances the design of the static heavy media cell varied within the testwork. This is addressed further in the Discussion in section 8.2 of this report.

6.3. Experimental Procedure:- Spirals.

The spiral testwork involved the use of the garnet mineral sand sample over two different spirals, therefore the tests involving spirals were split in two components; rougher and cleaner spirals. The sized mineral sand, produced in the sizing operation, was riffled to obtain a 3 - 4 kg feed material for the rougher spirals. A similar 4 kg unsized sample was introduced to the rougher spiral and a recirculating load was established, the adjustment of the splitters produced a concentrate of valuable garnet and tailing. This was then repeated for each of the sized fractions. Each of the products of the rougher spiral were subsequently riffled to obtain a representative sample for analysis. The remaining rougher concentrate from each fraction was then used as the feed material to the cleaner spiral and the tailings were placed in the treated ore bin. The aim of the cleaner spirals was to further upgrade the concentrate from the previous stage, i.e. the rougher spiral concentrate. The unsized rougher spiral concentrate was introduced to the cleaner spiral and a recirculating load established, the splitters were set to produce a cleaner concentrate and a tailing fraction. This was then repeated for all sized fractions. These products were then riffled to take a representative sample for analysis, and the remaining material placed in the treated ore bin. Samples of concentrate and tailings from each of the size fractions were then analysed using conventional quantitative metallography techniques.

7.0. RESULTS:

Photographs of each of the concentrates and tails were taken and are included in section 6.3. Using these photographs an analysis was performed. Quantitative metallography techniques were performed on each of these photographs, see Appendix 1. for a brief discussion of these techniques. The composition and hence grade of garnet of each sample was calculated using a sixteen point grid, where the number of intersections with these points of a specific mineral type was recorded for each of the points on the grid. This procedure was repeated twice more on each photograph to obtain a more representative composition. These were then used to calculate the average % composition as shown in Tables 6. and 7. The mineral types present were compiled into three groups; garnet being the valuable mineral, quartz being the gangue and the remainder being a black mineral of some form. The name or composition of this black mineral was unknown, possibly a form of iron oxide, and was classed as *"Other"*. The counts recorded are included in the Appendix 2., to show how these averages were taken and the variance in each of the counts.

7.1 Tabulated Results

7.1.2. Sizing.

Category	Mesh Range (Tyler #)	Size Range (μm)	Mass (kg)
Over Size	n/a	n/a	0.3
Coarse	3/16 - 14	6.7×10^3 - 1.18×10^3	13.7
Medium	14 - 35	1.18×10^3 - 425	24.0
Fine	35	< 425	8.15

Table 5:- Results of Screening

7.1.2 Rougher Spiral Assays, Average %

Size Fraction	Product	Garnet (%)	Quartz (%)	Other (%)
Unsized	Concentrate	48.1	10.6	41.9
	Tailings	26.9	37.5	35.6
Coarse	Concentrate	62.5	14.4	23.1
	Tailings	48.1	35.6	16.9
Medium	Concentrate	51.9	10.6	37.5
	Tailings	29.4	26.9	43.8
Fines	Concentrate	66.9	6.3	26.9
	Tailings	8.1	41.9	50.0

Table 6:- Quantitative Results Rougher Spiral

7.2.3 Cleaner Spiral Assays, Average %.

Size Fraction	Product	Garnet (%)	Quartz (%)	Other (%)
Unsized	Concentrate	35.6	18.8	45.6
	Tailings	75.0	6.3	18.8
Coarse	Concentrate	60.6	10.6	29.4
	Tailings	66.9	8.1	25.0
Medium	Concentrate	64.4	1.9	33.1
	Tailings	60.6	6.3	33.1
Fines	Concentrate	62.5	1.9	35.6
	Tailings	66.9	12.5	18.8

Table 7 :- Quantitative Results Cleaner Spirals

7.2.4. Metallurgical Results.

(i) Unsized	Rougher			Cleaner		
	Mass	Grade		Mass	Grade	
Feed	4.00	34.08	*	1.92	30.51	*
Cons	2.01	48.10		1.44	35.60	
Tails	1.47	26.90		0.10	75.00	
Recovery (%)		70.92			87.20	

(ii) Coarse	Rougher			Cleaner		
	Mass	Grade		Mass	Grade	
Feed	4.00	42.26	*	1.78	42.42	*
Cons	1.78	62.50		0.44	60.60	
Tails	1.21	48.10		0.73	66.90	
Recovery (%)		65.71			35.13	

(iii) Medium	Rougher			Cleaner		
	Mass	Grade		Mass	Grade	
Feed	3.80	60.45	*	1.64	30.67	*
Cons	1.76	51.90		0.64	64.40	
Tails	2.88	48.10		0.15	60.60	
Recovery (%)		39.72			81.93	

(iv) Fine	Rougher			Cleaner		
	Mass	Grade		Mass	Grade	
Feed	3.00	28.66	*	1.05	11.39	*
Cons	1.12	66.90		0.17	62.50	
Tails	1.39	8.10		0.02	66.90	
Recovery (%)		86.91			88.82	

Table 8 :- Results summary; including calculated recovery and feed assays (indicates a calculated result).*

7.3. Graphical Representation of Results, Chart 1:- Grade and Recovery Vs. Size Fraction Roughers

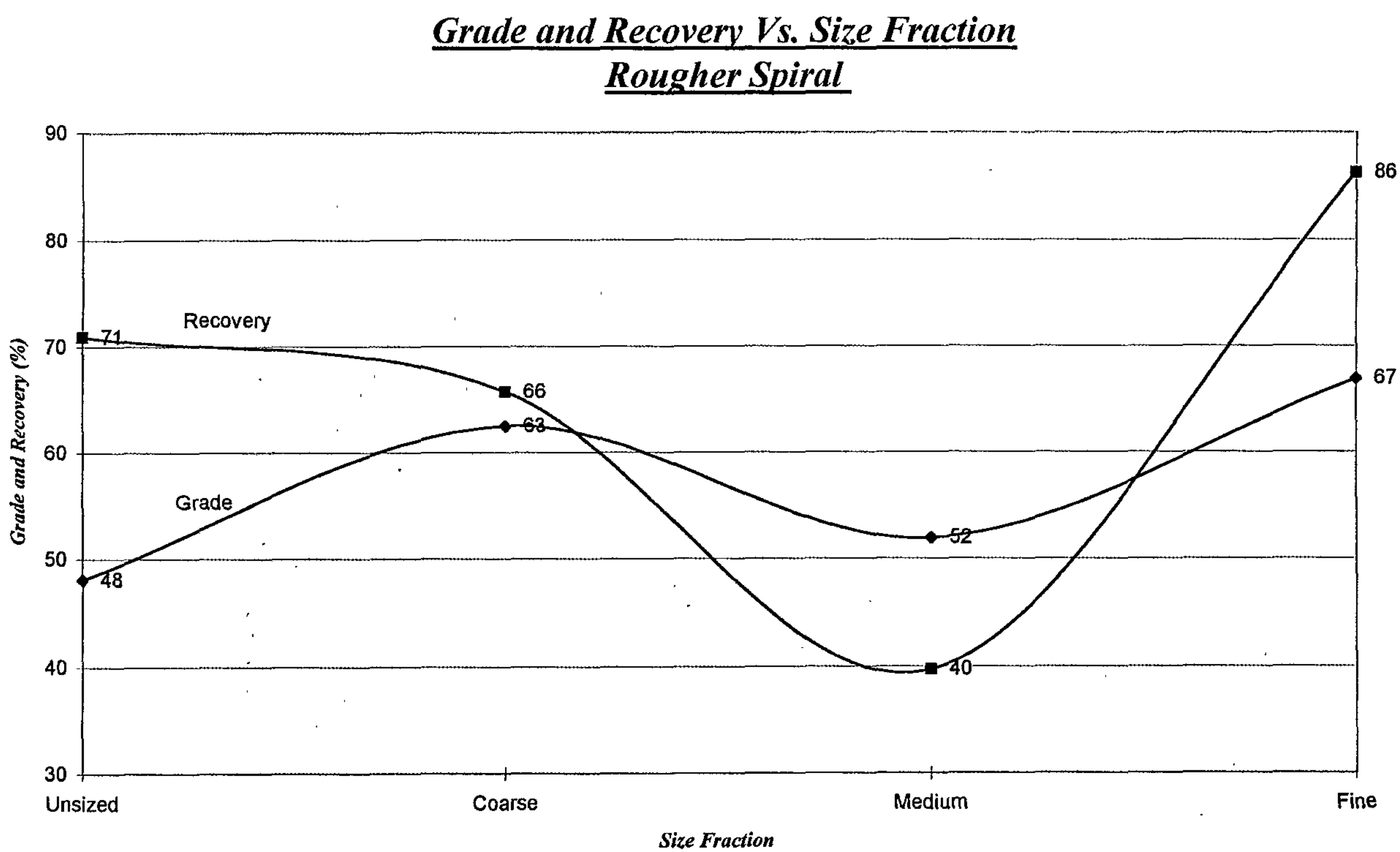
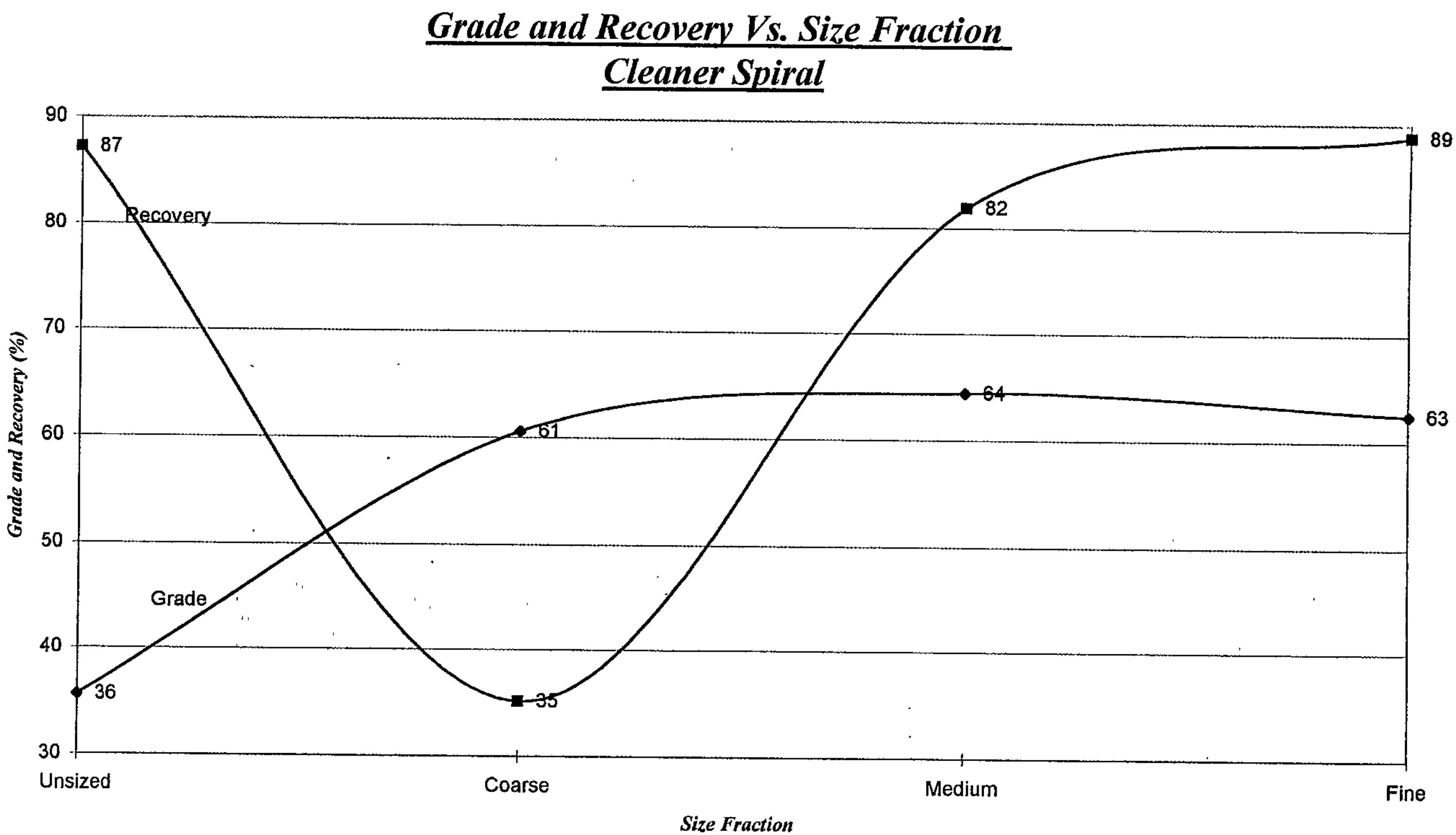
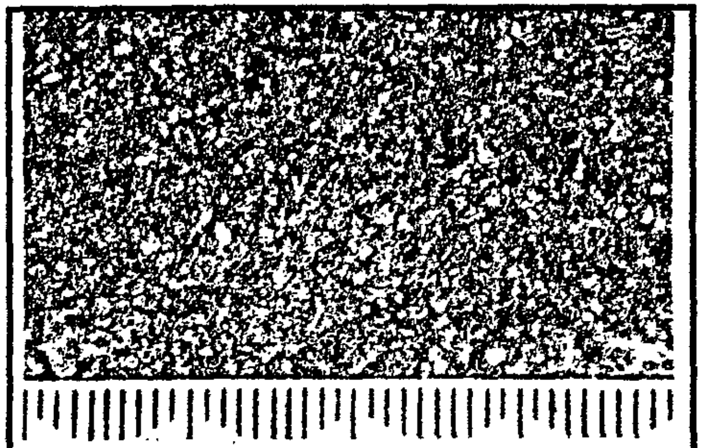


Chart 2:- Grade and Recovery Vs. Size Fraction Cleaners

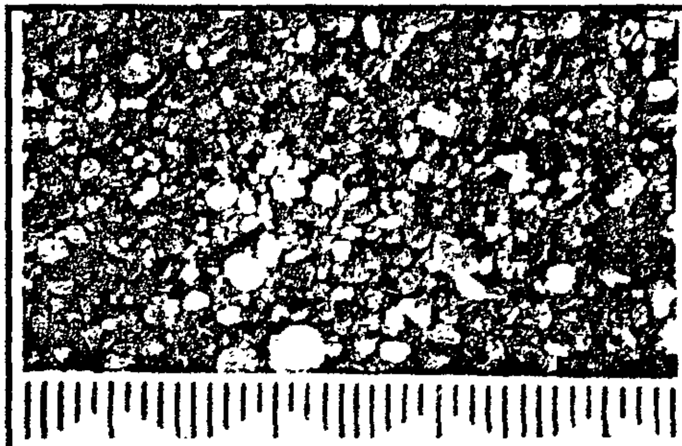


7.3. Photographic Results

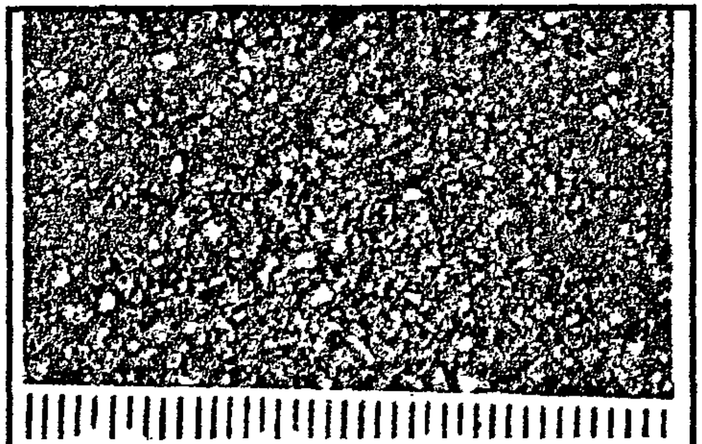
7.3.1. Results Unsized Garnet Sample.



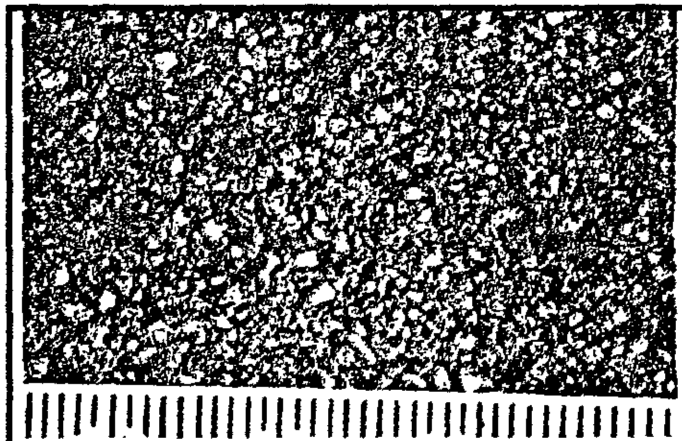
Photograph 1: Rougher Spiral Unsized Con.



Photograph 2: Rougher Spiral Unsized Tail.

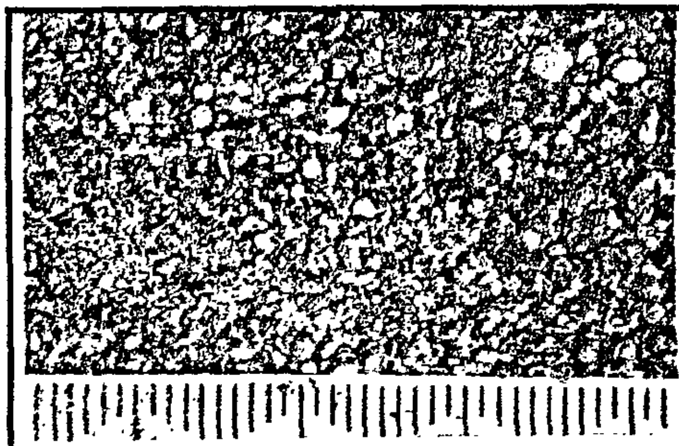


Photograph 3: Cleaner Spiral Unsized Con.

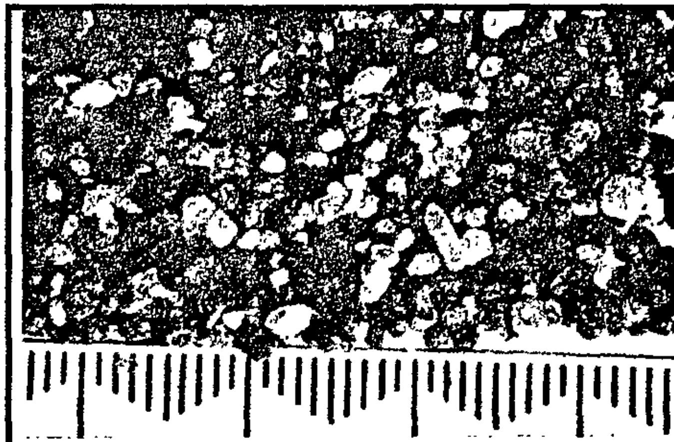


Photograph 4: Cleaner Spiral Unsized Tail.

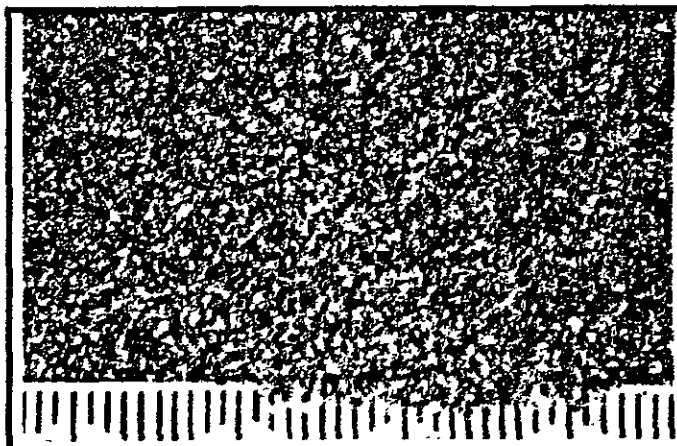
7.3.2. Results Coarse Sized Garnet Samples.



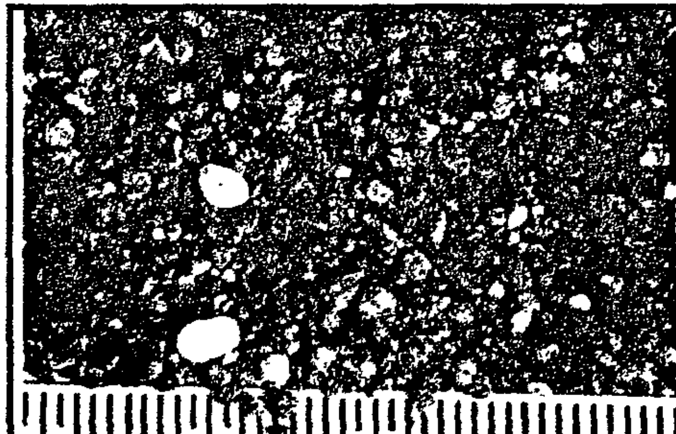
Photograph 5: Rougher Spiral Coarse Con.



Photograph 6: Rougher Spiral Coarse Tail.

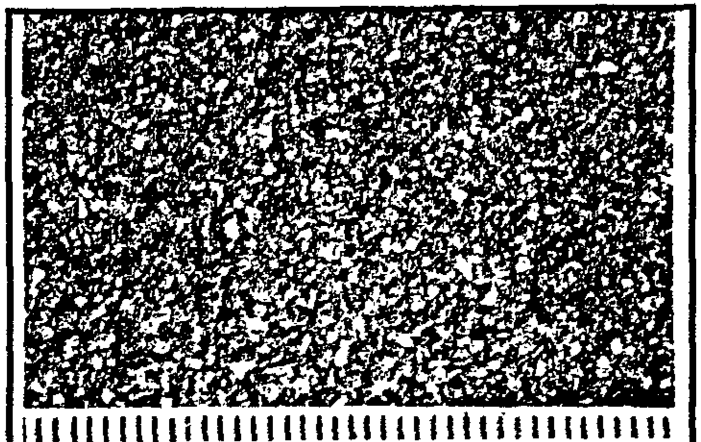


Photograph 7: Cleaner Spiral Coarse Con.

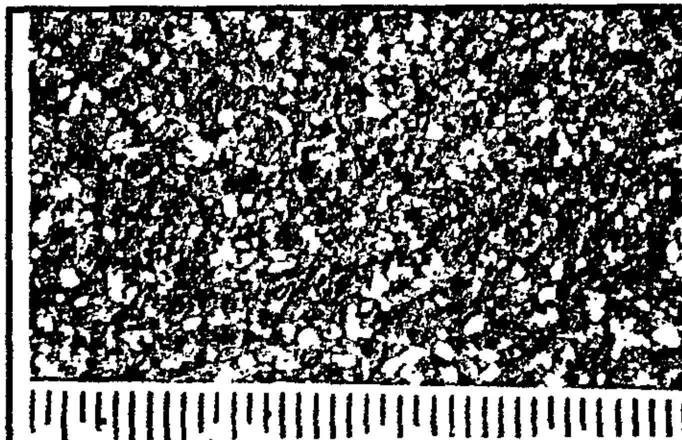


Photograph 8: Cleaner Spiral Coarse Tail.

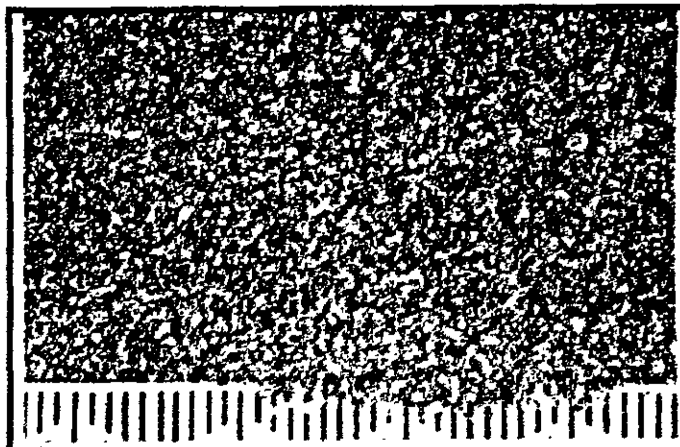
7.3.3. Results Medium Sized Garnet Samples



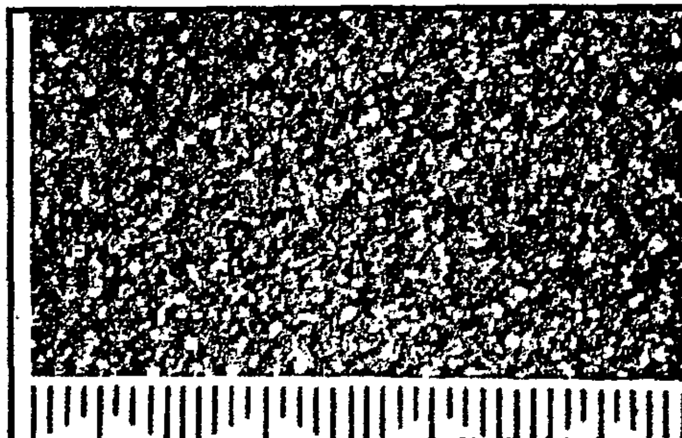
Photograph 9: Rougher Spiral Medium Con.



Photograph 10: Rougher Spiral Medium Tail.

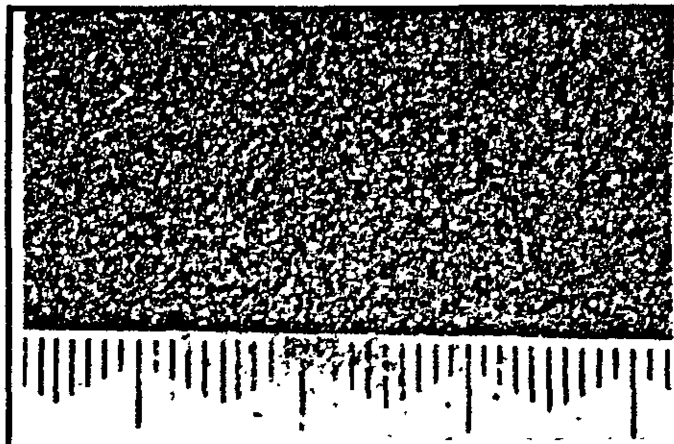


Photograph 11: Cleaner Spiral Medium Con.

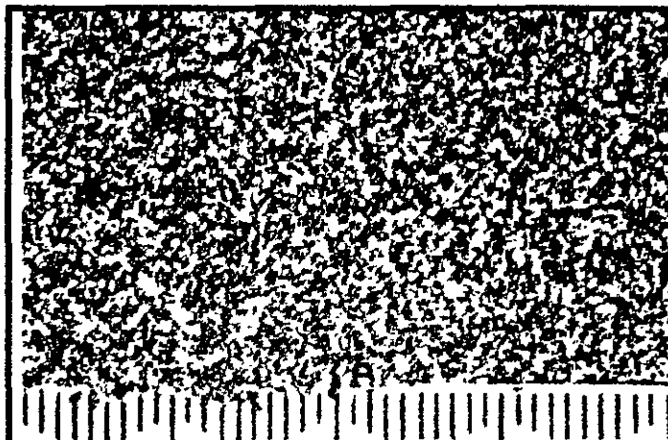


Photograph 12: Cleaner Spiral Medium Tail.

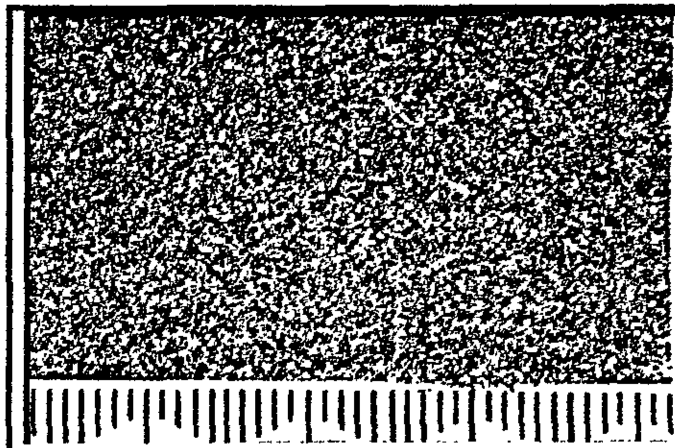
7.3.4. Results Fine Sized Garnet Samples



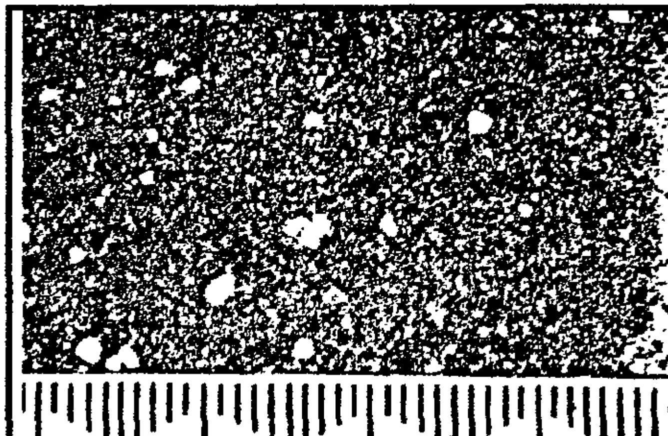
Photograph 13: Rougher Spiral Fine Con.



Photograph 14: Rougher Spiral Fine Tail.



Photograph 15: Cleaner Spiral Fine Con.



Photograph 16: Cleaner Spiral Fine Tail.

8.0 DISCUSSION:

8.1. Sizing.

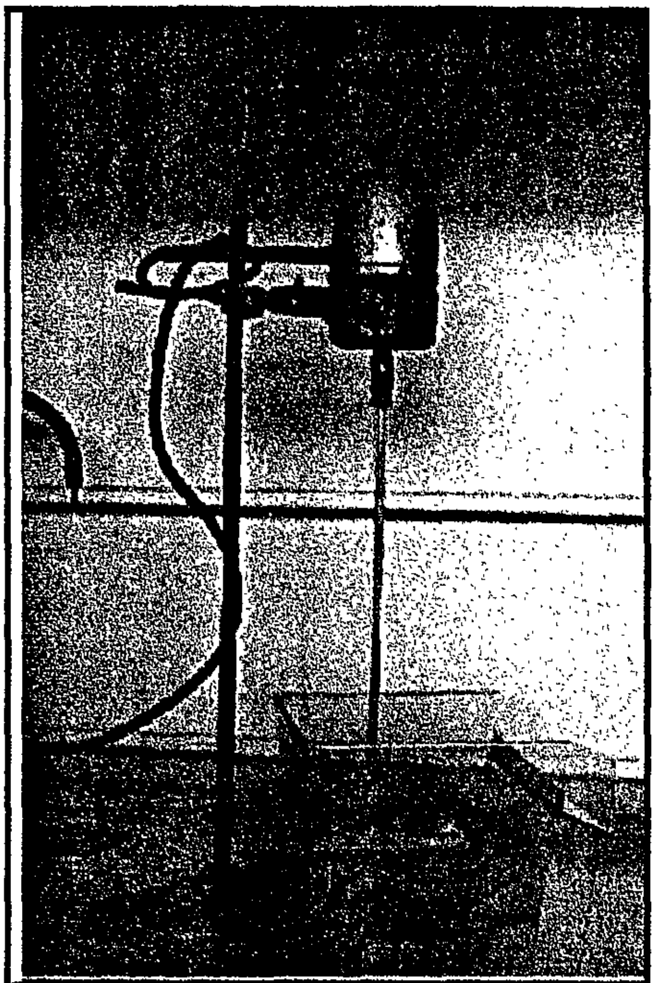
A better recovery of the garnet from the gangue was achieved when the sample of mineral was sized, as can be seen in Table 8 and shown graphically in Charts 1 and 2. This was because the particles were of the same size and therefore the difference in their densities could be exploited effectively. When the samples were unsized, the coarser particles were separating differently to the finer particles. This was not as a result of density which is the normal sizing mechanism, but the sizing was due to the mineral mass as there were considerable differences in their size. Thus, the coarser sized minerals would be forced further to the outside of the spiral. Because of such a large variation in size, some coarse heavy minerals tended to be positioned with the fine light minerals, making efficient separation very difficult. This resulted in the spiral often acting more like a size classifier rather then a gravity separator when treating the unsized sample.

8.2. Heavy Media.

Three different configurations of heavy media separation equipment were employed for the separation of the garnet from the gangue containing quartz and other minerals. However each attempt was unsuccessful, herein lies a discussion of each attempt.

8.2.1. Attempt One :- Agitation of Suspension with the use of a external mechanical stirrer.

The first attempt to model a heavy media separation device was with the introduction of a mechanical stirrer to a vessel containing the heavy media suspension. The setup for this is illustrated in photograph 17.



Photograph 17:- Apparatus used in attempt 1 at heavy media separation.

This method was based on the basic sink-float test. It involved establishing a suspension of the required density and subjecting it to agitation with the mechanical stirrer to keep the suspension stable. Garnet sand was then introduced to the vessel with a desired affect of making the quartz (of lower density) float off and the garnet present (of higher density) sink to the bottom of the vessel, therefore separating the two fractions, valuable and gangue minerals.

However this was not achieved, because to keep the ferrosilicon in suspension in this type of container, a higher stirrer speed was required. This higher speed created a vortex with turbulent flow, causing the gangue quartz to form a wide band between the stirrer and the surface. This is illustrated in the drawing in Figure 11.

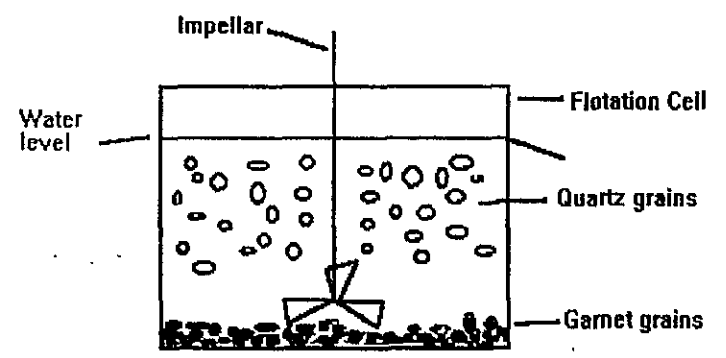
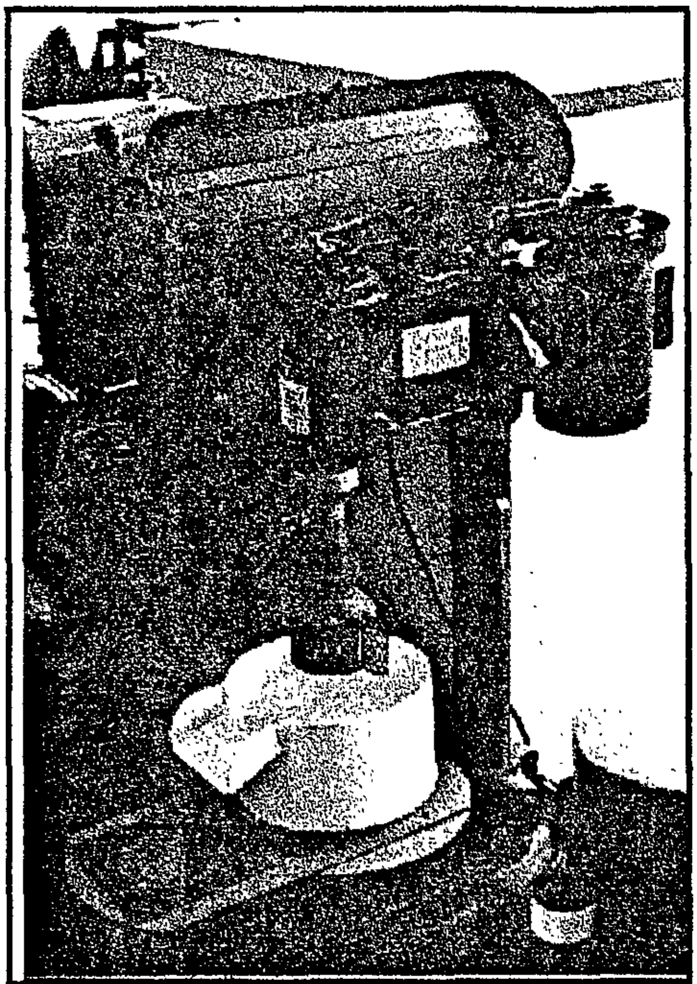


Figure 11:- Distribution of separated mineral in the apparatus used in attempt 1 at heavy media separation.

The large width of this gangue band posed problems with removal. Initially attempts were made to increase the volume at the same density so that the gangue suspended at the surface would simply overflow the vessel and be collected. However, this was not possible as the gangue band became wider with further volume additions of suspension being introduced. Only a very small proportion of the gangue was actually removed. This was followed by attempts to decrease the stirrer speed to remove the vortex and decrease the amount of turbulent flow, hence decreasing the thickness of the gangue band. This also was unsuccessful as the decrease in agitation caused the ferrosilicon to settle out of the suspension, consequently decreasing the density of the suspension and thus prohibiting the separation of the valuable and gangue fractions. Subsequent attempts to collect the gangue were based on a different approach, whereby an alternate technique was employed in the removal of the wide gangue band. In this approach bulk removal of the band by physical means was attempted. This was facilitated by the use of a fine net. This was tedious and ineffective as attempts to remove all of the quartz proved futile, and resulted in contaminating the separated garnet beneath. Therefore since none of the attempts to separate the two distinct fractions using this method were successful an alternate approach with new apparatus was trialed.

8.2.2. Attempt Two :- Agitation of Suspension by Flotation Cell.

The second attempt to model a heavy media separation device was in the use of a flotation cell, the agitation mechanism of this apparatus was employed in the agitation of the suspension. The drive belts of the agitation system were manipulated to many configurations in an attempt to provide the best agitation conditions for continued suspension of the ferrosilicon. This apparatus is demonstrated in photograph 18.

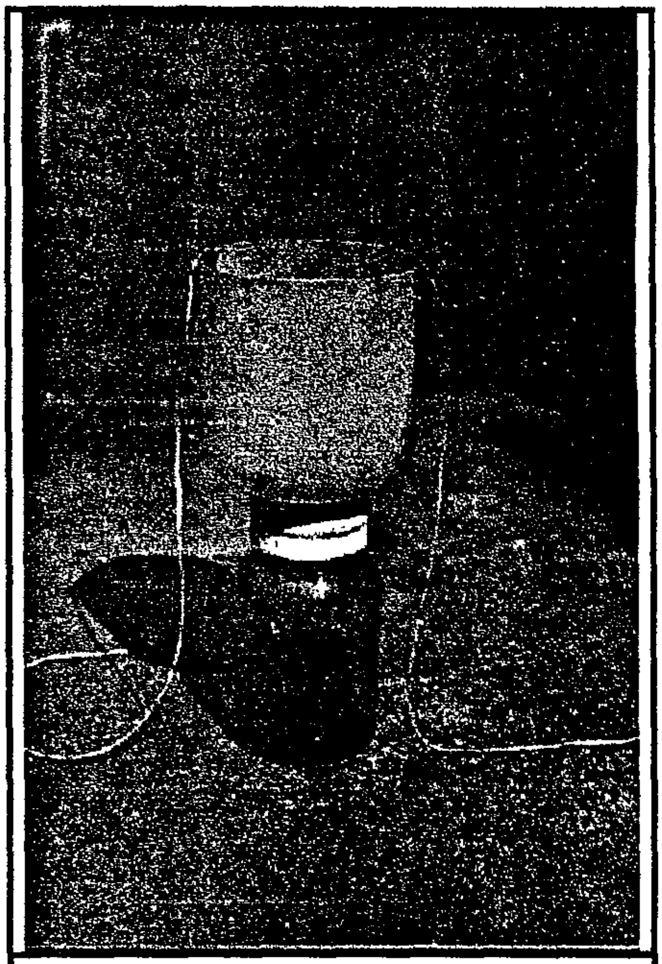


Photograph 18:- Apparatus used in attempt 2 at Heavy Media Separation.

However this attempt failed very early. It was found that with the density required for this heavy media separation that the agitation system of the flotation apparatus could not provide the necessary agitation required to keep the ferrosilicon in suspension. Whereby the solids were continually settling out of solution causing the agitator to "bog", therefore fear of damaging the flotation apparatus prevented to further use of this system.

8.2.3. Attempt Three :- Specific Purpose Built Cell.

The third attempt to model a heavy media separation process was design in conjunction with **Australian Standard 1661, (1979)** ***"Float and Sink Testing of Hard Coal"***. A photograph of the apparatus built is shown in Photograph 19 and a diagram of the recommend apparatus in Figure 12 is also shown.



Photograph 19:- Apparatus built for attempt 3 at Heavy Media Separation.

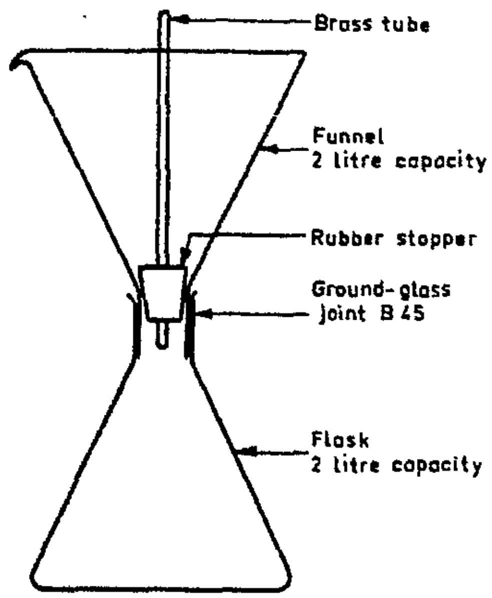


Figure 12:- Recommendation of Australian Standard 1661, (1979)

This piece of equipment was similar to previous items trialed, however this apparatus utilised a separate compartment for the removal of the garnet. The "purpose built" apparatus was designed to allow the stirrer to keep the ferrosilicon in suspension and thus facilitating a good separation in the top section of the equipment. The trapdoor to the bottom section was held up with the two strings attached. These were to open when the separation was thought to be efficiently working, and allow the garnet to fill the bottom part of the container, and be resealed before the gangue band was able to enter. This however did not succeed as when the trap door was opened, the ferrosilicon settled out of suspension before the garnet could enter the bottom section. This resulted in the remixing of the garnet and gangue constituents, and thus the separation was ineffective.

8.3. Spiral Separators.

8.3.1. Rougher spiral, unsized fraction: (photograph 1 & 2, c = 48.1 %, t = 26.9 %, R = 70.9 %)

Observation of photograph 1 shows a *concentrate* which contains a mixture of mostly fine grained minerals, however there is some coarse grained garnet present. Fine grained minerals present in the concentrate are a mixture of garnet, quartz, and the balance being a darker mineral. The quality of this concentrate is reflected in the grade obtained, that is % (garnet) = 48.1, and the suitability of this separation by the recovery calculated, that is Rec. (garnet) = 70.9 % .

The *tailing* obtained by this process is shown in photograph 2. Observation of this photograph shows a tailing which contains a mixture of coarse grained minerals, mostly quartz and garnet. The amount of garnet present is evident in the tail assay grade, where % (garnet) = 26.9. Such large losses of valuable mineral again suggest the lack of suitability of this process.

This is because the spiral acted as a sizing device rather than gravity concentration equipment. Under these conditions the coarse mineral reported to the tailings fraction, whilst the fine mineral reported to the concentrate fraction. This resulted in obtaining a "middling" region where both coarse and fine minerals were found and, depending on the position of the concentrate split, was responsible for the amount of coarse garnet found in the tailings. This demonstrates the sizing effect is at least as prominent as the density effect in this unsized mineral sample.

8.3.2. Cleaner spiral, unsized fraction: (photograph 3 & 4, c = 35.6 %, t = 75 .0 %, R = 87.2 %)

The feed to this second spiral separation was the unsized rougher *concentrate* discussed above, and as such was essentially a fine grained mineral sample containing quartz and some garnet with a small amount of coarse quartz, the result of a preferential sizing effect from this spiral. This is clearly evident in photograph 3. Whereby in the production of a cleaner concentrate, the coarse grained garnet was separated from the fine grained garnet in preference to the fine grained quartz. This downgrading of the rougher concentrate is reflected in the resultant cleaner concentrate assay, that is % (garnet) = 35.6.

The *tailing* obtained from this cleaning stage is shown in photograph 4. Observation of this photograph clearly shows that the tailing obtained is more of a garnet concentrate than the actual concentrate. That is, the tailing appears to contain more garnet than the concentrate. This is because of the preferential sizing effect where the coarse grained garnet present reports to the tailings in preference to the fine quartz. An effect further evident by the tailing grade, where % (garnet) = 75.0. This further supports the discussion in the above section on the performance of the unsized rougher separation. Therefore, since this sample feed was a result of the previous rougher stage, there was obviously a large proportion of coarse grained garnet present. However this result is not reflected in the recovery obtained for the separation because of the mass of the tailings is very small, that is T = 0.1 kg as opposed to C = 1.4 kg.

8.3.3. Rougher spiral, coarse fraction: (photograph 5 & 6, c = 62.5 %, t = 48.1 %, R = 65.7 %)

The *concentrate* from this separation is shown in photograph 5. This concentrate had a noticeably higher assay of garnet (in comparison to the unsized stages), probably as a result of a more constant grain size in the feed. This visual result is quantified by calculated results where, % (garnet) = 62.5. However the influence of larger particle sizes and the range of particle sizes in this coarse size fraction was again evident by the amount of smaller quartz in this concentrate.

The *tailing* produced by this separation is displayed in photograph 6. Observation of this photograph shows a tailing consisting of a mixture of very coarse mineral particles. The difference between the sizes of mineral particles obtained in the concentrate and in the tailings is clearly evident. This again suggests that the size fraction of the feed to the spiral does have a dramatic effect. The calculated results are as follows; the tailings assay, % (garnet) = 48.1, and recovery, Rec. = 65.7 %.

8.3.4. Cleaner spiral, coarse fraction: (photograph 7 & 8, c = 60.6 %, t = 66.9 %, R = 35.1 %)

The cleaner spiral *concentrate* is shown in photograph 7. This concentrate appears to be very similar to that obtained in the roughing stage. This is backed up by the assay obtained, where % (garnet) = 60.5. A downgrading most probably explained by the further influence of the sizing effect of the mineral garnet concentrate.

The resultant *tailing* from the cleaner spiral stage is shown in photograph 8. In this photograph the large amount of coarse grained garnet present is clearly evident. This is quantified by the calculated results where, % (garnet) = 66.9. This coupled with a large mass of the tailings, T = 0.7 kg resulted in a very poor recovery. Thus this situation proves to be a "worst case scenario" whereby the majority of the tailings consists of coarse grained garnet, present as a result of the influence of particle size in spiral separation.

8.3.5. Rougher spiral, medium fraction : (photograph 9 & 10, c = 51.9 %, t = 29.4 %, R = 51.9 %)

The *concentrate* obtained from the medium size fraction is shown in photograph 9. Observation of this photograph shows a concentrate consisting of garnet, quartz, and some small amounts of a dark mineral. The sample does not "look" like a concentrate as it does not have the ruby colour typical of previous garnet concentrates. This is supported by the calculated results, where % (garnet) = 51.9.

The *tailings* obtained from this stage are shown in photograph 10. Observation of this photograph shows a sample with particles of similar size to those in the concentrate. That is, influence of particle size does not appear to be as pronounced in this size fraction. However there still appears to be too much valuable mineral in the tailing. This is further evident by observation of the calculated results where, % (garnet) = 29.4 and recovery, Rec. = 51.9 %. Whilst this is the first size fraction where the influence of particle size seems to be less pronounced and separation is as a result of density differences, the results are still unacceptable in terms of loss of valuable mineral.

8.3.6. Cleaner spiral, medium fraction : (photograph 11 & 12, c = 64.4 %, t = 60.6 %, R = 81.9 %)

The *concentrate* produced as a result of the cleaning stage is shown in photograph 11. This photograph shows a concentrate which appears to contain more garnet than the previous sample. There also appears to be much less quartz present. The calculated results from this stage support this, where the assay, % (garnet) = 64.4.

The *tailings* obtained from this stage are shown in photograph 12. This photograph shows a sample with a some garnet present amongst the gangue constituents. The calculated results also show this with the tailings assay being very high, % (garnet) = 60.4. This result is almost as high as that of the concentrate from this stage. However because of the low mass of the tailings, T = 0.2 kg, this was not reflected in the recovery. This was most probably due to the influence of the particle size on the spirals operation. Whilst the influence of particle size was only minor in the rougher separation of this size fraction a definite effect was noticeable in this cleaner separation.

8.3.7. Rougher spiral, fine fraction : (photograph 13 & 14, c = 66.9 %, t = 8.1 %, R = 86.2 %)

Photograph 13 displays the fine rougher *concentrate*. Observation of this photograph reveals a sample clearly of a high grade. It consists of a large amount reddish coloured minerals amongst only a minor amount of gangue. This observation is supported by the calculated assay, where % (garnet) = 66.9.

The *tailing* from this stage is shown in photograph 14. Here the majority of minerals in the field of view are seen to be mainly quartz and the dark gangue mineral. Comparison of apparent sizes of the concentrate and the tail suggest that there is no size influence effecting this separation. This is supported by the assay of the tailings, where % (garnet) = 8.1, and the calculated recovery, where Rec. = 86.2 %.

8.3.8. Cleaner spiral, fine fraction : (photograph 15 & 16, c = 62.5 %, t = 66.9 %, R = 88.8 %)

Photograph 15 shows the *concentrate* obtained from the cleaner stage. The photographs shows no noticeable increase in the grade of this concentrate. Calculated results show that in fact the concentrate was actually downgraded, where the % (garnet) = 62.5. That is, the cleaner stage adversely effected the quality of the concentrate.

Photograph 16, the cleaner *tailings* also support this. Here the photograph shows a sample with a large proportion of red mineral amongst the gangue. If this photograph is compared to photograph 14, the rougher tailings for the fine size fraction, the massive difference between these two samples is clearly evident. This is because in potential further upgrading of the concentrate more garnet was lost in final removal of the gangue constituents. Calculated results, % (garnet) = 66.9, for this stage show that the inclusion of this stage would only be viable if a small tailing fraction was cut. This tailing fraction would then need to be recycled through the rougher stage.

8.4. Comparison with Published Work.

The work of **Hubbard et al. (1950)** revealed particle size limits for the treatment of ores, upper limit d = 1 mm, and lower limit d = 50 -70 μm. The results gathered in these trials conferred with this work, whereby the metallurgical results for the unsized, d = variable, and coarse, d = 6.7×10^3 - 1.18×10^3 μm size fractions were unacceptable. The particle sizes in these fraction are clearly above the upper limited set by **Hubbard et al. (1950).** The other fractions treated in this investigation were within the limits set by **Hubbard et al. (1950)**, the results for the fine fraction, d < 425 μm, agreeing with expectations and giving excellent results, however the results obtained for the medium size fraction, d = 1.18×10^3 - 425 μm, continued to be poor. A possible solution to this problem would be to further reduce the amount of coarse particles in this size fraction. This is achievable by rejecting these coarse grained particles to the coarse fraction, thus expanding the size range of the coarse size fraction. Alternately supplying the spirals with a relatively constant particle sized feed could also aid this problem.

9.0. CONCLUSION:

This experimental investigation was based on the separation of the valuable mineral garnet from the gangue constituents, chiefly quartz, using two conventional gravity concentration techniques. These were heavy media separation and spiral separators.

The influence of mineral particle size was cited early as a potential problem area, so the sample was screened into three different fractions; coarse where $d = 6.7 \times 10^3 - 1.18 \times 10^3$ µm, medium $d = 1.18 \times 10^3 - 425$ µm, and fine where $d < 425$ µm. To contrast the results from these size fractions a unsized sample was taken from the bulk by riffling.

Heavy media separation relies on density differences between the valuable mineral and the gangue constituents. A number of heavy media separation vessels were trialed unsuccessfully with the garnet feed provided. The design of each vessel was based on conventional commercial static heavy media separation vessels and were flexible enough to allow changes according to process variables. These trials were unsuccessful because the equipment employed designs which were unable to control important variables including, turbulence created due to agitation and continued suspension of the dense media particles.

Static heavy media separation, for example using the ferrosilicon at an appropriate density, was expected to work best for the coarse particles and not as well for the finer particles. This is because the minerals will have a buoyancy effect associated with them, an affect more pronounced with the finer sized particles. The sinking force due to the density of the suspension for finer minerals is also smaller due to the smaller particle size. These two forces, the buoyancy and sinking forces, will reach a similar magnitude as the mineral size becomes smaller. If the mineral particle is too small, no matter what the density of the suspension the mineral will become suspended also, due to the density forces on the mineral being too small due to the minerals size. Therefore in a static heavy media separator, fine mineral particles will not be affected as strongly a coarse particle would. This expectancy is visually represented in Figure # one.

The investigation using spiral separators also relied on density differences between the valuable mineral and the gangue constituents. However, during experimental work over various size fractions (both sized and unsized) the size of individual mineral particles was found to be of utmost importance. That is, the mineral particle size directly effected the grade and recovery obtainable in each size fraction. The influence of size in this work was found to decrease with decreasing particle size. That is, this influence was found to be greatest in the unsized and coarse sized fraction and have the least effect in the fine size fraction.

When treating fractions with a coarse particle size, typically $d = 6.7 \times 10^3 - 1.18 \times 10^3$ μm, the spirals acted as a sizing device and not a gravity concentrating device. As a result the concentrate was one which contained similar sized particles and not the valuable dense garnet mineral as desired. Whereas when treating the fractions with a fine particle size, typically $d < 425$ μm, the spirals operated effectively giving a concentrate that contained the valuable dense mineral garnet and a tailing which contained the less dense gangue constituents. This sizing effect was noticed in both the roughing and cleaning stages. However its effect was most severe in the cleaning stage, where in an attempt to upgrade the rougher concentrate by the removal of quartz a large loss of previously recovered garnet to the tailings fraction occurred.

Therefore for spiral separation of garnet to be viable, a feed preparation stage is required. In this feed preparation stage the garnet bearing ore would have to be sized accordingly by the use of equipment such as a hydrosizer. After which the fines would be treated by spiral separation. The remaining size fractions could be treated for garnet recovery by employing an alternate method of gravity concentration such as heavy media separation. Whilst the heavy media separation testwork in this project was unsuccessful, it has been proven to work under different conditions, (e.g. for manganese ores at Groote Eylandt, NT). Thus any recommendations that have been made are based on the theoretical knowledge obtained by the authors, from the references listed.

Therefore from the experimental results gathered in this investigation and theoretical data reviewed, the best configuration of heavy media and spiral separators for use in the concentration and recovery of valuable mineral garnet the following suggestions can be made;

① Size the ore into at least two sizes using a hydrosizer i.e. coarse and fine, where coarse $d = 6.7 \times 10^3 - 1.18 \times 10^3$ μm and fine $d < 425$ μm. Treat the coarse fraction with heavy media separation and treat the fine fraction with spirals.

② Use the heavy media separation as a primary concentration stage, in which the majority of the coarse quartz will be removed and sent to tails. This "rougher" concentrate will then subsequently sized in preparation for an appropriate spiral. Then use these spirals in a bank of cleaner, recleaners and scavengers to produce the final product.

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11.0. Appendices :

11.1. Appendix 1 :- Description of Quantitative Metallography.

The method employed to analyse the results in this testwork was to estimate the % mineral by use of a number of point counts. To facilitate this analysis, photographs of each resultant samples were taken so a visual agreement with the calculations can be made. Point counting consists of an ordered (non random) array of points such as on a transparent screen template or microscope eyepiece covering the sample to be analysed, and a record of the mineral at each intersection being recorded. This count is said to be "systematic" as the same procedure is followed a number of times on each sample. *It may be statistically shown that point counting can give results showing the least variance provided that samples are taken of different errors* **(SM753, (1995))**. For this testwork, each point count was completed three times on each sample photograph, each count being randomly placed of a different area of the photograph.

The commonly used graticules used are:

① A square grid with nine points for rapid and easy counting.

② Square grid of sixteen points gives nearly twice the number of points per placement but takes longer to count with a greater risk of error, if not done correctly.

③ Circle test line of known circumference.

④ Straight test line with the ends clearly marked.

⑤ Graduated test line.

For this analysis work, graticule ② was chosen as it gave a large number of counts. In using this method, it was imperative that placements and subsequent counts were carried out in a nonbiased and totally random manner. Thus, the systematic errors associated with this quantitative technique were minimised to give the most accurate results.

11.2. Appendix 2 :- Quantitative Metallography Results.

11.2.1. Results: Rougher Spiral Test Samples.

16 Point Grid		Garnet	Quartz	Black
Coarse	Cons	10	2	4
		10	3	3
		10	2	4
	Average	10	2.3	3.7
	Tails	8	6	2
		6	6	4
		9	5	2
	Average	7.7	5.7	2.7
Medium	Cons	9	1	6
		8	1	7
		8	3	5
	Average	8.3	1.7	6.0
	Tails	4	6	6
		4	4	8
		6	3	7
	Average	4.7	4.3	7.0
Fine	Cons	12	0	4
		10	2	4
		10	1	5
	Average	10.7	1.0	4.3
	Tails	1	6	9
		2	8	6
		1	6	9
	Average	1.3	6.7	8.0
U/S	Cons	7	2	7
		9	1	6
		7	2	7
	Average	7.7	1.7	6.7
	Tails	4	7	5
		4	5	7
		5	6	5
	Average	4.3	6.0	5.7

11.2.2. Results: Cleaner Spiral Test Samples

16 Point Grid

		Garnet	Quartz	Black
Coarse	Cons	11	1	4
		10	2	4
		8	2	6
	Average	9.7	1.7	4.7
	Tails	13	0	3
		12	2	2
		7	2	7
	Average	10.7	1.3	4.0
Medium	Cons	10	1	5
		11	0	5
		10	0	6
	Average	10.3	0.3	5.3
	Tails	10	1	5
		8	1	7
		11	1	4
	Average	9.7	1.0	5.3
Fine	Cons	10	0	6
		11	1	4
		9	0	7
	Average	10.0	0.3	5.7
	Tails	11	2	2
		11	1	4
		10	3	3
	Average	10.7	2.0	3.0
U/S	Cons	5	2	9
		6	4	6
		6	3	7
	Average	5.7	3.0	7.3
	Tails	15	0	1
		10	1	5
		11	2	3
	Average	12.0	1.0	3.0

INPROSYS

INTERNATIONAL PROCESS SYSTEMS, INC.

1510 Swadley Street, Lakewood, CO 80215, USA
Tel: (303) 237-8737, Fax: (303) 237-8624

FAX

TO :	Mr. Uwe Barfuss	PAGE	1 OF 3
CO.:	Barfuss Corp. P/L	DATE:	January 14, 1997
FR :	Ron Gehauf	FAX #:	61-3-9739 6578
RE :	Garnet Testing	REF #:	97- 0088

Dear Mr. Barfuss,

I have just completed some preliminary tests on the sample of garnet ore you sent to us. The material may be identified as INPROSYS No. 97-007. Please find following the material balances for the tests.

Procedure

In conducting these tests, the material was fed onto the belt with a vibrating feeder. The belt carried the material across the magnetic roll, producing Mag 1 and Non-Mag 1 products. The Non-Mag 1 product was again fed onto the belt producing Mag 2 and Non-Mag 2 products, etc. The feed rate of pass 2, etc., was adjusted to simulate a cascading, production machine. As the roll speed was reduced, the less magnetically responsive minerals were recovered in the magnetic product. The feed rates are reported as metric tonnes per hour per meter of processing magnet. Our standard machines are 1.0 and 1.5 meter wide but we also manufacture 0.5 meter wide machines.

Discussion

Since the material had a broad size range, I initially screened the material at 20 mesh (0.85 mm) and processed each fraction separately. The initial separation attempt removed all of the garnet as well as most of a dark mineral which was slightly less responsive than the garnet, leaving all of the silica/feldspar minerals as non-magnetic. This was re-mixed to try to achieve a better quality garnet.

There was a was a noticeable amount of highly magnetic material in each fraction which was removed with a scalper (lower intensity) roll before removing the garnet. The garnet was then removed in stages to try to minimize the amount of dark minerals which reported as magnetic. However, a noticeable amount of finer dark particles reported with the garnet.

Conclusions

It appears that a silica-free garnet concentrate can be produced easily. However, there are some dark minerals which are slightly more responsive than garnet and relatively large amount of dark minerals which are similarly or slightly less responsive. In order to reduce the amount these dark minerals, the feed material must be screened at close intervals. If the dark minerals are to be eliminated, another method must be used.

Recommendations

It may be possible to eliminate 20% to 30% of the initial weight by pre-concentration with minimal screening and magnetic separation. In order to produce the best possible products, it will be best to screen the material into the product sizes before magnetic separation.

The products from these tests are ready to be shipped back to you. Please let me know your address for their return. If you have any questions, feel free to contact me.

Best regards,

Ron Gehauf

Ron Gehauf
Technical Services Manager

INTERNATIONAL PROCESS SYSTEMS, INC.

MAGNETIC SEPARATION TEST PRODUCT BALANCE

ID NO. : 97-007
TEST DATE : January 14, 1997
MATERIAL : Garnet Ore
FEED PREP. : Screen

CUSTOMER : Barfuss Corp P/L
ACC. NO. :
SEP. ID. : LP 10-30
NOTES :+20 mesh (+0.85 mm) - 42.98 wt%
: -20 mesh (-0.85 mm) - 57.02 wt%

TEST NO.	PRODUCT	FEED RATE TPH/M	RL SPD RPM	MASS DIST. % WT	CUM WT%	GRADE %
+20 1	FEED	6.2	350	100.00		
4:4	MAGS 1			1.12		
1.0 mm	NMAGS 1		350			
4:2	MAGS 2			26.34	27.46	
0.25 mm	NMAGS 2		300			
	MAGS 3			32.17	59.63	
	NMAGS 3		250			
	MAGS 4			18.82	78.45	
	NMAGS 4			21.55	100.00	
-20 1	FEED	4.3	350	100.00		
4:4	MAGS 1			3.62		
1.0 mm	NMAGS 1		450			
4:2	MAGS 2			25.40	29.02	
0.25 mm	NMAGS 2		380			
	MAGS 3			38.08	67.10	
	NMAGS 3		330			
	MAGS 4			27.80	94.90	
	NMAGS 4			38.42	133.32	

INPROSYS

1510 SWADLEY ST.
LAKEWOOD, CO 80215
PHONE (303)237-8737, FAX (303)237-8624

TO : MR. UWE BARFUKS
CO.:
FR : JOHN RIOTT
RE : 0.50M MACHINE W/CHUTES

DATE: January 14, 1997
FAX #: 011-61-3-97396578
REF #: 97- 0082

DEAR MR. BARFUKS:

HERE ARE THE DRAWINGS YOU REQUESTED. DRAWING GA00137 IS THE GENERAL ARRANGEMENT AND DRAWING HS10109 IS THE DISCHARGE CHUTE.

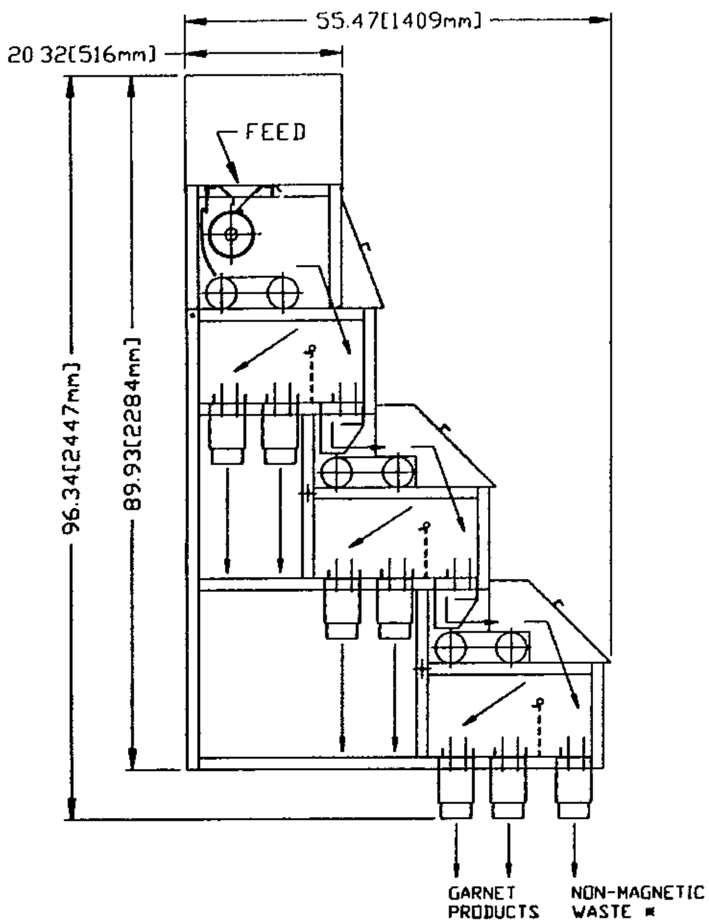
IF YOU NEED ANY FURTHER INFORMATION, PLEASE CONTACT ME.

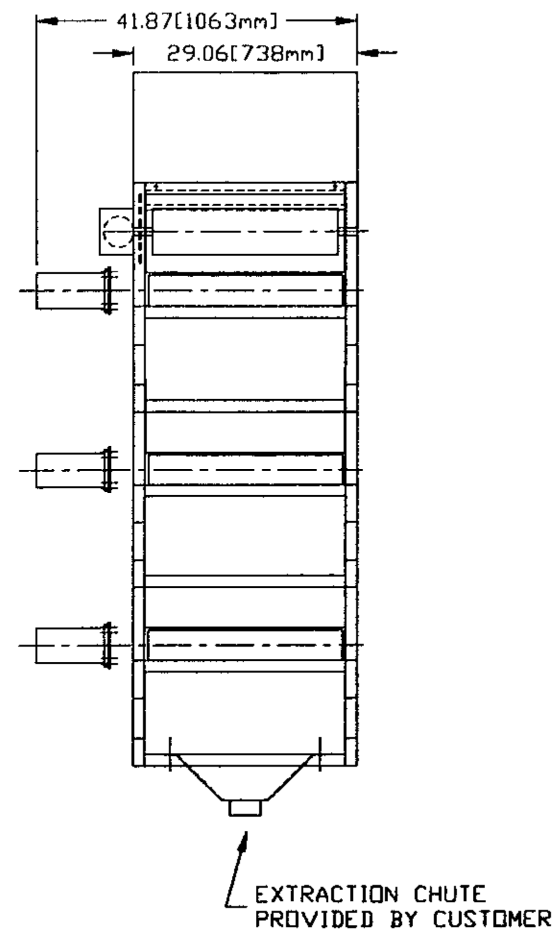
BEST REGARDS,

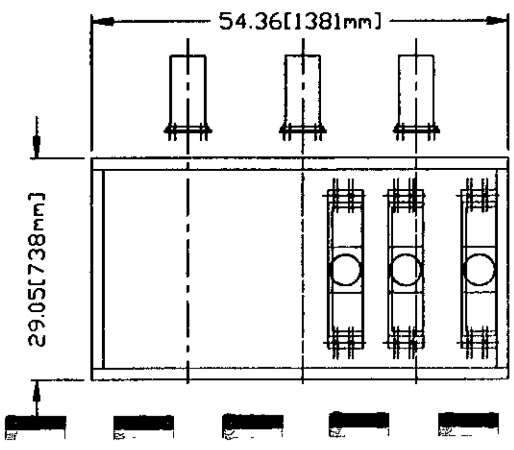
JOHN RIOTT
CHIEF ENGINEER

ZONE	REV	DESCRIPTION	DATE	APPROVED
-	A	ADDED SEPARATE CHUTES & FLOW PATTERN	1/6/96	KAS

NOTE DIMENSIONS & WEIGHTS ARE APPROXIMATE







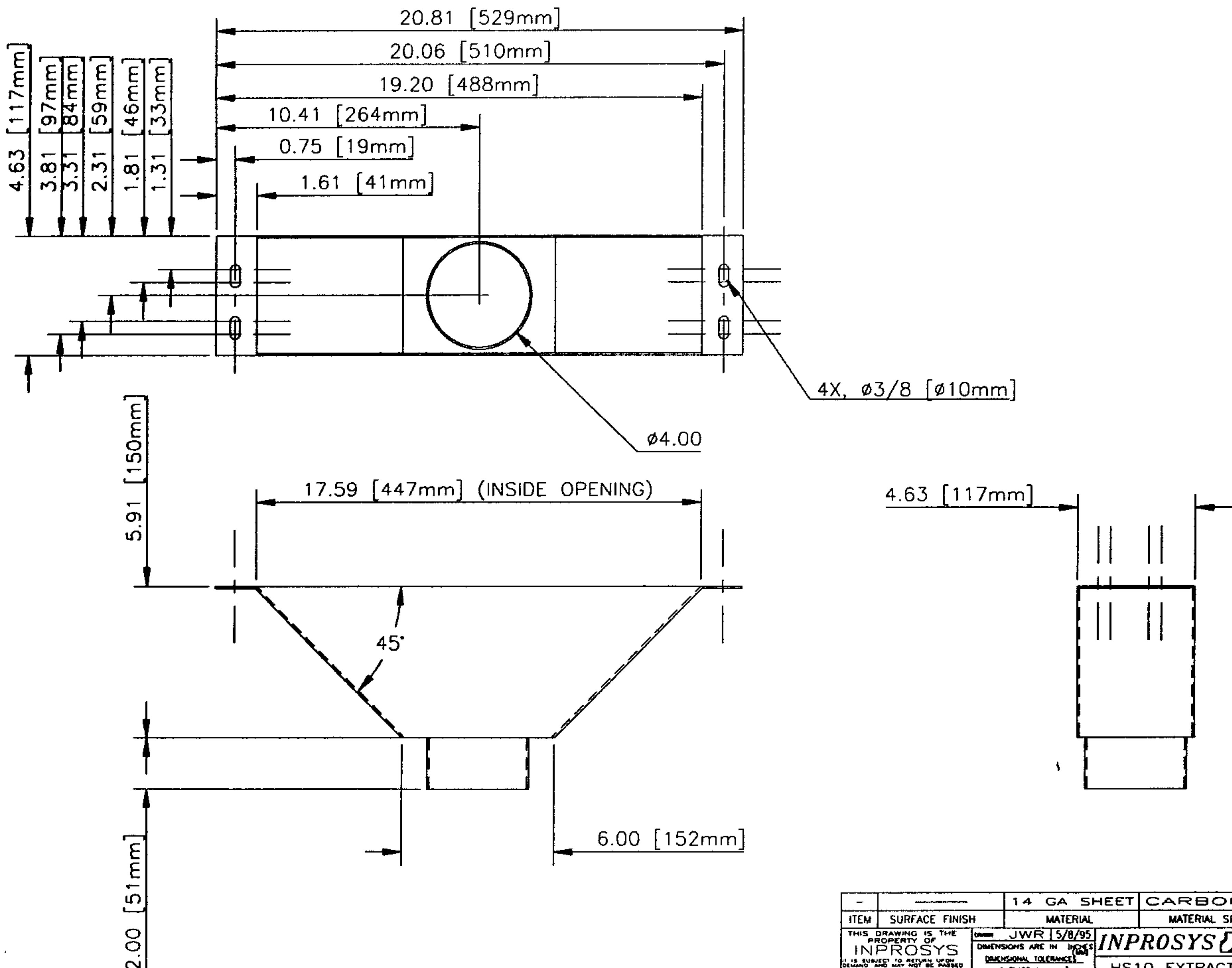
POWER:
1 INSTANT AT START-UP: 6 AMP
2. IN OPERATION. ABOUT 1 AMP @ 220V

APPROX. WEIGHT W/ CRATE = 750 KG.

ITEM	SURFACE FINISH	MATERIAL	MATERIAL SPECIFICATION
THIS DRAWING IS THE PROPERTY OF INPROSYS	DRAWN JWR 5/4/95 DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES 1 PLACE ± .1 [redacted] ± .06 [redacted] ± .01 ANGLE ± 15°	INPROSYS	GENERAL ARRANGEMENT TRIPLE [redacted] W/RE[redacted] 0.50M[redacted]
[redacted] INTERNATIONAL PROCESS SYSTEMS	SCALE 1=20	SIZE A	DWG NO GA00137 REV A

PRIMER AND PAINT MACHINE GREY

ZONE	REV	DESCRIPTION	DATE	APPROVED
–	B	ADDED METRIC DIMENSIONS	10/28/96	JWR



–	———	14 GA SHEET	CARBON STEEL
ITEM	SURFACE FINISH	MATERIAL	MATERIAL SPECIFICATION

THIS DRAWING IS THE PROPERTY OF INPROSYS [redacted]

JWR 5/8/95

DIMENSIONS ARE IN INCHES

DIMENSIONAL TOLERANCES

1 PLACE ± [redacted] .06 [redacted] .010 [redacted]

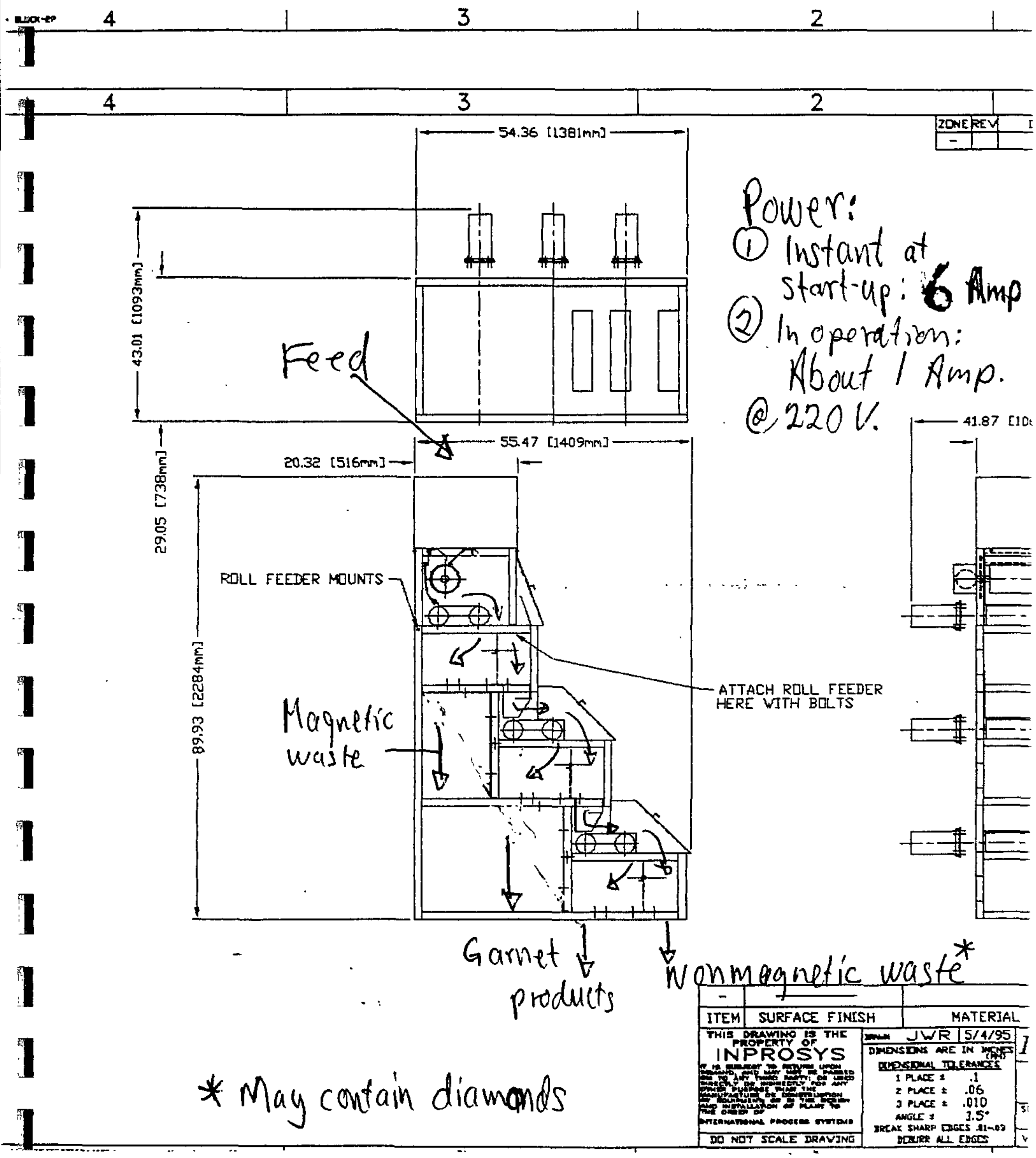
ANGLE ± 1.5°

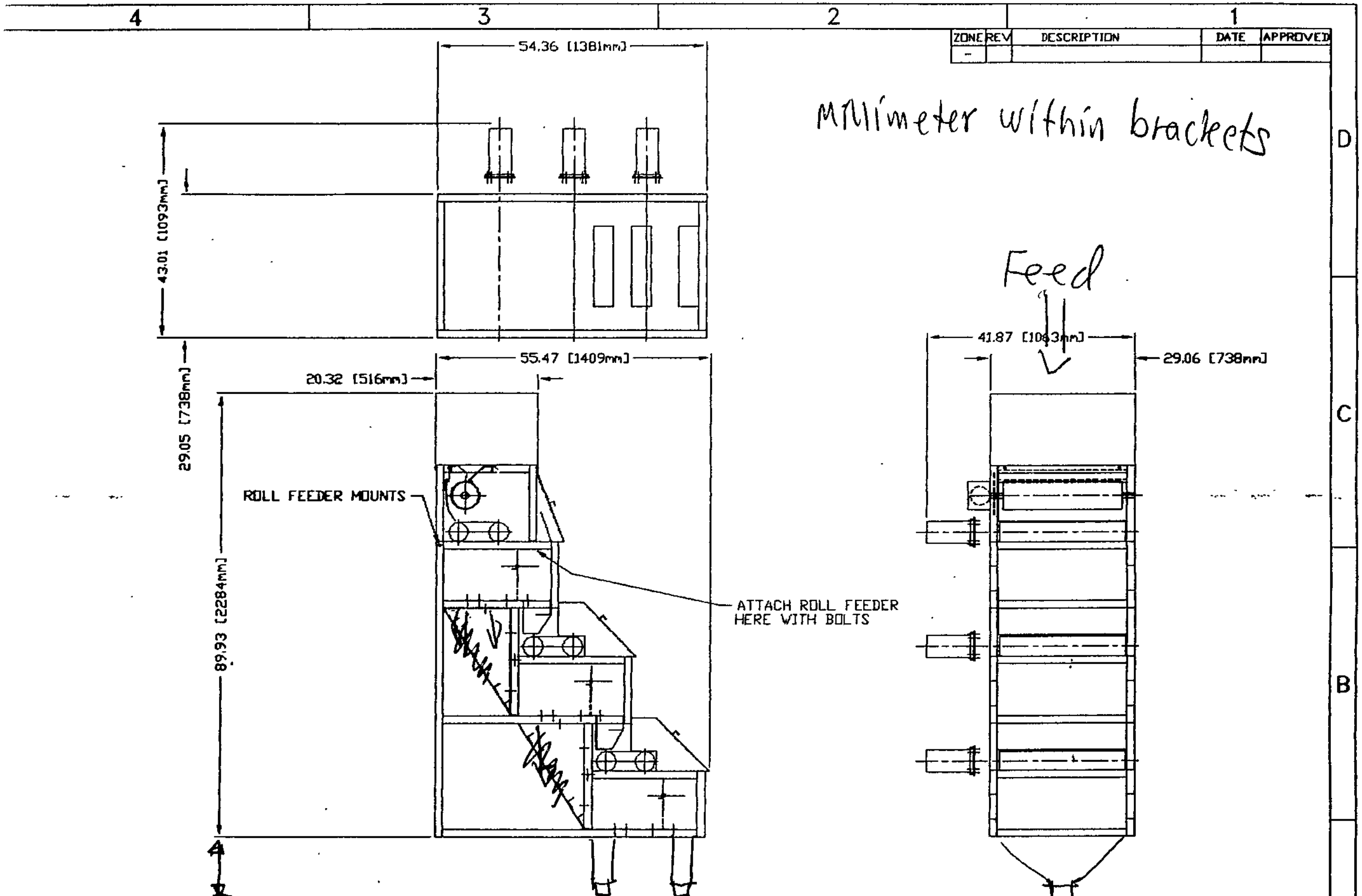
INPROSYS

HS10 EXTRACTION CHUTE

50M[redacted]CENT[redacted]SCH[redacted]

SCALE NONE | SIZE A | DWG NO HS10109 | REV B


4
3
2
ZONE
REV
54.36 [1381mm]
43.01 [1093mm]
29.05 [738mm]
55.47 [1409mm]
20.32 [516mm]
89.93 [2284mm]
41.87
Power:
① Instant at start-up: 6 Amp
② In operation: About 1 Amp.
@ 220 V.
Feed
ROLL FEEDER MOUNTS
ATTACH ROLL FEEDER HERE WITH BOLTS
Magnetic waste
Garnet products
Nonmagnetic waste*
* May contain diamonds
ITEM
SURFACE FINISH
MATERIAL
THIS DRAWING IS THE PROPERTY OF
INPROSYS
INTERNATIONAL PROCESS SYSTEMS
DO NOT SCALE DRAWING
JWR
5/4/95
DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES
1 PLACE ± .1
2 PLACE ± .06
3 PLACE ± .010
ANGLE ± .5°
BREAK SHARP EDGES
DEBURR ALL EDGES



ZONE	REV	DESCRIPTION	DATE	APPROVED
-				

-	———		
ITEM	SURFACE FINISH	MATERIAL	MATERIAL SPECIFICATION

THIS DRAWING IS THE PROPERTY OF [redacted] PR[redacted]YS [redacted] IT IS SUBJECT TO RETURN UPON

DRAWN JWR 5/4/95 [redacted]NSION[redacted]IN [redacted] DIMENSIONAL TOLERANCES

INPROSYS [redacted]

Facsimile Transmission

Routine ☐ Urgent ☐ Confidential ☐

A DIVISION OF
CLYDE INDUSTRIES LIMITED
ACN 000 002 031

POSTAL ADDRESS
PO BOX 5044
GOLD COAST MAIL CENTRE
QUEENSLAND 4217

81 ASHMORE ROAD
BUNDALL 4217
TELEPHONE (07) 5539.9055
FACSIMILE (07) 5539.9863
INTER FAX 61 7 5539.9863
TELEX AA 40438
INTERNET mdmintec@ontnenet.com.au

MINERAL
TECHNOLOGIES

Date: AUGUST 1, 1996

Attn: *MR H BARFUSS*

Company:

From: *BILL WELDON*

Fax:Number: *03 9729 3084*

Our Ref: *MFWW1244* 7736

Subject: *GARNET SAMPLE*

No of pages: THREE

Dear Mr Barfuss,

My apologies for the delay in returning our results on the gravity separations conducted on your sample.

The separation data are summarised as follows:

Size Fraction		Density of Separation			
Mesh	Head Totals	-2.85 WT%	-3.6+2.85 WT%	-4.05+3.60 WT%	+4.05 WT%
+4	Nil	Nil	Nil	Nil	Nil
-4+12	28.22	7.35	8 35	12.33	0.19
-12+0	71.78	11.99	31.40	22.69	5.70
TOTALS	100.00	19.34	39.75	35.02	5.89

We observed the red brown garnet occurring in the R.D. Fraction -4.05+3.60 predominantly with an over yield of 35.02% -4+12 mesh yield 12.33% -12+0 mesh 22.69%.

Please reply to this fax number 07-5539 9863 advising of a return address for the sample fractions. You will need to analyse them for product quality.

With respect to a simple pilot plant process we believe it is reasonable to assume from the gravity separation data that a two stage process could be successful in producing a heavy mineral concentrate which would contain a high concentration of garnet mineral.

The precise quality will be only proven by a detailed laboratory study or field trials with a pilot plant.

From our limited scope of work we suggest you consider the following option for a pilot plant flowsheet. I must stress this may not be the only option, however this will offer a system that Mineral Technologies would be in a position to help with detailed design and equipment supply.

Pilot Plant Process Stages

1. Mining selectively in specific areas of interest or in a broad strike is up to you to decide upon.

2. Feed receival hopper

3. Screening plant to separate +12 mesh from -12 mesh

4. The +12 mesh would pass into a small jig set up to concentrate the very heavy +3.6 SG garnet into the hutch, and from there dewatered by screen and stock piled.

   The jig overflow would be predominantly lighter quartz sand and would be dewatered over a screen and discarded.

   The water could be re-used as jig hutch water.

5. The -12 mesh would be pumped to hydrocyclones which would remove the ultra fines -200 mesh. These fines and water could then be returned to the tailings dam.

6. The -12 mesh +150 mesh would be treated by high grade HG10 spirals to concentrate the garnet.

   A single stage may be suitable for the pilot plant however, in full scale we would at this stage advise you consider 3 to 4 stages to ensure maximising recovery.

7. The spiral (VHM garnet) product may need dewatering prior to stockpiling in the pilot plant it would be very simple to build a small holding bunker with adequate drainage and access by bob cat for retrieval when dry.

8. The spiral tails will join the jig tails to go back into the reclamation. They will require dewatering. We would advise the use of hydrocyclones for this duty.

   The overflow could be used as make up water or returned to a fine tailings dam to contain it.

PRICING:

I will require your input on the size of plant you need to do your pilot processing. You will need to consult with local government to establish what is going to constitute mining and what may be classed as prospecting/exploration.

For our equipment to be operating at correct capacity I suggest you consider a 3-5t/h capacity pilot plant.

1. We would then offer a two stage spiral plant which should produce a high quality garnet rich product with reasonable recovery.

2. We can supply suitable hydrocyclones.

3. We will need more time to discuss jig sizing and pricing.

4. You will require screening equipment pumps and sumps to have a working pilot plant.

5. Mineral Technologies can do a turn key plant, however for this we need to understand your budget constraints and design a system accordingly.

Yours faithfully

Bill Weldon
Area Sales Manager

Report of the feasibility of Vermiculite Mining, Entire Creek, Harts Range, Northern Territory.

Vermiculite

A study of the Vermiculite in the E/L has been undertaken to establish if a clean product can be produced. Some areas total up to 50 metres in diameter. If this can be achieved, then there is a ready overseas market for insulation (fireproof doors and wall systems) and decorative material is also in demand.

A good reliable market can be found, providing, the product can be cleaned and produced to a quality standard similar to Phalabora Vermiculite.

Tests have been conducted for the presence of Asbestos, resulting in no Asbestos being found.

The real commercial value is a very important aspect to further serious exploration for vermiculite.

Further interpretations of the Airborne Magnetic Survey should reveal further Vermiculite anomalies, which will be closer examined at a later date.

Vermiculite (additional information)

Samples of Vermiculite were taken to make a bulk sample composite.
Colour silver/gold and bronze, the particle size ranging from 1mm up to 50mm diameter, most in the size range of 1mm to 12mm.

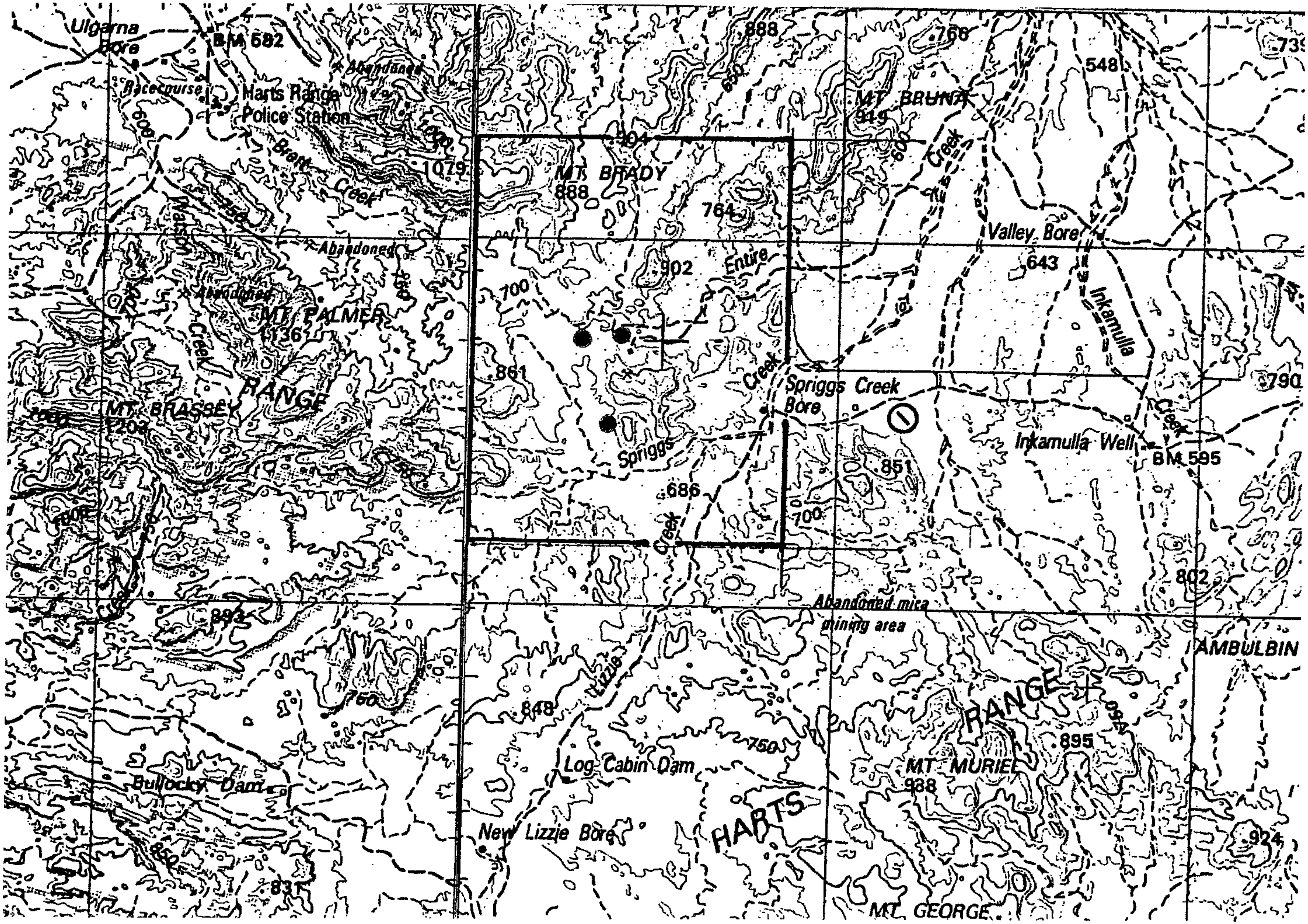
This work in particular was carried out to obtain commercial samples to test the market and receive feedback information regarding sizing, quality and colour.

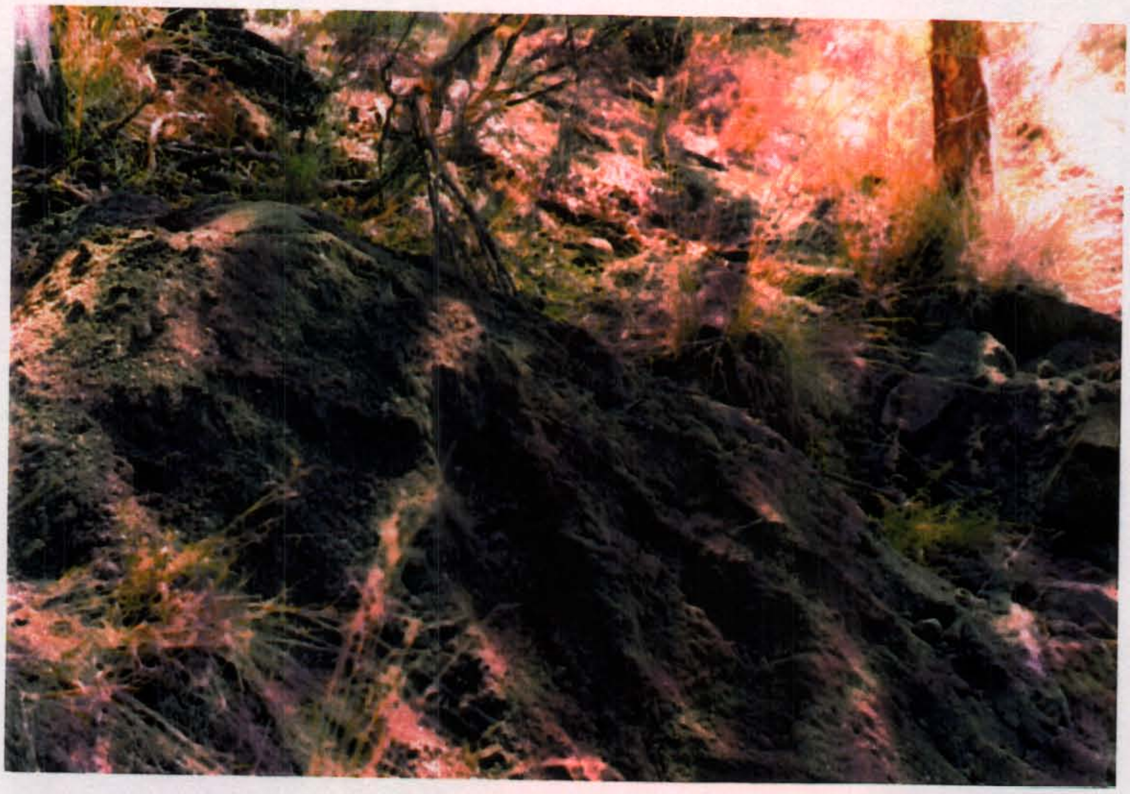
Further interpretations of the Airborne Magnetic Survey should reveal further information, which will be examined at a later date.

Map attached showing the areas:

Positions:

135o01'900 / 23o04'920
135o02'315 / 23o04'890
135o02'210 / 23o06'200


Ulgarna Bore
BM 682
Racecourse
Harts Range Police Station
Abandoned
Brent Creek
1079
888
MT BRADY
888
704
764
MT BRUNA
949
766
548
739
Watson Creek
Abandoned
Abandoned
MT PALMER
1136
RANGE
MT BRASSEY
1202
700
902
Entire
Valley Bore
643
Inkamulla
861
Spriggs Creek Bore
Spriggs
Creek
686
700
851
Inkamulla Well
BM 595
790
802
893
Abandoned mica mining area
AMBULBIN
750
848
Lizzie
750
RANGE
895
Log Cabin Dam
MT MURIEL
938
Bullocky Dam
New Lizzie Bore
HARTS
924
831
MT GEORGE



KILPATRICK AND ASSOCIATES PTY LTD A.C.N. 006 911 324

Occupational Hygiene and Ergonomics Consultants

Occupational Hygiene and Ergonomics Consultants

239 Bay Street
Brighton 3186
Phone: (03) 9596 7655
Fax: (03) 9596 7920

RESULTS OF QUALITATIVE IDENTIFICATION OF ASBESTOS

JOB NO: S1016

CLIENT: Barfuss Corporation Pty Ltd

SAMPLES RECEIVED: 12 September, 1996

SAMPLING LOCATION: Northern Territory

TEST METHOD: Polarised light microscopy/dispersion staining as outlined in Methods Manual A02. Sample analysed "as received"

Sample Number	Location	Sample Description and Sample Size	Result
69362	Northern Territory.	Vermiculite ore - 180g.	No asbestos detected.(1)

(1) Confirmation by an independent analytical method advised due to nature of sample.

Analyst: David Kilpatrick

Signatory:

Date: 12/9/96

NATA

This Laboratory is registered by the National Association of Testing Authorities, Australia. The test(s) reported herein have been performed in accordance with the terms of registration. This document shall not be reproduced except in full.

Directors: David Kilpatrick, Peter Bird, Mark Paholski, Russell Pretty, Andrew Stewart

W. J. KYTE,
R.S.D. 1155,
Rutherglen, V. 3685.

Telephone 060 328 376
Facsimile 060 328 376

20.7.1997.

Mr U. Barfus,
Box 352,
Lilydale, V. 3140.

Dear Sir,

TESTING OF VERMICULITE SAMPLE FROM HARTS RANGE

Mr Uwe Barfus brought a sample of vermiculite ore to the Author from Harts Range in the Northern Territory. The aim was to make a preliminary sizing and washing test to assess what commercial treatment is required, and to gain data for discussions on sale to vermiculite users.

On 22.5..1997 a 325 lb sample was sized on a Kason pilot-plant shaking screen, using screens of apertures ½ in., ¼ in., 1/8 in. and 1/16 in. The two coarse fractions were wet-sieved, with the dried undersize fractions being added to the next sieve for further sizing.

The sizing results are:

+ ½ "	68 lb	21
+ ¼	34	31
+1/8	60	50
+1/16	20	56
-1/16	143	44
total	325	100.

Very little high-pressure water was required to wash the clay from the vermiculite, showing that a high grade product could be produced in production. There was a small amount of iron mineral, probably goethite, with the vermiculite after washing.

This letter is not on letterhead, because the Author has moved into a private mining position, and is no longer a Consultant.

Yours sincerely,

W. J. Kyte.

W. J. KYTE.

amdel

Analysis code X5

Results in %

Sample	Fe	SiO2	Al2O3	CaO	MgO	TiO2
Vermiculite	9.05	37.4	15.8	2.00	17.1	1.85

Sample	K2O	MnO	P2O5	S	H2O-	LOI
Vermiculite	3.20	0.115	<0.002	0.038	<0.010	9.3

amdel

Sample	Total Cation Exchange Capacity (MEQ NH4Cl per 100GM)
VERMICULITE	34.5

Sample	pH
VERMICULITE	8.7

WATER

A Study and Research Into the availability of Water for Mining and Exploration Pilot Plant Processing.

Water

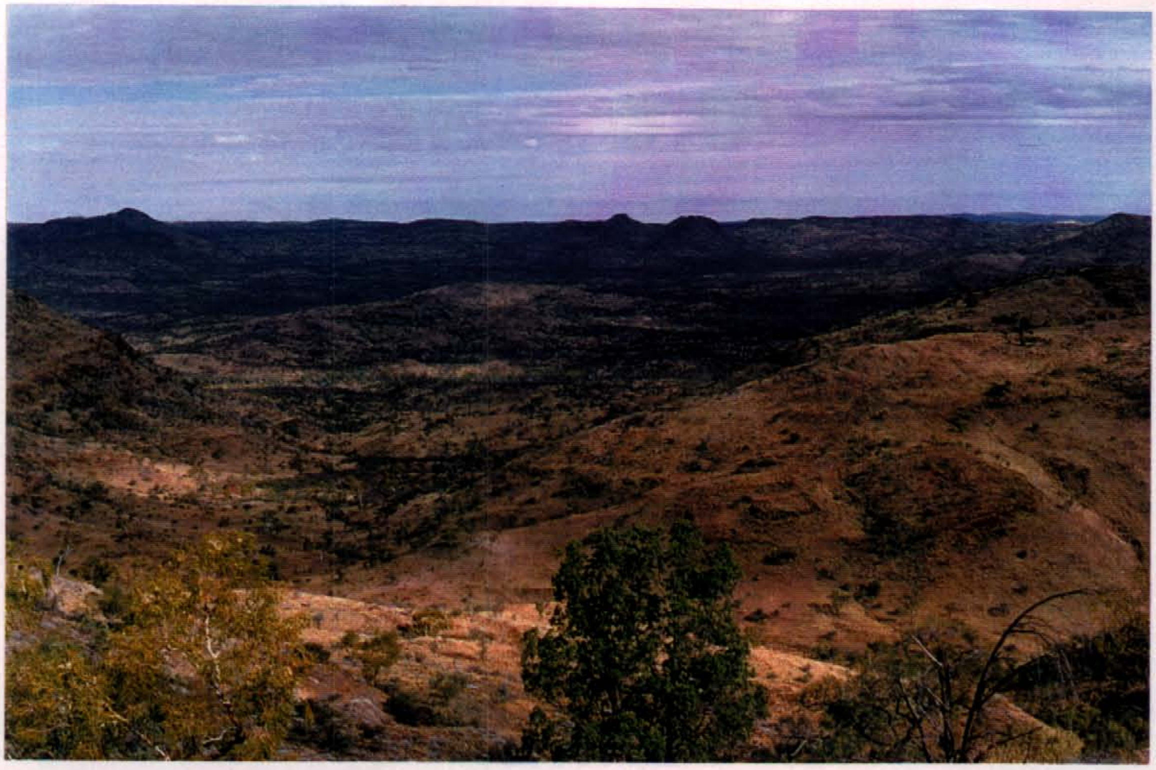
Examination of future water supply for exploration pilot Plant Processing of Bulk Samples will become a necessary step prior to establishing a Garnet or and other mining operation.

A study was carried out to establish that sufficient quantities of water could be expected to be found on or near the minerals processing site. (Ruby Mine area)

The closest useable water bore, equipped with a windmill, is well number 15262. This well is too far away and not economically viable (well shown in photo.)

The study concluded that the 3 sites chosen (as shown in report) show good promise of sufficient water to support pilot plant operation, and will also be able to provide water for future mining operations.

It is estimated that each bore has about a 50% chance of obtaining a useful supply.



DEPARTMENT OF LANDS, PLANNING AND ENVIRONMENT

PO Box 1521
ALICE SPRINGS NT 0871
Telephone: (08) 8951 8603
Fax: (08) 8951 8620

File 400.1C

Mr Uwe Barfuss
Barfuss Corporation
PO Box 352
Lilydale
Melbourne
Victoria 3140

Dear Sir,

The area around the Ruby Mine has been inspected and the report is attached.

The track into the mine and the sites will require some work to provide access for a drilling rig. You are reminded that sacred sites clearance is needed before drilling proceeds.

If you require any further information please contact Bob Read on 89518616.

Yours faithfully,

Peter McDonald
Regional Manager Land and Water Resources

24 October, 1996

GROUNDWATER PROSPECTS AT THE RUBY MINE, HARTS RANGE

Location

The area is in the NW corner of the Illogwa Creek 1:250,000 sheet.

Previous Drilling

No previous drilling is known near the mine. Bores to the east in Table 1.

Table 1 Known bores

Registered Number	Depth m	Supply l/s	SWL m	TDS mg/l	Comments
2560	30	?		880	Equipped
3679	10	dry			
3690	14	?		1580	Equipped
4777	107		0.07	1350	
15258	50	2.4	14	1385	Fluoride too high for human consumption
15259	40	dry			
15260	66	dry			
15261	50	dry			
15262	35	1.9	9	2165	Equipped with windmill. Marginally too saline for human consumption

It can be seen that about half the bores drilled have yielded useful supplies, but only one is suitable for human consumption. The rocks in the area around the mine are less weathered and lower yields can be expected.

Geology

The geology of the area is shown on the "Quartz" 1:100,000 sheet. Briefly the area around the mine is underlain by layered amphibolites, plagioclase gneisses, and porphyroblastic felspar gneisses.

Drilling Sites

Three sites were picked. Details are given in Table 2 below. No major fault zones occur in the mine area, and sites were chosen in places where the rocks appeared to be slightly better jointed than elsewhere.

Bores should be drilled to about 50 m. The vegetation indicates that standing water levels should be only a few metres below creek level.

Table 2 Sites picked

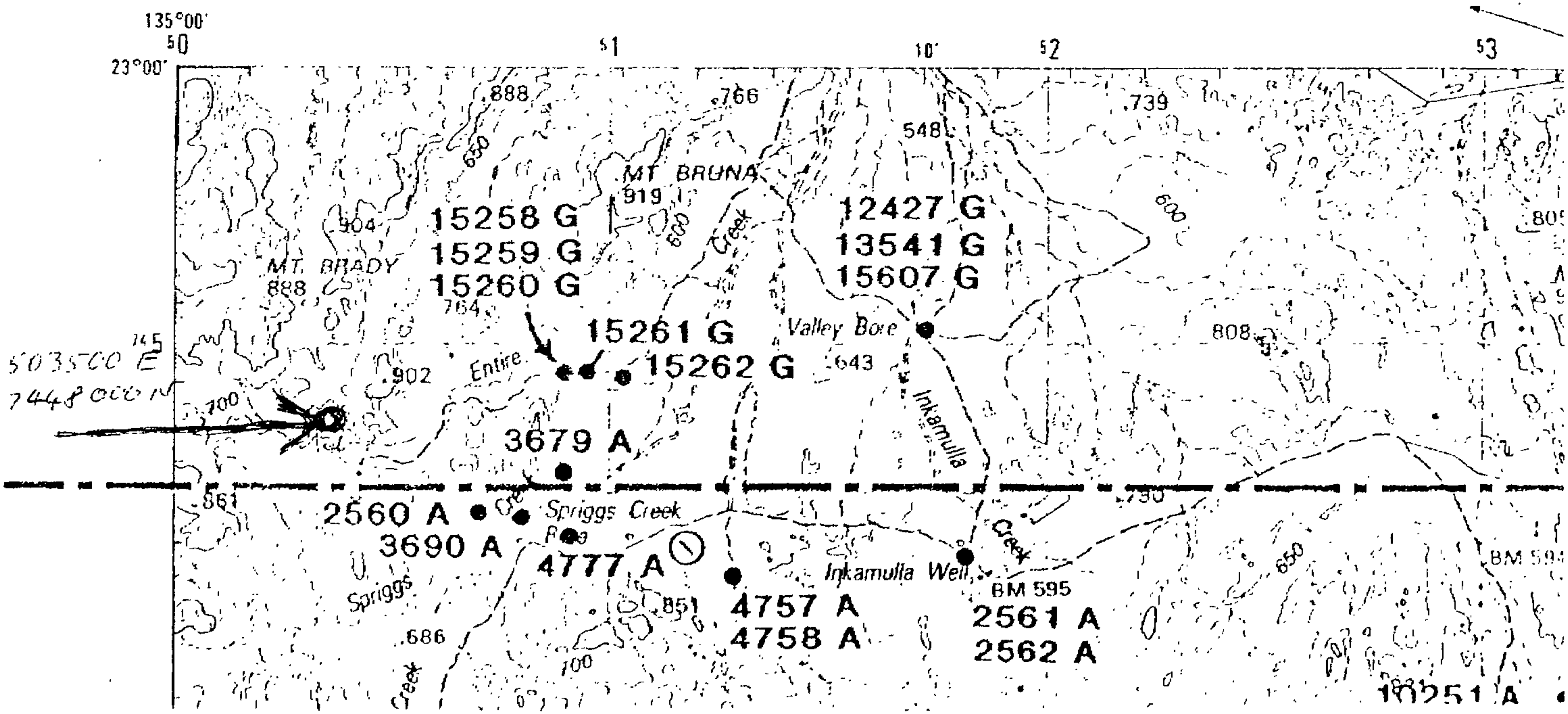
Site	Easting	Northing	PHOTO			Position		Location	Geological setting
			Year	RUN	No.	mm E	mm N		
1	504200	7447400	1970	1	205	51 W	41 S	50 m S of the track, adjacent to a small creek. It is marked by a wooden stake with red and white flagging and flagging on a tree.	Sited over a weak E-W linear feature and a weak N-S zone of better jointing. and calc-silicates.
2	504700	7447200	1970	1	205	55 W	39 S	400 m E from the camp and then 200 m along an old track to a bull-dozed trench used as a rubbish pit. Site marked by a piece of old pipe with red and white flagging. The site is a few metres above the nearby creek, but a suitable site could not be found at creek level.	Adjacent to a fault zone filled with a pegmatite dyke. Layered amphibolite.
3	506300	7447700	1970	1	205	29 W	22 S	Approximately 3 km east of the camp, 100 m past the second crossing over Entia Creek. Site marked by flagging tape	In a zone of fracturing with a quartz dyke. Porphyroblastic felspar gneisses.

The required supply is stated to be 50 l/hour, that is only 0.014 l/s. There is some doubt as to the practicality of equipping such a small supply. Such a small supply would not normally be noticed during drilling.

It is estimated that each bore has about a 50% chance of obtaining a useful supply.

R.E.READ
Hydrogeologist

AUSTRALIA 1:250 000
TOPOGRAPHIC SURVEY



Diamonds

Diamond Exploration
and Geophysical Interpretations.

Diamond Exploration.

The interpretation of Airborne Magnetic data carried out by Geophysical Exploration Consultants Pty Ltd, indicated among other things, 6 distinct anomalies indicative of possible kimberlite pipes. The most interesting aspect is that they are truly elliptical. This is very encouraging, as true Diamond bearing Kimberlite pipes are nearly always elliptical in shape.

Intense preliminary field examinations of the 6 anomalies has been conducted consisting of examination of stream sediments and drainage areas, soil examination sieving, screening and searching for any signs of Diamonds or any other gems and Minerals of interest.

The prospecting carried out did not reveal and Diamonds or other Gem material. The terrain is difficult and the lack of water made it impossible to use a Pleitz Jig on site.

It was concluded that further systematic sampling on a broader scale should be conducted in the near furture.

<u>Diamonds</u> (additional information)

The intensive field examination was carried out for the purpose of deciding if further systematic sampling is justified and the planning of such a program. During this field work no evidence of diamonds was found in the soil/sediment.

See **Future Exploration** (as per report), and map showing the Kimberlitic Anomalies marked P, which shows the locations.

I am including a copy of that map with the locations highlighted in yellow. Showing the areas covered by intensive visual field examinations

Future Exploration.

Systematic examination of each anomaly should be carried out, taking approximately 50 soil samples of drainage and stream sediments from each site.

These samples to be treated by a Plietz Jig, the concentrates recorded and examined for traces of Diamonds, followed up by trenching on selected sites.

The occurrence of garnets and Chromium Diopsides should also be recorded if near the pipes.

Ultimately, if diamonds or other encouraging signs are found, then Diamond core drilling is to be recommended.

GEOPHYSICAL EXPLORATION CONSULTANTS PTY LTD

AN INTERPRETATION OF AIRBORNE

MAGNETIC DATA FROM SPRIGGS CREEK, NT

FOR BARFUSS CORPORATION

Hugh Rutter

Figure 6

See image file
Attached.

CONTENTS

FIGURES

1. INTRODUCTION

Spriggs Creek is in the north west corner of the Illogwa Creek 1:250,000 sheet in the Northern Territory; approximately 150km north east of Alice Springs.

The geology consists of rocks from the Harts Range Group of the Arunta Complex. These include the Bruna Gneiss, the Naringa Calcareous Member, the Riddock Amphibolite Member, the Irindina Gneiss and the Brady Gneiss.

Folding is tight with fold axes in many directions.

Mica is a common mineral in the area, with the rare metals, uranium, niobium, tantalum, thorium and cerium occurring not far to the east.

Also to the east there is an outcrop of the Inkamulla Granite which domes the metasediments of the Harts Range Group producing an overall dip to the west at Spriggs Creek.

The airborne magnetic data is part of a much larger survey flown by PNC Exploration (Australia) Pty Ltd. It was flown in December 1994 by World Geoscience (Job No 1072). Flight lines are east-west, spaced at an interval of 200m; north-south tie lines are spaced at 2000m. The flight height was 80m, with navigation achieved with a GPS satellite positioning system.

The field data was gridded with a cell size of 70m, microlevelled, and contoured with an interval of 5 nano Teslas.

2. INTERPRETATION OF THE MAGNETIC DATA

The data supplied to Barfuss Corporation by PNC consisted of a paper print at a scale of 1:25,000 showing contours of total magnetic intensity for the Barfuss exploration licence only.

The data in digital format was not provided, nor was any of the radiometric data.

Consequently, the interpretation is limited to the spatial identification of the magnetic units and structure only, without depth estimates or radiometric associations; the result of the interpretation is shown on the attached plan.

The magnetic response is the eastern part of the E.L. is active and complex; this is part of a more extensive magnetic area which extends to the north east.

It is separated to some extent from the less active western section by a series of NW faults.

An attempt has been made to identify and define the individual magnetic units in the east. They become progressively more magnetic in the easterly direction. The magnetic anomalies have been subdivided in to two units, labelled 1 and 2, both of which have been further divided in to three sub units. In some cases the response from these sub-units is very similar and they probably represent a rock unit of comparable composition; alternatively they may be faulted, or folded repetitions of the source unit.

Folding along north-south axes is prevalent in the south and north, but trends more to the north east in the central eastern section.

Faulting is complex, probably more complex than indicated by the magnetic data.

The western section of the EL has a much more subdued magnetic signature, but contains some very interesting magnetic anomalies.

The very weak anomalies, often recognisable as an inflexion in the contours with no closure are likely to represent concentrations of magnetite on the surface. These may be the result of water sorting in the old creek channels, or wind sorting in to the component of an old dune system.

There are five more prominent anomalies (marked by the letter P) which represent solid rock rather than accumulations of magnetite. The could be pipe-like intrusions of a doleritic rock or flat-lying remnants of basaltic material. Also, the possibility that they represent kimberlitic material should not be discounted. The three central of these five anomalies have a linear relationship parallel to the fault direction seen to the east, which suggests that they also, may be fault controlled.

In the south, 1500m east of the estimated position of Spriggs Camp is a circular magnetic anomaly which could represent an intrusive rock with moderate magnetic properties.

3. CONCLUSION AND RECOMMENDATIONS

The magnetic data has indicated a complex geological situation in the eastern part of the EL and less magnetic lithologies in the west compared to the information available on the 1:250,000 Iliogwa geological map; this is a considerable advance in knowledge.

However, only a field inspection will determine the prospectivity of these units.

The postulated alluvial (or aeolian) deposits may be prospective for minerals derived from adjacent rocks by erosion; gem stones may also be found here.

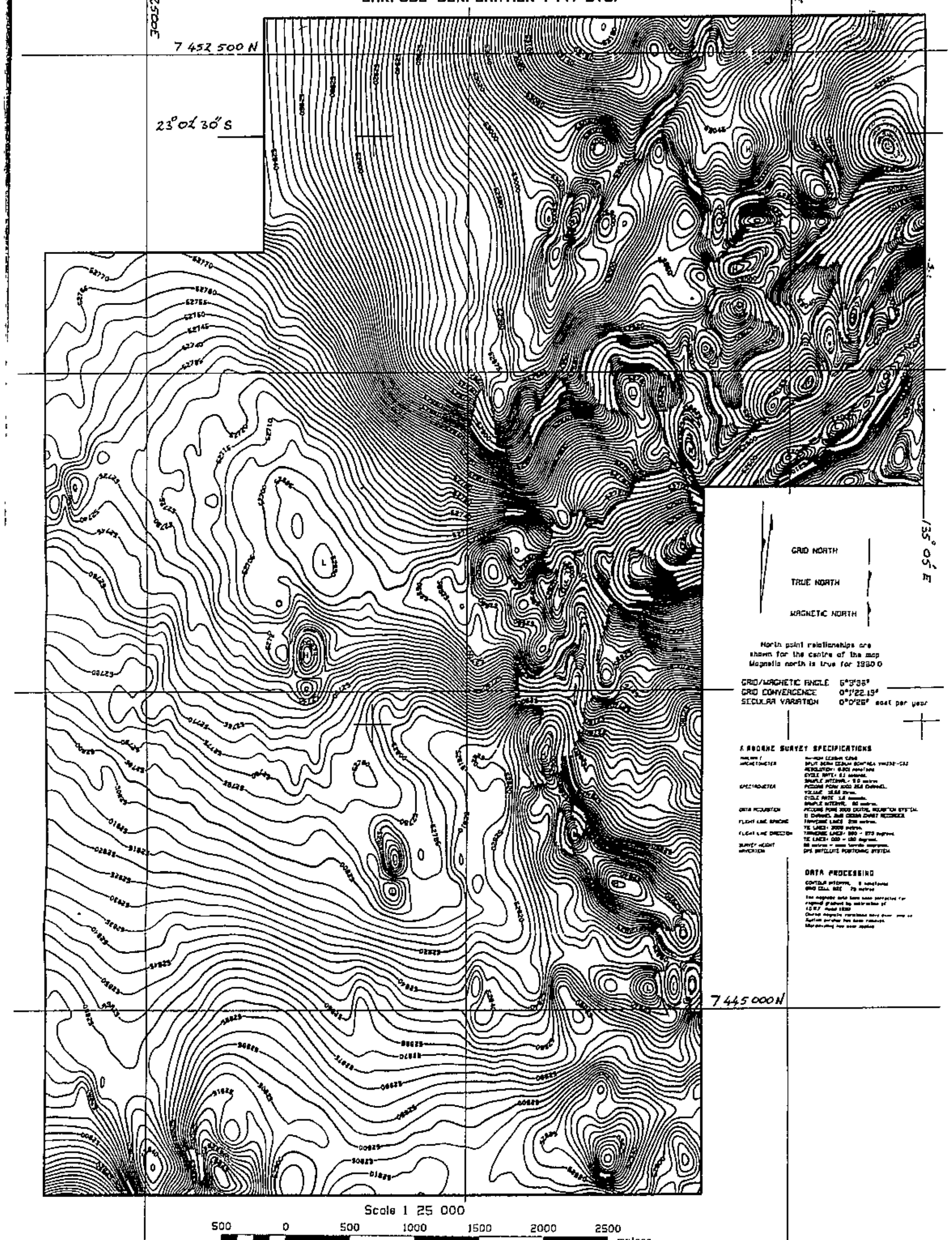
The location of the five isolated anomalies indicated by the letter P should be examined carefully for evidence of kimberlitic rocks, and there relevance to gem stone occurrence.

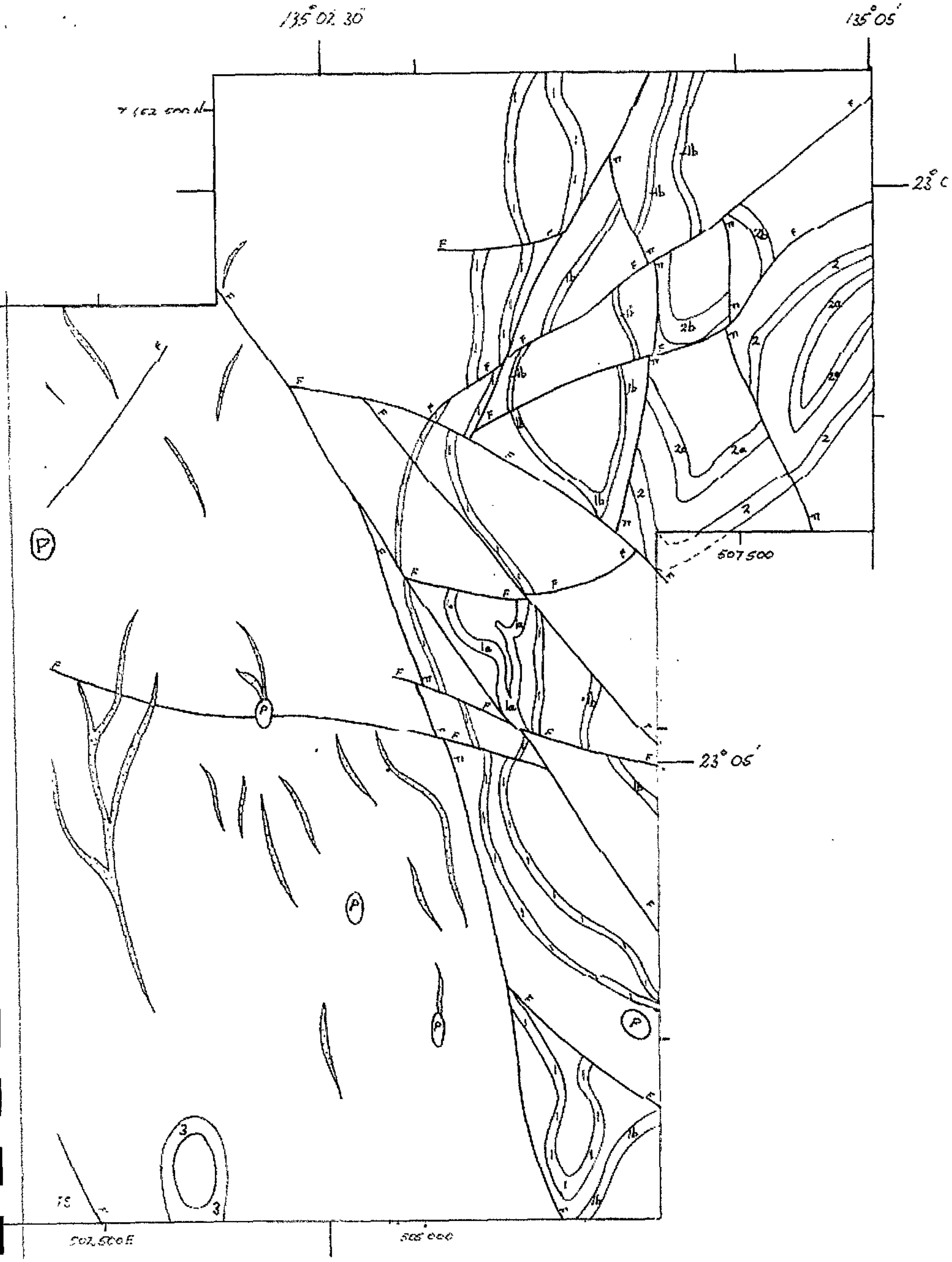
Finally, it is recommended that if possible, the digital magnetic data, and all the radiometric data is obtained from PNC. The radiometric data will provide another dimension to exploration within the EL area; and in a digital form, profiles and image enhancements can be produced in the future, if required.

HUGH RUTTER
CONSULTING GEOPHYSICIST

TOTAL MAGNETIC INTENSITY CONTOURS

BARFUSS CORPORATION PTY. LTD.

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135° 05'
23° 05'
507 500
502 500 E
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