

AUSTRALASIAN ANTARCTIC EXPEDITION

1911-14.

UNDER THE LEADERSHIP OF SIR DOUGLAS MAWSON, KT., D.Sc., B.E.

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SCIENTIFIC REPORTS.

SERIES A.

VOL. IV.

**GEOLOGY.**

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PART I:

**THE ADELIE LAND METEORITE.**

BY

P. G. W. BAYLY, F.I.C., AND F. L. STILLWELL, D.Sc.

WITH TWO PLATES.

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VOL.	PRICE.
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I. GEOGRAPHY AND PHYSIOGRAPHY. ( <i>In preparation.</i> )	
II. OCEANOGRAPHY.	
PART 1.—SEA-FLOOR DEPOSITS FROM SOUNDINGS—	
By FREDERICK CHAPMAN, Ass. Linn. Soc. (Lond.), F.R.M.S., &c., National Museum, Melb.	0 6 0
III GEOLOGY. ( <i>Adelie Land and King George Land.</i> )	
PART 1.—THE METAMORPHIC ROCKS OF ADELIE LAND—	
By F. L. STILLWELL, D.Sc., Aust. Antarc. Exped. Staff	2 2 0
„ 2.—THE METAMORPHIC LIMESTONES OF COMMONWEALTH BAY, ADELIE LAND. By C. E. TILLEY, B.Sc.	0 1 6
„ 3.—THE DOLERITES OF KING GEORGE LAND AND ADELIE LAND. By W. R. BROWNE, D.Sc., Lecturer, Geological Department, Sydney University	
„ 4.—AMPHIBOLITES AND RELATED ROCKS FROM THE MORAINES, CAPE DENISON, ADELIE LAND. By F. L. STILLWELL, D.Sc., Aust. Antarc. Exped. Staff	
IV. GEOLOGY. ( <i>Will deal principally with Queen Mary Land.</i> ) ( <i>In preparation.</i> )	
PART 1.—THE ADELIE LAND METEORITE—	
By P. G. W. BAXLY, F.I.C., and F. L. STILLWELL, D.Sc.	0 1 6
V. GEOLOGY ( <i>Macquarie Island.</i> ) ( <i>In preparation.</i> )	
VI. GLACIOLOGY. ( <i>In preparation.</i> )	

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## CONTENTS.

	PAGE
I. Introduction ... ..	1
II. Physical Characters ... ..	2
III. Petrographical Characters ... ..	3
IV. Chemical Examination ... ..	4
1. Method ... ..	4
2. Details of Analyses ... ..	5
3. Ascertained Composition ... ..	11
4. Table of Operations ... ..	12
V. Description of Plates ... ..	13

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## INTRODUCTION. (F.L.S.)

A STONY meteorite was found on 5th December, 1912, by the Western Sledging party from the Main Base at Cape Denison in charge of F. H. Bickerton. Bickerton's party set out from Cape Denison on 2nd December, and, after ascending the ice plateau, travelled due west for an approximate distance of 150 miles, at an average altitude of 1,500 to 2,000 feet above sea-level. The outward and return journeys were accomplished without encountering any rock exposure to break the monotony of the snow surface. About 20 miles from Cape Denison, on the outward journey, they stumbled across a small, black object lying on the snow in a slight depression, about  $2\frac{1}{2}$  inches below the mean surface, which has proved on examination to be a stony meteorite. There was nothing to indicate that there had been any violent impact. The date of the actual fall is, of course, unknown.

The actual finding of a black object on the snow surface is remarkable. It is very probable that the meteorite would, in falling, penetrate a little distance into the snow or ice surface, partly because of its momentum and partly because of its heat. It would not appear at the surface until the thickness of the over-lying snow had been

removed by ablation. If there chanced to be a calm summer day after its appearance at the surface, the sun's heat would be absorbed by the black body, the snow in contact with it melted, and the black stone would sink. It would sink to a depth of a foot or more till sheltered from the sun's rays and covered by a pool of thaw water. When the thaw pool froze again the stone would be buried a second time and remain so, until again brought to the surface by ablation. A similar burial could be expected during the summer that followed its appearance at the surface as the result of the winter's ablation. Accumulations of snow drifts during snowfalls and blizzards would also tend to keep the stone beneath the surface. The ablation of the ice and snow in Adélie Land is, however, considerable, on account of the phenomenal wind velocities. The surface level of the blue glacier ice at Cape Denison during the seven months from 2nd March to 3rd October, 1912, was lowered 5 inches by ablation. This large quantity, combined with the infrequent occurrence of calm sunny days, are the two factors which made possible the chance find in the early summer.

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#### PHYSICAL CHARACTERS. (F.L.S.)

The weight of the meteorite, as found, is 2 lb. 4½ oz. After chipping and slicing the specimen for examination, the weight is 2 lb. ½ oz. The specimen is a little elongated in one direction, being 5 inches long, 3½ inches broad, and 2¼ inches high. It has rather a pointed nose, and a broad, smoothly sloping tail. Its under surface is rough in comparison with the smooth back, and probably represents a fractured surface sustained some time during its flight as a meteor. The whole surface, except where chipped, is covered with a thin, black skin. The skin is broken in a few places, and Bickerton reports that three or four small pieces of this scale were lying on the snow within 3 inches of the stone. In a few places on the skin there are small, fused, and slaggy patches. The skin shows a system of minute cracks forming polygonal patterns, which have the appearance of surface markings. The white rock underneath the black skin renders the cracks visible. Surface angles on the specimen have been rounded, and the surface itself shows thumb-mark depressions. The surface is also pitted, and the largest pit is ⅝ inch in diameter and ½ inch deep. Most of the pits, however, are only shallow depressions.

The specimen is on the whole compact; but it is traversed by two or three irregular cracks. The fresh surface has a dull light-grey colour, in which are scattered small pieces of nickel-iron. Where the black skin has been broken the colour is light brownish-grey, due to a small amount of rusting. Exposed particles of nickel-iron are coated with rust, while even some of the surfaces exposed on the sliced surface, after the preparation of a section, shows traces of rusting. Apart from this small amount of rusting, the specimen shows no trace of normal weathering.

## PETROGRAPHICAL DESCRIPTION. (F.L.S.)

The rock is made up of an aggregate of rounded fragments set in a greyish-white matrix. The rounded fragments consist of the characteristic chondrules and pieces of nickel-iron. The average size of the chondrules is about 1 mm. Some are less than 5 mm. and some are as much as 3 mm. Individual pieces of nickel-iron are as much as 3 mm. in diameter. The chondrules stand out like rounded nodules on the weathered surface and, when they have been knocked out, they leave hollow casts. The chondrules give the rock a fragmental appearance, not unlike that of a tuff.

In thin section the rock consists of olivine (hyalosiderite), pyroxene (hypersthene and clino-hypersthene<sup>1</sup>), nickel-iron, and troilite. The structure is typically chondritic, consisting of the rounded chondrules and pieces of nickel-iron set in a matrix of irregular crystals of the above minerals of various sizes. The olivine is found in clear grains and crystals with two sets of poorly developed cleavage cracks. It is frequently idiomorphic, and has its normal straight extinction and high polarisation colours. The chemical examination by P. G. W. Bayly has shown that the olivine forms 41.22 per cent. of the rock, and that the proportion of magnesium to iron in the olivine is 2.2 to 1. The olivine thus falls in the group of the hyalosiderites. The percentage of pyroxene is 47.87 per cent., being slightly greater than the olivine. The ratio of magnesium to the iron in the pyroxene is 3 to 1, and there is 5.64 per cent. of alumina besides. The pyroxene is thus determined as hypersthene and clino-hypersthene, the latter being distinguished by its oblique extinction. In some cases the hypersthene and clino-hypersthene are intergrown. The pyroxene is partly clear and colourless and partly cloudy. The total absence of colour distinguishes it from the common hypersthene that occurs in terrestrial rocks. The clear mineral shows good cleavage, low polarisation colours, and sometimes lamellar twinning. The cloudy pyroxene forms the base of the rock, is sometimes fibrous and fills the interstices between the larger pyroxene and olivine crystals. The grey cloudy pyroxene has at times the appearance of a grey glass, but in the thinnest parts of the section it is not so dense, always affects polarised light, has a high refractive index, and cannot be distinguished from pyroxene. The nickel-iron appears in both small and large grains. One of the larger grains, about 3 mm. in diameter, was mounted and polished, and an attempt to etch it produced no definite figures. The analysis has shown that there is 18.1 per cent. of nickel in the nickel-iron, which is fairly high. The ratio of Fe to Ni is 4.5, and the nickel-iron thus belongs to the group of nickel-rich ataxites. In addition to the nickel-iron with its bluish-black lustre, there is also an opaque mineral with a bronzy-yellow tinge in reflected light, which is probably troilite. No feldspar has been detected under the microscope. The analysis discloses a percentage of 2.27 of alkalis. Hypersthene may contain

<sup>1</sup> Term suggested by G. T. Prior to correspond with clino-enstatite. "Classification of Meteorites," *Min. Mag.*, vol. xix, 1920, p. 56.

small amounts of the alkalis, but it is most improbable that the hypersthene in the meteorite contains 4.5 per cent. of alkalis. It is much more probable that there exists a small amount of undetected feldspar in the meteorite.

The rounded chondrules are abundant, and show a great variety in structure and content. Some consist entirely of olivine, with the interstices filled with fibrous pyroxene and nickel-iron. Some consist entirely of pyroxene, with a radiate structure. In these the crystal fibres may radiate from more than one centre, or they may be eccentrically arranged. Some consist of a rounded crystal of pyroxene with a nucleus of small olivines. Some of the chondrules are sharply bounded by a border of nickel-iron, while others contain irregular masses or the grate-like network of bars of nickel-iron (Plate II, fig. 2).

In Brezina's classification, the stone would fall either in the group of white chondrites or into the group of grey chondrites. In Prior's classification, the Adélie Land meteorite becomes a member of the family of Hypersthene Chondrites, in the chondrite division of the Meteoric Stones or Aerolites.

#### CHEMICAL EXAMINATION. (P.G.W.B.)

The chemical examination has been carried out in the Laboratory of the Geological Survey of Victoria through the courtesy of the Director, Mr. H. Herman. It was commenced in December, 1915, and carried on as time permitted until the author went into camp at Broadmeadows. The uncompleted fractions were then finished by Mr. J. C. Watson. The determination of sulphur and phosphorus was completed on a fresh sample after the conclusion of the war. The completion of the results was thus interrupted by the author's service in England as chemist under the Imperial Ministry of Munitions and subsequent removal from Victoria.

#### METHOD.

The methods of analysis followed closely those of L. Fletcher<sup>1</sup>, especially as modified by Bowman and Clarke in their examination of the Chandakapur stone<sup>2</sup>, and the Rana stone<sup>3</sup>. The method consists of:—

1. Rough crushing followed by treatment with a weak magnet giving—
  - (a) *Attracted*.—Metallic constituents: Nickel-iron, with small amounts of included silicates, schreibersite, and troilite.
  - (b) *Unattracted*.—Non-metallic constituents with small amount of included magnetic material.

<sup>1</sup> Chemical Analysis of Meteoric stone found at Makariwa, N.Z., 1879. *Min. Mag.*, x, 1894, p. 287. "Meteoric Stone which fell near Zomba, British Central Africa," *Min. Mag.*, xiii, 1901, p. 1.

<sup>2</sup> "Structure and Composition of the Chandakapur Stone." H. L. Bowman and H. E. Clarke. *Min. Mag.*, xv, 1908-10, p. 350.

<sup>3</sup> "Composition of a Stone from a Meteoritic Shower, Dokachi, Bengal." H. L. Bowman and H. E. Clarke. *Min. Mag.*, xvi, 1910, p. 35.

2. Treatment of each portion by mercuric chloride whereby the extraction of metallic constituents was effected—
  - (c) *Soluble*.—Metallics (nickel-iron).
  - (d) *Insoluble*.—Non-metallics.
3. Analysis of soluble portions of (a) =  $c_1$  (Analysis A).
4. Analysis of soluble portions of (b) =  $c_2$  (Analysis B).
5. Treatment with magnet of combined insoluble portions from (2).
  - (e) *Attracted*.—Magnetite, schreibersite.
  - (f) *Unattracted*.—Silicates and rust.
6. Treatment of (e) by ignition with hydrogen, followed by further treatment with mercuric chloride as in (2) giving—
  - (g) *Soluble*.—Metallics (schreibersite) (Analysis C).
  - (h) *Insoluble*.—Non-metallics : : Silicates.
7. Treatment of (f) as in (6) giving—
  - (k) *Soluble*.—Metallics (nickel-iron) (Analysis D).
  - (l) *Insoluble*.—Non-metallics : Silicates.
8. Treatment of portion of combined insoluble portions (h) and (l) with dilute HCl and  $\text{Na}_2\text{CO}_3$  giving—
  - (m) *Attacked*.—Olivine.
  - (n) *Unattacked*.—Enstatite, clino-enstatite, chromite.
9. Analysis of (m) (Analysis E).
10. Analysis of (n) (Analysis F).

## THE ANALYSES.

1. The specimen was rough-crushed giving 7.6662 grms. and separated by a weak magnet—

(a) <i>Attracted</i> .—	1.0610	...	...	...	...	13.8 per cent.
(b) <i>Unattracted</i> .—	6.5784	}	...	...	...	86.2 „
Loss—	.0268					

2. Both portions were treated with mercuric chloride solutions consisting of 7.8 grms. of  $\text{HgCl}_2$  and 3.1 grms.  $\text{NH}_4\text{Cl}$  in 1 litre. The material was placed in small flasks with 100 cc. of the solution and a slow stream of coal gas passed through. The gas was first washed in a train, consisting of water, caustic potash, and sulphuric acid. After twenty-four hours the solutions were decanted through a filter without disturbing the residue, and a fresh amount of solution added to the flasks. This treatment was continued for ten days, the solutions being renewed every twenty-four hours. The final residue after an interval was further treated for five days and decanted. Then further solution was added which remained on for thirteen days. The total time of contact was twenty-eight days.



The metallic portion of (a) disintegrated leaving a fine yellow powder weighing .5815 grms. Portion (b) did not show much alteration, being principally non-metallics.

3. The combined filtrates from (a) were acidified with HCl and the mercury removed by H<sub>2</sub>S. The mercuric precipitate was ignited and tested for copper, which was absent.

The filtrate after removal of H<sub>2</sub>S was treated by a triple precipitation: (1) Ammonia, (2) Basic acetate, (3) Ammonia, this treatment having been found from experience to be the best to completely remove nickel and cobalt from the precipitate. These were then determined together as oxide and the cobalt by the nitrite method.

*Analysis A.*

Fe ...	...	...	...	...	.4094
Ni ...	...	...	...	...	.0530
Co ...	...	...	...	...	.0042
SiO <sub>2</sub> ...	...	...	...	...	.0238
CaO...	...	...	...	...	.0083
MgO ...	...	...	...	...	nil.
TiO <sub>2</sub> ...	...	...	...	...	nil.
Cu ...	...	...	...	...	nil.
					.4987

4. The combined filtrates from (b) were treated similarly as in (3).

*Analysis B.*

Fe ...	...	...	...	...	.0979
Ni ...	...	...	...	...	.0340
Co ...	...	...	...	...	.0018
SiO <sub>2</sub> ...	...	...	...	...	.0145
CaO ...	...	...	...	...	.0097
MgO ...	...	...	...	...	nil.
TiO <sub>2</sub> ...	...	...	...	...	nil.
Cu ...	...	...	...	...	nil.
					.1579

The presence of SiO<sub>2</sub> and CaO in analyses A and B shows that the mercuric solution had attacked the silicates to some extent. It was surprising that no MgO was found in these analyses, but such was the case. The total amount of silicate separated

in these solutions however is only .73 per cent. of the total rock, which is very small. The Fe, Ni, Co in analysis B indicate that a certain amount of nickel-iron was included in the unattracted portion (b).

The metallic extracts were therefore as follow:—

	From A.	From B.	Total.
Fe ... ..	.4094	.0979	.5073
Ni ... ..	.0530	.0340	.0870
Co ... ..	.0042	.0018	.0060
Ratio of Ni to Co ... ..	12.6 : 1	19.0 : 1	14.5 : 1
Proportion of Ni to Nickel-iron ...	11.4%	25.7%	.....

*Rate of Solution of Nickel-iron in the A portion.*—In the first fifteen days .4007 gms. Fe was dissolved and in the next thirteen days .0087, making a total of .4094 gms. Fe. In the .0087 there is included a very small amount extracted in a further treatment. This shows that 98 per cent. of the metallic iron was extracted in fifteen days.

5. The residues from (a) and (b) after treatment were combined and treated with a magnet. The total weight was 6.8840.

(e) *Attracted.*—0.163.

(f) *Unattracted.*—6.8677.

6. Both fractions were treated separately by ignition in hydrogen and then by continuous treatment with mercuric solution as described in (2). The (e) fraction was treated for three days and produced—

(g) *Soluble.*—Metallics, schreibersite.

(h) *Insoluble.*—Non-metallics, silicates.

Analysis of soluble portion (g) as in (3).

*Analysis C.*

Fe ... ..	.0015
Ni(Co) ... ..	.0044
SiO <sub>2</sub> ... ..	.0007
CaO... ..	trace.
MgO ... ..	.0013
TiO <sub>2</sub> ... ..	nil.
Cu ... ..	nil.

.0079

7. Treatment of the (*f*) fraction as in (6), giving—

(*k*) *Soluble*.—Metallics (nickel-iron).

(*l*) *Insoluble*.—Silicates, rust from treatment.

Analysis of soluble portion (*k*) as in (3) :—

<i>Analysis D.</i>					
Fe ... ..	...	...	...	...	·0351
Ni(Co) ... ..	...	...	...	...	·0181
SiO <sub>2</sub> ... ..	...	...	...	...	·0034
CaO... ..	...	...	...	...	trace.
MgO ... ..	...	...	...	...	·0025
TiO <sub>2</sub> ... ..	...	...	...	...	trace.
Cu ... ..	...	...	...	...	nil.
—————					·0591

8. The combined insoluble portions (*h*) and (*l*) weighed 6·8051 grms. Of this, an amount of 2 grms. was taken and treated with HCl (S.G. 1·06) and filtered. The insoluble portion was then treated with Na<sub>2</sub>CO<sub>3</sub> solution to dissolve gelatinous silica.

(*m*) *Attacked silicate*.—Olivine. ·9254 (by difference).

(*n*) *Unattacked silicate*.—Enstatite, &c.

9. Analysis of solution (*m*), the attacked silicate :—

<i>Analysis E.</i>							
					I.	II.	III.
SiO <sub>2</sub> ... ..	...	...	...	...	·2977	36·83	32·17
Al <sub>2</sub> O <sub>3</sub> ... ..	...	...	...	...	·0045	·57	·48
FeO ... ..	...	...	...	...	·2211	27·40	23·89
MgO ... ..	...	...	...	...	·2769	34·32	29·92
CaO ... ..	...	...	...	...	Nil.	Nil.	Nil.
NiO ... ..	...	...	...	...	·0017	·22	·19
TiO <sub>2</sub> ... ..	...	...	...	...	·0013	·16	·15
MnO ... ..	...	...	...	...	·0040	·50	·43
—————					·8072	.....	.....
Undetermined* ... ..	...	...	...	...	·1182	* ..... .....	12·77
—————					·9254	100·00	100·00

The total amount accounted for in this analysis (·8072) does not make up the difference (·9254) between the 2 grms. taken and 1·0746 weighed as “unattacked.”

\*A determination of alkalis was made later on a sample of the “unattacked” portion.

Columns II and III give the percentages calculated on the amount actually determined in solution (.8072) and on the total amount presumably in solution from the 2 grms. (.9254).

10. Analysis of "unattacked" silicate (*n*), weighing 1.0746 grms. :—

	<i>Analysis F.</i>	Per cent.
SiO <sub>2</sub> ... ..	.6066	56.45
Al <sub>2</sub> O <sub>3</sub> ... ..	.0606	5.64
FeO ... ..	.1313	12.22
MgO ... ..	.2198	20.46
CaO ... ..	.0360	3.35
NiO ... ..	.0015	.14
TiO <sub>2</sub> ... ..	.0025	.25
MnO ... ..	.0023	.21
Alkalies and undetermined ...	.0140	1.30
	1.0746	100.00

Chromite absent.

11. A further portion of the meteorite was utilised in November, 1920, for the determination of sulphur, phosphorus, and alkalies, which had been previously omitted. Portion of the sample was rough-crushed and treated repeatedly with a weak magnet, giving—

*Attracted.*—13.49 per cent.

*Unattracted.*—86.51 per cent.

This proportion is very similar to that obtained in the original operation, viz., 13.89 per cent. of attracted material (*a*). As in the previous work, it was found that the attracted portion contained a considerable amount of silicate, although great pains were taken to separate the magnetic fractions. The following determinations were made :—

1. *Sulphur.*

	Percentage in fractions.	Percentage in total bulk.	
		Sulphur.	Calculated as Fe S. Troilite.
Attracted (A) ... ..	.80	.108	.30
Unattracted (B) ... ..	.78	.677	1.86
	.....	.785	2.16

2. *Phosphorus.*

	Percentage in fractions.	Percentage in total bulk.	
		Sulphur.	Calculated as FeN <sub>2</sub> P. Schreibersite.
Attracted (A) ... ..	·055	·0074	·048
Unattracted (B) ... ..	·145	·1254	·815
	.....	·1328	·863

Bowman and Clarke<sup>1</sup> agree that the amount of schreibersite may be calculated from the total percentage of phosphorus present on the composition Fe<sub>2</sub>NiP, and troilite from the total sulphur as FeS. On this assumption the amounts of these minerals present are—

Troilite ... ..	2·16 per cent.
Schreibersite ... ..	·86 „

It is noteworthy that the sulphur obtained from the “unattracted” portion is considerably more than in the “attracted.” This may be due to the mineral not being sufficiently magnetic to be attracted by the light magnet used, or again, it may suggest that sulphates are present in the silicate portion of the stone. Similarly the phosphorus determination shows a much higher figure in the “unattracted” portion, and this suggests either that the mineral is not sufficiently magnetic or that the phosphorus may exist in some degree as phosphate in the silicate portion.

12. The determination of the alkalis was made by Mr. J. C. Watson in a portion of the “unattracted” residue.

This analysis showed—

	Percentage in fraction analysed.	Equivalent percentage in total rock.
K <sub>2</sub> O ... ..	0·07	·08
Na <sub>2</sub> O ... ..	1·90	2·19
Li <sub>2</sub> O ... ..	faint trace.	

This alkali would be included in the analyses of the silicates, Analysis E and Analysis F.

<sup>1</sup> *Min. Mag.*, xv, 1908-10, p. 369.

## ASCERTAINED COMPOSITION.

13. From the foregoing analyses the following composition has been determined on the amount of material actually dealt with, viz., 7.6394 grms. :—

	In 7.6394 grammes.	Per cent. of total meteorite.
<i>Metallic Alloys—</i>		
Fe ... ..	·4026	
Ni ... ..	·0903	
Co ... ..	·0060	
	·4989	6.53
<i>Schreibersite—</i>		
Fe ... ..	·0366	
Ni ... ..	·0192	
P ... ..	·0102	
	·0660	0.86
<i>Troilite—</i>		
Fe ... ..	·1047	
S ... ..	·0599	
	·1646	2.16
<i>Chromite...</i>	.....	Nil.
<i>Silicates—</i>		
Olivine ... ..	3.1486	41.22
Pyroxene ... ..	3.6565	47.87
		89.09
<i>Loss in crushing (b) ...</i>	·0504	·66
<i>Undetermined ...</i>	·0544	·70
	7.6394	100.00

## Percentage composition of the Metallic Alloy—

Fe ... ..	80.7 per cent.
Ni ... ..	18.1 „
Co ... ..	1.2 „

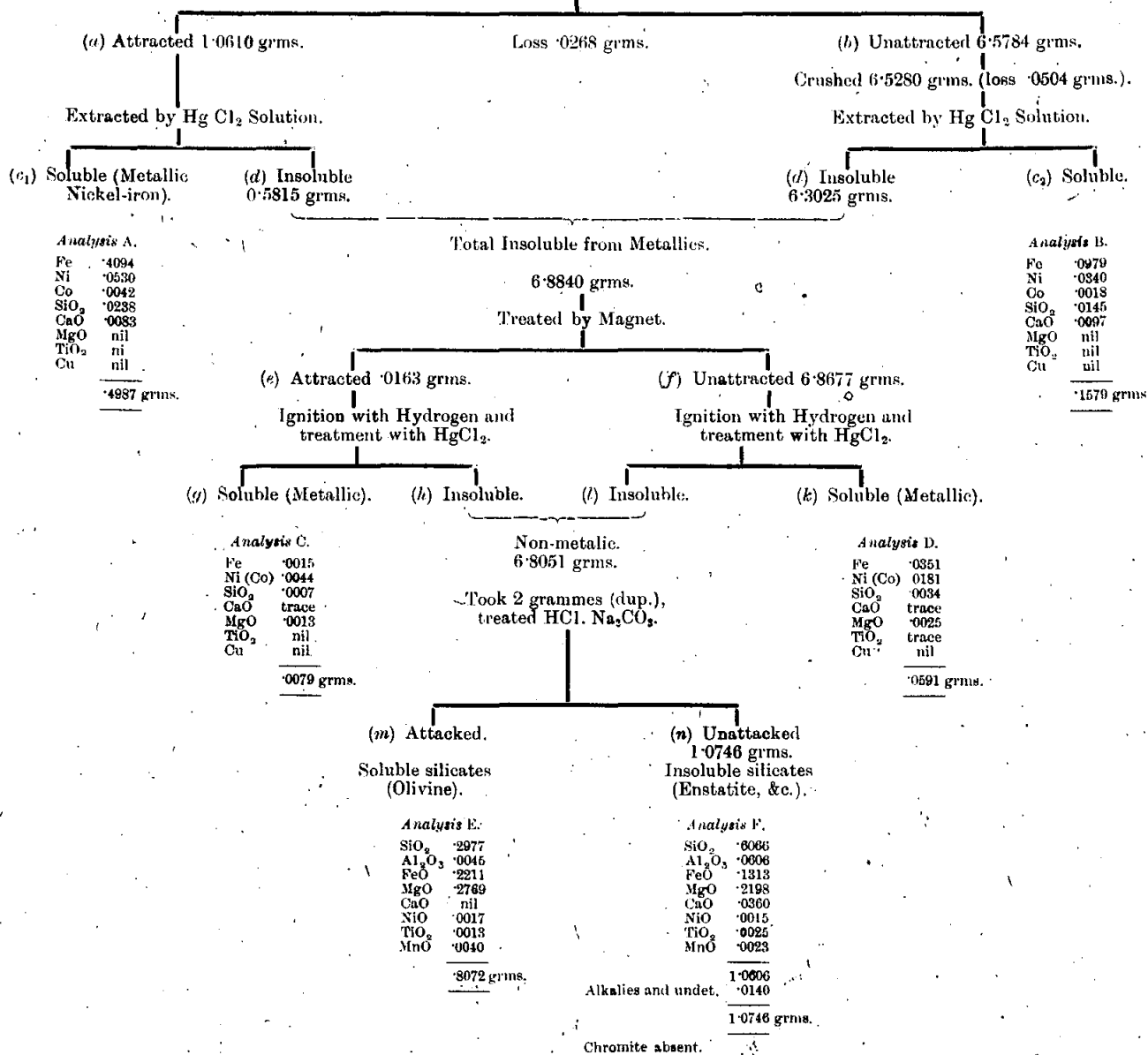
In determining the metallic alloy present, allowance is made for the schreibersite and troilite present thus :

Total Fe (Metallics) ... ..	·5439
Less Fe (Schreibersite) ... ..	·0366
Less Fe (Troilite) ... ..	·1047
	·4026
Fe in Metallic Alloy ... ..	·4026
Total Nickel ... ..	·1095
Less Ni in Schreibersite ... ..	·0192
	·0903
Ni in Metallic Alloy ... ..	·0903

## TABLE OF OPERATIONS.

Rock Crushed, 7.6662 grms.

1. Treated by Magnet.



*DESCRIPTION OF PLATES.*

PLATE I.

Fig. 1. The Adelie Land Meteorite as it rested on the ice surface.

Fig. 2. View of the Adelie Land Meteorite showing the under surface.

(Photographed by A. Vaughan, Government Photo-Lithographer, South Australia.)

PLATE II.

Fig. 1. Microphotograph of the meteoric stone, showing chondrules consisting of clear porphyritic olivine in a base of cloudy pyroxene. Ordinary light, magnified 45 diameters.

Fig. 2. Microphotograph of the meteoric stone showing an olivine chondrule with a branching inclusion of nickel-iron. Ordinary light, magnified 45 diameters.

(Photographed by F. L. Stillwell.)



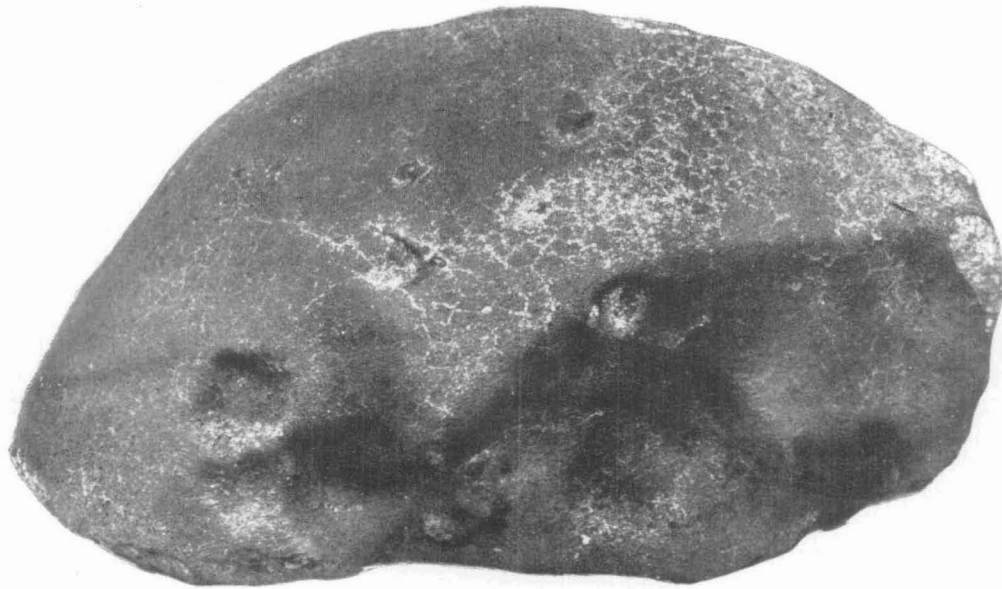


Fig. 1.

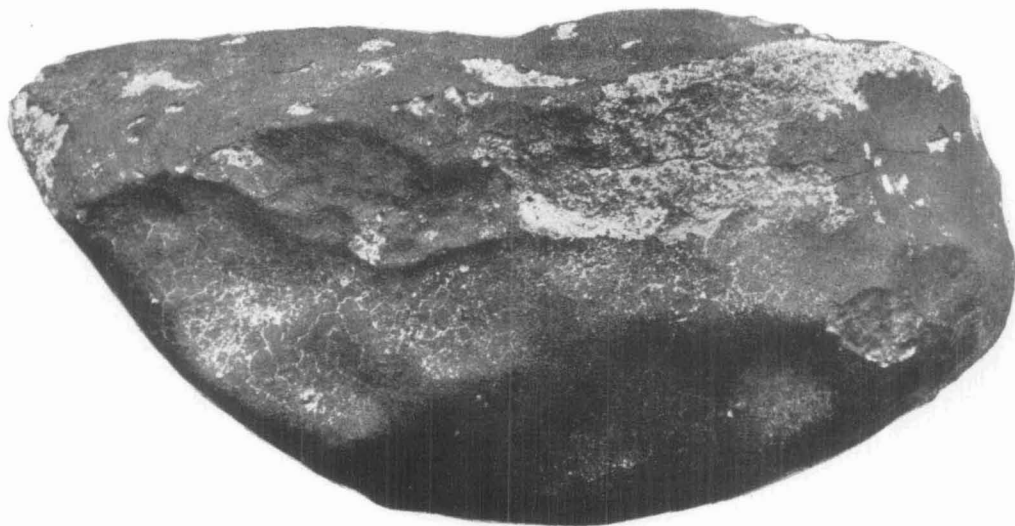


Fig. 2.



Fig. 1.

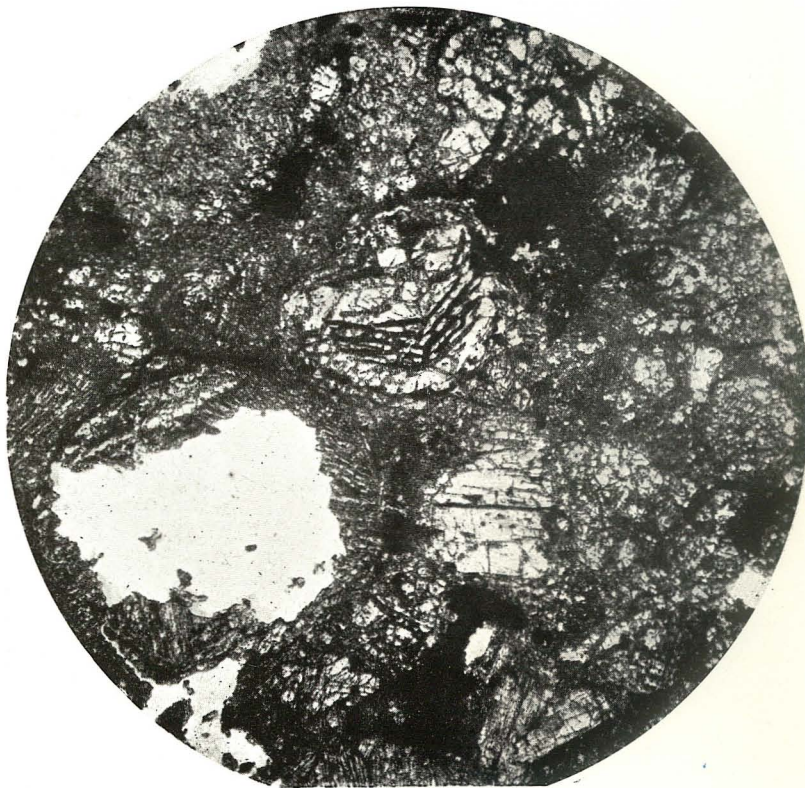


Fig. 2.