

NEW ZEALAND OCEANOGRAPHIC INSTITUTE



TEXTURAL, CHEMICAL AND MINERALOGICAL
ANALYSES OF MARINE SEDIMENTS

by Willem J. M. van der Linden

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by

Willem J. M. van der Linden

INTRODUCTION

This manual is a compilation of the analytical methods in sedimentary petrography commonly used by the New Zealand Oceanographic Institute. The methods described are not very different from techniques used elsewhere. However, for practical purposes and because of specific requirements special instruments have been built and modifications made to well established analytical techniques.

The selection of a quantitative analytical method should be based on the sampling method. It is no use carrying out a detailed grain-size analysis when the equipment does not produce a representative sample. Samples of the bottom of the sea can be obtained by many devices. The best piece of sampling equipment is a corer which brings an undisturbed sample to the surface. Using this is not always practicable because of factors such as the nature of the bottom, texture of the sediment and weather conditions. The next best is a grab. A conical shaped canvas bag draped over the grab prevents material being washed out while being hauled to the surface. Dredged bottom samples are usually of limited value but a more or less representative sample is obtained provided there are no rapid changes in sediment properties over the course of the dredge haul. A canvas bag mounted inside a dredge will greatly improve the quality of the sample obtained.

In most cases dessication and decay of organisms in the sample have a marked effect on the grain size especially of the finer particles. Clay minerals may form aggregates which are not always destroyed by subsequent wetting and organic decay may reduce grain size of soluble minerals. As on the spot analyses are mostly impossible the manner in which samples are stored is very important. Air-tight packing and the use of preservatives and dispersants will greatly increase the value of a sample.

It is doubtful whether results of grain size analyses by different techniques are comparable. Certainly there is no simple conversion method and it is therefore advisable to use a standardized technique. It will, however, be clear that the method applied will depend both on sampling equipment and on the detail and accuracy required.

GRAIN SIZE ANALYSIS (sieve-pipette method)

1. REQUISITES

A. Instruments and Apparatus

- a. 6 x beakers, 600 ml + 6 x watch glasses, diam. 5"
- b. 1 x precision balance (Mettler K5)
- c. washing and filtering equipment -
 - 1 x vacuum pump (Speedivac)
 - 2 x Buchner funnels for filter paper, diam. 12.5 cm
 - 2 x filtering flasks, 1000 ml
 - filter paper (Schleicher und Schull 55 no. 595 diam. 12.5 cm)
 - rubber tubing
 - 2 x tube clamps
- d. coarse-fine separation unit -
 - 1 x retort stand
 - 1 x clamp and bosshead
 - 1 x glass funnel, diam. 6"
 - 1 x sieve, diam. 4", mesh 240 (64)
 - 1 x 4" length of rubber tubing to fit over funnel stem
 - 1 x tube clamp
 - 1 x brush
 - 1 x pipette, 50 ml
- e. thermostatically controlled hotplates or water baths
- f. dry-sieving unit -
 - 1 sieve shaker (Rotap)
 - 1 set of sieves, diam. 8"

mesh no.	μ	mesh no.	μ
1	16,000	30	500
2	8,000	44	353
4	4,000	60	250
8	2,000	85	178
12	1,400	120	125
16	1,000	170	89
22	700	240	64

- g. pipetting unit -
- 1 x pipette stand (enabling horizontal and vertical pipette movement)
 - 1 x vacuum suction pipette, 20 ml
 - 1 x vacuum pump (Speedivac)
 - rubber tubing
 - 7 x spoutless measuring cylinders, 1000 ml
 - 7 x rubber bungs
 - 1 x thermometer (allowing readings between 10° and 30°C with an accuracy of 0.5°C)
 - 1 x stopwatch
 - 1 x three-way stopcock
- h. 31 x nickel evaporation dishes, 50 ml
- i. 1 x desiccator
- j. 1 x drying oven (temp. up to 120°C)
- k. 1 x analytical balance (Mettler B5) or
1 x multipurpose balance (Mettler H3)
- l. squeeze bottles, spatulas, forceps, marking ink

B. Chemicals

- a. 10% peroxide (H_2O_2)
To make up one litre of 10% H_2O_2 solution take 250 ml of the standard 130 Vol. O. H_2O_2 solution ($\pm 39\%$) and add 750 ml of demineralized water.
- b. 1 N hydrochloric acid (HCl)
To make up one litre of 1N HCl take 100 ml of the standard 35.4% HCl solution and add 900 ml of demineralized water.
- c. 6N hydrochloric acid (HCl)
To make up one litre of 6N HCl take 600 ml of the standard 35.4% HCl solution and add 400 ml of demineralized water.
- d. *20% sodium dithionite (sodium hydrosulphite) $\text{Na}_2\text{S}_2\text{O}_4$
To make up a 20% $\text{Na}_2\text{S}_2\text{O}_4$ solution add 10 grams of $\text{Na}_2\text{S}_2\text{O}_4$ to 50 ml of cold water.
N.B. The solution should be prepared immediately before use.

* Solutions (d) and (e) only to be used if sample contains a high amount of iron.

- e. *1% (10 grams of NaCl/litre)
- f. peptizer (0.1 mole Na-oxalate + 0.02 mole Na_2CO_3 per litre).

To make one litre of peptizer dissolve 13.4 grams of dry Na-oxalate and 2.12 grams of dry Na_2CO_3 in 1 litre demineralized water.

2. PROCEDURE

For practical purposes it is advisable to work with six samples at a time.

A. Initial Amount

Homogenise the sample by carefully mixing with a spatula. Depending on overall grain size distribution take amounts of 50, 25 or 10 grams to ensure an adequate concentration of the suspension in the pipette cylinders (5-20 grams/litre).

50 grams if the material is predominantly coarse sand.

25 grams if the material is predominantly sand or sandy mud.

10 grams if the material is predominantly muddy.

For coarser grained material (average sizes 2000 μ) another analytical method should be used. For instance up to and including the pebble class samples can be separated into size classes by using sieves with apertures of 4,000, 8,000 and 16,000 μ . For even larger size classes it is necessary to measure the intermediate diameter (b-axis) of a certain number (usually 50 to 100) of pebbles, cobbles or boulders to provide estimates of size comparable to sieve separated size fractions. Errors caused by such comparisons are normally introduced because of differences in petrologic composition. (Sieve separation provides weight percentages in the various size classes, measurement of b-axes provides approximate volume percentages.)

It is often necessary to sample from bulk. To ensure that the ultimate sample to be analysed is truly representative of the bulk and that repeat tests can be made if necessary divide the sample either with a sample splitter or by the quartering method. The latter is illustrated step by step in Fig. 1. The original bulk quantity is mixed carefully and shaped into a cone on a flat surface. Flatten the cone to a circular pile of uniform thickness. Divide it into four quarters with two right angle cuts separating the material slightly with a lateral movement. Remove two opposite quarters. Mix the remaining quarters completely, form a cone, and repeat the procedure until the sample is the desired size.

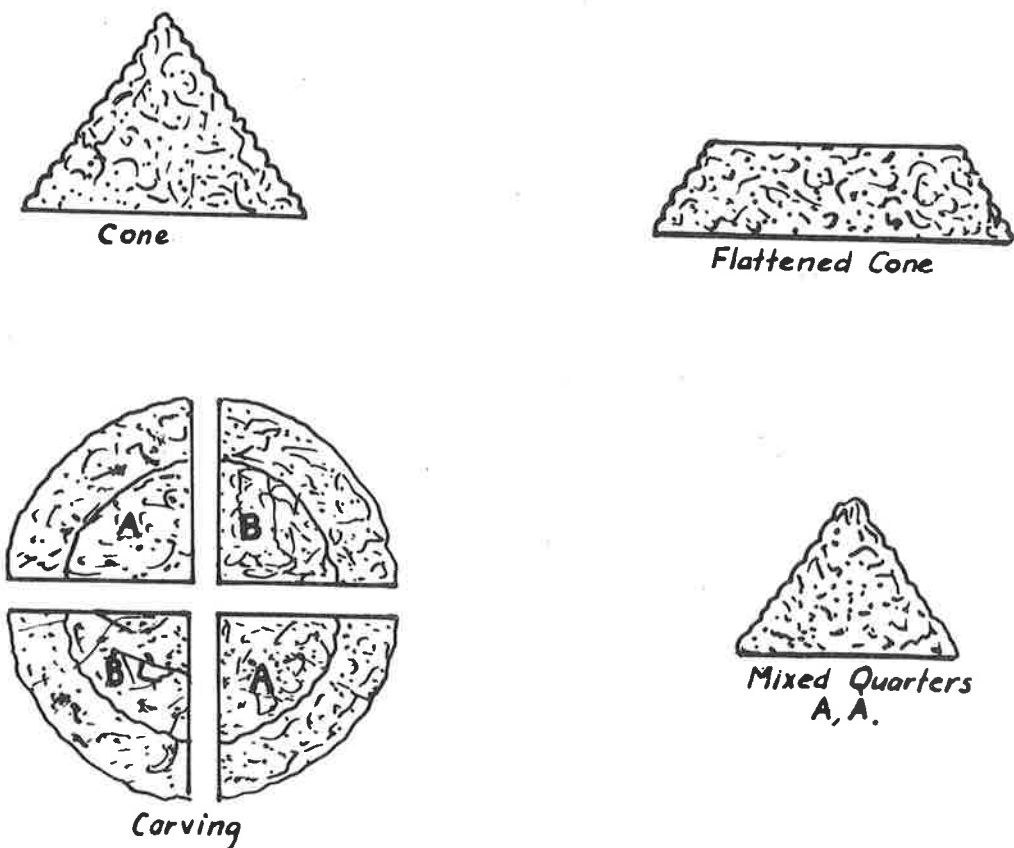


Fig. 1 Sampling from bulk. The quartering method. (after Milner, 1962)

B. Peroxide Treatment

To remove organic material the samples are treated with H_2O_2 . Put the initial amount (50, 25 or 10 grams) in a numbered 600 ml beaker and add 50 cc of 10% H_2O_2 solution. Cover the beaker with a watch glass. Add small amounts of 10% H_2O_2 as reaction ceases and place on a water-bath. If there is almost no further reaction remove the watch glass to allow some evaporation.

At this stage it is advisable to leave overnight on the water-bath with the watchglass cover.

C. Acid Treatment

To remove carbonate cement and iron oxide films the samples are treated with HCl.

After the peroxide treatment cool the sample, clean the watchglass over the beaker with water (squeeze bottle) and add 50 cc of 6N HCl gradually, to start with, to avoid too violent a reaction on unknown sample material. Shake the sample every so often. If there is no further reaction add more 6N HCl. Repeat until all reaction has ceased. Put the sample on a water-bath for 30 minutes.

N. B. 1. This treatment attacks iron and affects heavy minerals such as apatite, olivine and monazite. Extended HCl treatment should be avoided. If a sample has a high iron content it is advisable to remove excess iron by treatment with sodium-dithionite (E).

2. Where information is required on the grain size distribution of sediment, including clastic or non-clastic carbonates, HCl cannot be used for disintegrating purposes. Instead treat the sample with a NaOH solution or a detergent.

D. Removal of Acid. Fig. 2

Place a Büchner funnel on a filtering flask and connect the flask with rubber tubing to a vacuum pump. Place a filter paper in the funnel and wet this thoroughly after applying vacuum. Once the filter sets without leaks in the funnel carefully place the sample on the filter.

If no dithionite treatment (E) is needed (the usual case) proceed from here to the washing procedure (F). After filtering the filter and funnel should be cleaned and the sample put back in the 600 ml beaker.

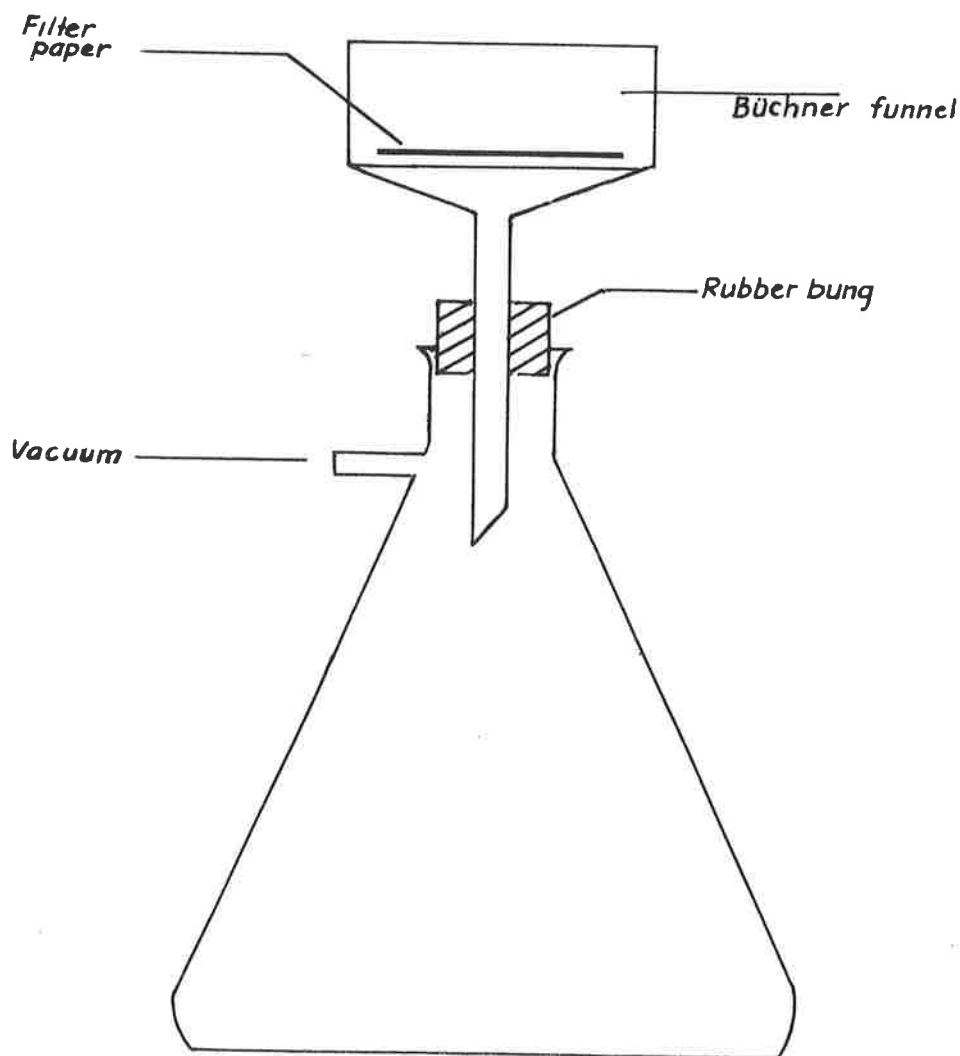


Fig. 2 Washing and filtering unit.

E. Sodium Dithionite Treatment

This method ensures iron is removed without attacking other minerals.

The sample is placed in the beaker with only a small quantity of water on top. Loosen the sample with a spatula and add 50 cc 20% $\text{Na}_2\text{S}_2\text{O}_4$. Place beaker for 20-30 minutes on the waterbath and shake regularly. The sample turns grey. Let it cool and filter as in (D) with a Büchner funnel and filtering flask.

F. Washing (Set up as in D)

1. If the sample was treated with $\text{Na}_2\text{S}_2\text{O}_4$ wash with a 1% NaCl solution and after suction has been applied repeat a few times especially for very fine sediments. To prevent sulphur precipitation, which would be a nuisance if the filter bursts, empty the filter flask before continuing.
2. Wash the sample through the Büchner funnel with demineralized water 5 times and return to the 600 ml beaker. Clean funnel and filter thoroughly into the beaker.

G. Coarse-fine Separation. Fig. 3

Attach a short length of rubber tubing fitted with a tube clamp to the stem of a 6" funnel. Clamp the funnel on a retort stand. Place a 64 μ sieve (diam. 4") in the funnel and a 1000 ml pipette cylinder underneath. Put the sample on the sieve and separate the material finer than 64 μ using a brush and demineralized water. It is advisable to use sufficient water to cover the sieve mesh. Empty the funnel into the cylinder and repeat the procedure until all particles smaller than 64 μ have passed through the sieve. The fraction coarser than 64 μ is put on a nickel evaporation dish and left to dry on a water bath and later in a drying oven for 10 minutes at 120°C. Clean the funnel into cylinder and add 50 cc of peptizer to the fine suspension. Fill the cylinder up to the 1000 ml mark with demineralized water. Close the pipette cylinder with a rubber bung, shake the suspension and leave standing overnight on the pipette stand to ensure complete dispersion. Add one cylinder of demineralized water and 50 cc of peptizer, in which a thermometer is placed, to a series of six cylinders containing suspension.

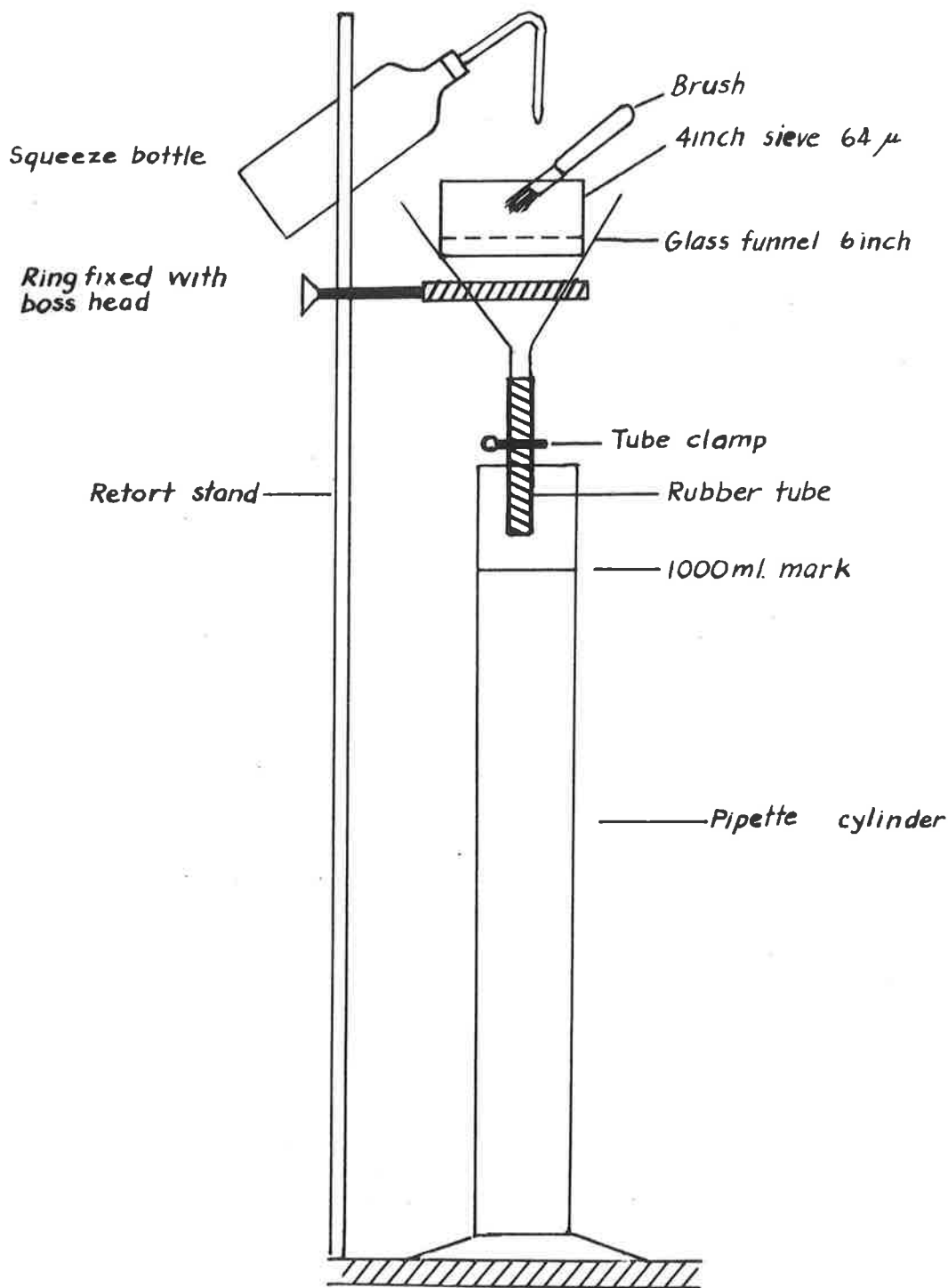


Fig. 3 Coarse-fine separation unit.

H. Sieving

After drying the fraction coarser than 64 μ is brought on the sieve series and shaken for 15 minutes. The sieve fractions are put into nickel dishes and subsequently weighed on an analytical or multi-purpose balance to the nearest 0.0001 gram.

All material that passes the 64 μ sieve is also weighed and, after being moistened with alcohol is added to the pipette cylinder. Enter all results on the computation list (pp. 9, 10).

GRAIN SIZE ANALYSIS (Computation List)

Geology Lab. N. Z. O. I.
Wellington

Sample No.

Analysed by:

Bulk sample: wet/moist/dry

Initial amount gm Treated with $H_2O_2/HCl/Na_2S_2O_4$

Beaker No:

Pipette Cylinder No: Pipetting temp. : °C

1st sample	gm	2nd sample	gm
Dish No. : _____	gm -	Dish No. : _____	gm
Fraction < 64 μ	gm x 50 =	gm	
Fraction < 32 μ	gm	32-64 μ	gm
Dish No. : _____	gm -		
	gm x 50 =	gm	
Fraction < 16 μ	gm	16-32 μ	gm
Dish No. : _____	gm -		
	gm x 50 =	gm	
Fraction < 8 μ	gm	8-16 μ	gm
Dish No. : _____	gm		
	gm x 50 =	gm	
Fraction < 4 μ	gm	4-8 μ	gm
Dish No. : _____	gm -		
	gm x 50 =	gm	
Fraction < 2 μ	gm	2-4 μ	gm
Dish No. : _____	gm -		
	gm x 50 =	gm	
Correction :	_____ gm -	< 2 μ	gm
Peptizer:	_____ gm		
Dish No. :	_____ gm -		
Correction :	_____ gm x 50 =		gm

* The correction should always be subtracted from the finest fraction estimated. (Normally 8 μ).

Computation List cont.

				%	Cum. %
(> 16,000 μ)				
(8,000	- 16,000 μ)				
(4,000	- 8,000 μ)				
(2,057	- 4,000 μ)		or > 2057 μ		
1,400	- 2,057 μ		gm		
Dish No.:		<u> </u>	gm -		
					gm
1,000	- 1,400 μ		gm		
Dish No.:		<u> </u>	gm -		
					gm
700	- 1,000 μ		gm		
Dish No.:		<u> </u>	gm -		
					gm
500	- 700 μ		gm		
Dish No.:		<u> </u>	gm -		
					gm
353	- 500 μ		gm		
Dish No.:		<u> </u>	gm -		
					gm
250	- 353 μ		gm		
Dish No.:		<u> </u>	gm -		
					gm
178	- 250 μ		gm		
Dish No.:		<u> </u>	gm -		
					gm
125	- 178 μ		gm		
Dish No.:		<u> </u>	gm -		
					gm
89	- 125 μ		gm		
Dish No.:		<u> </u>	gm -		
					gm
64	- 89 μ		gm		
Dish No.:		<u> </u>	gm -		
					gm
32	- 64 μ		gm		
16	- 32 μ		gm		
8	- 16 μ		gm		
(4	- 8 μ)		gm		
(2	- 4 μ)	or < 8 μ	gm		
(< 2 μ)	(or < 4 μ)	gm		
			<u> </u>		gm +
TOTAL					gm

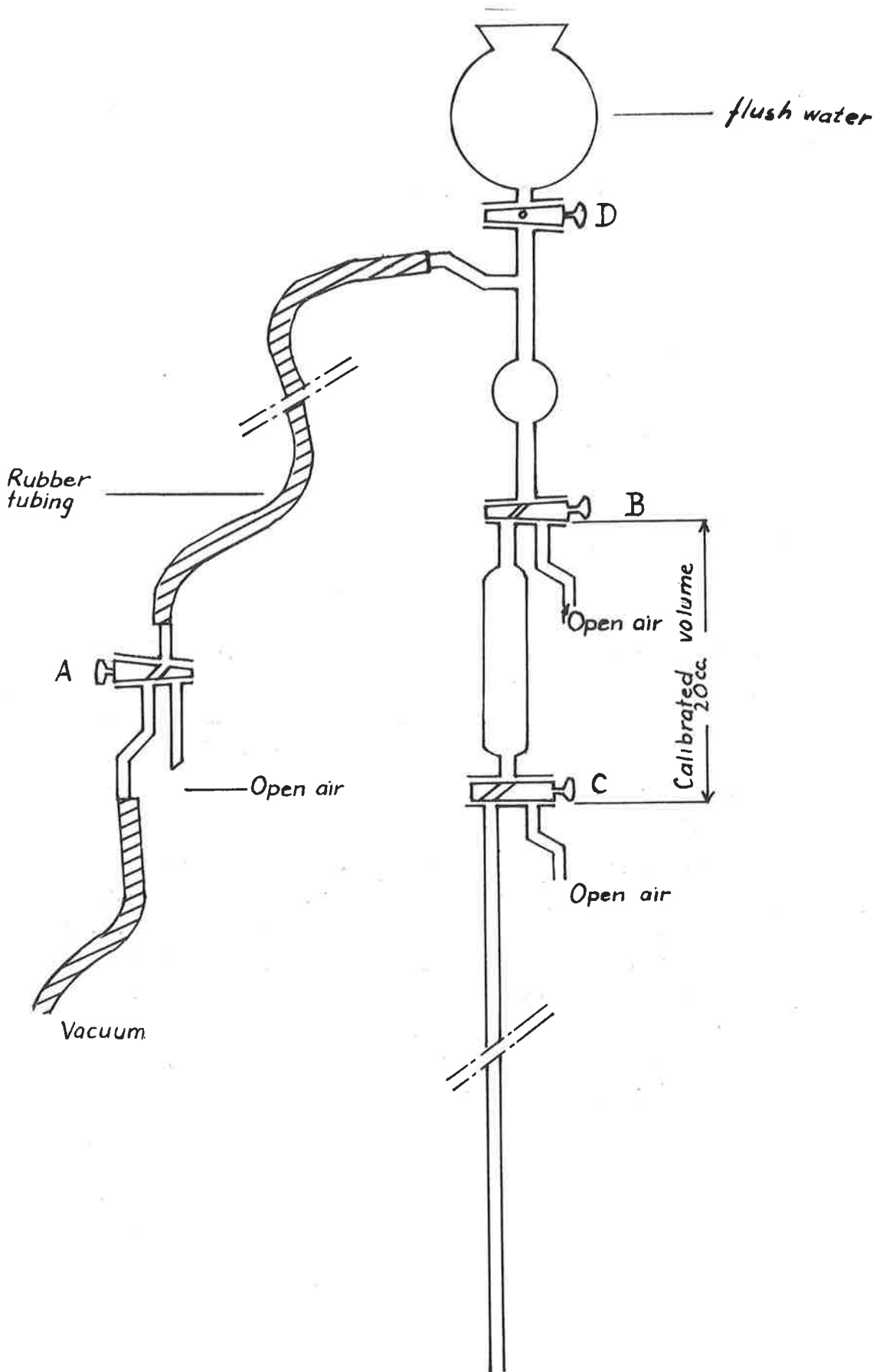


Fig. 4 Pipette (construction by Chemistry Division, DSIR) With taps C and D closed and taps A and B in the position indicated lower the pipette in the cylinder. Open C as indicated and let the suspension rise in the pipette until well over B. Close C and, by turning A, connect the pipette to the open air. Remove excess sample by opening B to open air. Clean the upper part of the pipette by quickly opening and closing D. Now turn B back to its original position. Collect the sample at C by turning the tap and flush the pipette again (into evaporation dish) by quickly opening and closing D.

I. Pipetting. Figs 4, 5.

(The procedure as described applies to the pipette and pipette stand used by N. Z. O. I.)

Place a rubber bung on the pipette cylinder and shake the sample to loosen all material from the bottom and to obtain a homogenous suspension. Immediately after putting the cylinder down take a sample (20 cc) at a depth of 20 cm.

Empty the pipette sample into a nickel evaporation dish and place the dish on a water bath. For a control repeat the procedure of taking a sample at a depth of 20 cm immediately after renewed shaking of the cylinder. This provides two samples of the total fraction smaller than 64μ . After all moisture has evaporated place the samples for 10-15 minutes in a drying oven at 120°C . The weight of one should differ from the other by no more than 2%.

Shake the cylinder and place it on the pipette stand. After 4 minutes take a sample at the depth indicated in Table 1. (The temperature is read off the thermometer in the water-peptizer cylinder). This provides the total fraction smaller than 32μ per 20 cc. Without further shaking samples are taken, in the same way, after 16 minutes and 30 minutes at the appropriate depths to obtain the fractions smaller than 16μ and smaller than 8μ respectively.

For a normal analysis it is not necessary to subdivide the $< 8 \mu$ fraction as the silt-clay ratios in a given area are fairly constant for the tail end of a grain size distribution. Should this information be required, however, proceed in the same way taking further samples according to the time-temperature-depth table. The various fractions after evaporation on the water bath and subsequent drying in an oven for 10-15 minutes at 120°C are weighed on the analytical balance to the nearest 0.0001 gram.

TABLE 1
Pipetting depth in cm.

Temp °C	Fraction < 32 μ 4 min.	Fraction < 16 μ 16 min.	Fraction < 8 μ 30 min.	Fraction < 4 μ 60 min.	Fraction < 2 μ 120 min.
10		16.9	7.9		
10.5		17.1	8.0		
11		17.4	8.1		
11.5		17.6	8.2		
12		17.8	8.4		
12.5		18.1	8.5		
13		18.3	8.6		
13.5		18.6	8.7		
14		18.8	8.8		
14.5		19.1	8.9		
15		19.3	9.0	4.4	2.2
15.5		19.6	9.2	4.5	2.2
16		19.8	9.3	4.5	2.3
16.5		20.1	9.4	4.6	2.3
17		20.3	9.5	4.6	2.3
17.5		20.6	9.6	4.7	2.4
18		20.8	9.8	4.8	2.4
18.5		21.1	9.9	4.8	2.4
19		21.4	10.0	4.9	2.4
19.5		21.6	10.1	4.9	2.5
20		21.9	10.3	5.0	2.5
20.5		22.2	10.4		
21		22.5	10.5		
21.5		22.7	10.7		
22		23.0	10.8		
22.5		23.3	10.9		
23		23.6	11.0		
23.5		23.8	11.2		
24		24.1	11.3		
24.5		24.4	11.4		

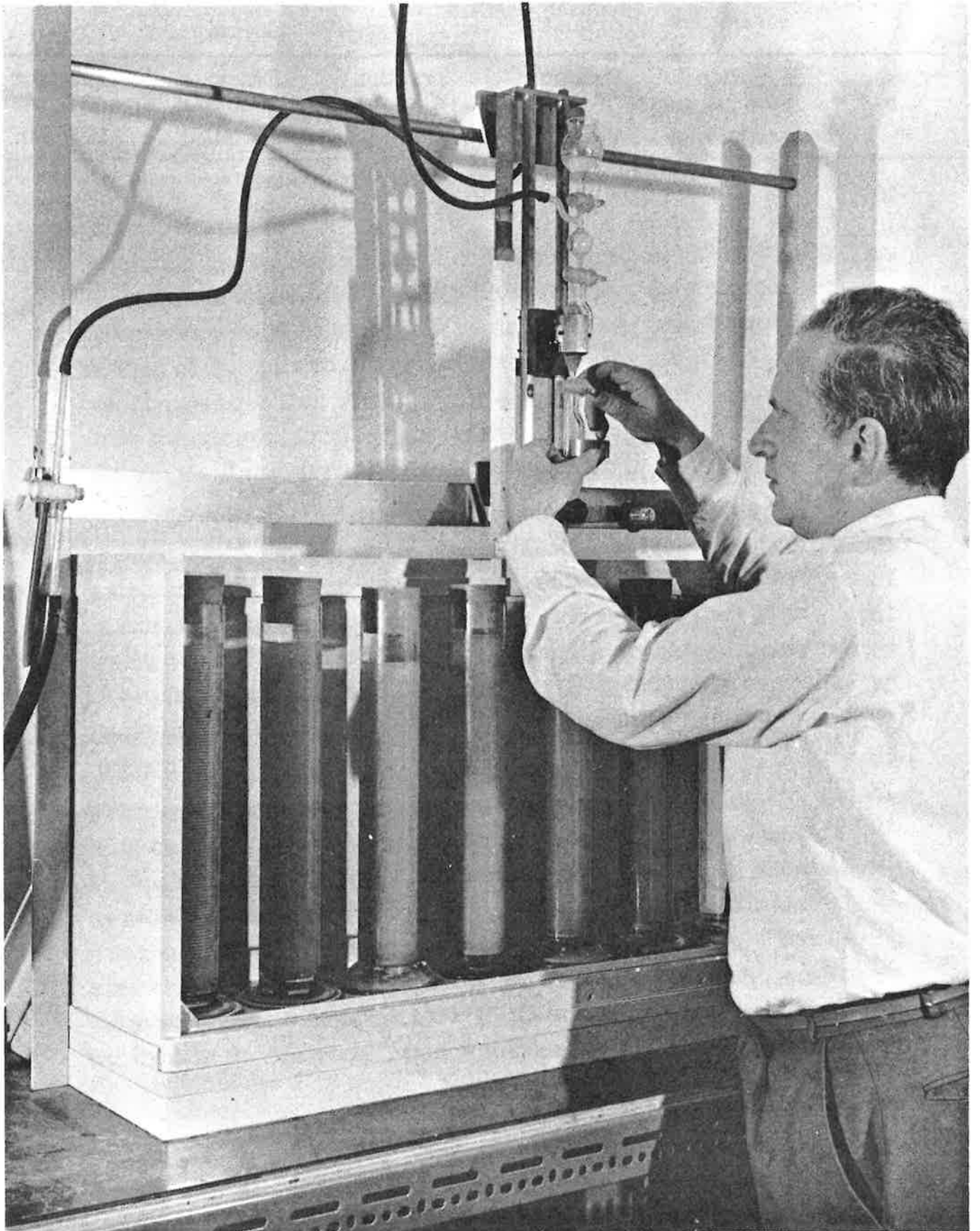


Fig. 5 Pipette stand with 6 cylinders (construction by Physics and Engineering Lab., DSIR)

J. Calculation of Results

The weights of the pipette fractions are entered on the computation list (pp. 9) and the total amounts per litre calculated (multiplication by 50). Subtracting the total amounts finer than a given size gives the distribution over the various size fractions. From the fraction smaller than 8μ (4μ or 2μ) the total amount dry weight of peptizer is subtracted. This amount, indicated on the computation list as correction, is 0.776 grams. Every time new peptizer solution is prepared a test sample should be taken from the solution in the water-peptizer cylinder (G) to verify that the correction factor is indeed 0.776 grams. After evaporation and drying the sample weight should be 0.015-0.016 grams.

The calculated results of the size classes smaller than 64μ are added to the column presenting the results of the sieve analysis and the total of all fractions estimated. With a slide rule the percentages and cumulated percentages are now calculated to the nearest 0.0001 gram.

TABLE 2
Conversion of mm to ϕ diameters
Tolerance less than 1% unless otherwise indicated.

mm	ϕ		mm	ϕ	
16,000	- 4	} interval 1 ϕ	0,178	2,5	} interval 0.5 ϕ
8,000	- 3		0,125	3,0	
4,000	- 2		0,089	3,5	
2,000	- 1		0,064	4,0 (\pm 1%)	
1,400	- 0,5 (\pm 3%)	} interval 0,5 ϕ	0,032	5,0	} interval 1%
1,000	0,0		0,016	6,0	
0,700	0,5 (\pm 3%)		0,008	7,0	
0,500	1,0		0,004	8,0	
0,353	1,5		0,002	9,0	
0,250	2,0				

K. Evaluation of Data

To avoid time consuming calculations of logarithmic values the ϕ (phi) scale is introduced:

$$\phi = -\log_2 \xi$$

in which ξ (zeta) is the size in mm.

Table 2 gives the conversion of mm to ϕ units. Cumulative percentages are now plotted against phi diameter on arithmetic probability paper (Gormack Graph Paper, Christchurch, No. 5G) and a smooth line drawn through the points. From the curve the following percentages are now read to the nearest 0.1 ϕ : 5%, 16%, 25%, 50%, 75%, 84% and 95%. This permits calculations of the following statistical parameters (after Folk and Ward, 1957).

$$\begin{aligned}
 1 \text{ Mean size} \quad M_Z &= \frac{\emptyset 16 + \emptyset 50 + \emptyset 84}{3} \\
 2 \text{ Sorting} \quad \sigma_i &= \frac{\emptyset 84 - \emptyset 16}{4} + \frac{\emptyset 95 - \emptyset 5}{6,6} \\
 &\quad \text{(Inclusive Graphic Standard Deviation)} \\
 3 \text{ Skewness} \quad Sk_i &= \frac{\emptyset 16 + \emptyset 84 - 2\emptyset 50}{2(\emptyset 84 - \emptyset 16)} + \frac{\emptyset 5 + \emptyset 95 - 2\emptyset 50}{2(\emptyset 95 - \emptyset 5)} \\
 &\quad \text{(Inclusive Graphic Skewness)} \\
 4 \text{ Kurtosis} \quad Kg &= \frac{\emptyset 95 - \emptyset 5}{2,44(\emptyset 75 - \emptyset 25)} \\
 &\quad \text{(Graphic kurtosis)}
 \end{aligned}$$

Calculation and Evaluation of results by computer.

A computer programme "Pebbles" was prepared for the calculation of size parameters. It is written in Algol, a language linking classical mathematical notations to the binary notation with which the Elliott 503 computer works.

The input to the computer, punched on eight channel paper tape, is in weights per size class. The computer prints out size ranges with their respective percentages and cumulative percentages and will then interpolate linearly between successive points. From this the distribution parameters are calculated and printed. They are followed by a graph of cumulative percentages against size in \emptyset units. A modal analysis of the size frequency distribution can be incorporated in the programme.

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CARBONATE ANALYSIS

(Acidimetry)

1. REQUISITES

A. Instruments and Apparatus

- a. 1 x agate mortar and pestle
- b. 1 x sieve mesh 120 ($125\ \mu$), diam. 4"
- c. 1 x sieve mesh 30 ($500\ \mu$), diam. 4"
- d. 6 x beakers, 100 ml
- e. 1 x analytical balance (Mettler B5)
- f. thermostatically controlled hot plates
- g. 1 x 50 cc burette, 0.1 cc divisions
- h. 1 x pipette, 20 ml
- i. 1 x Erlenmeyer, 250 ml
- j. 1 x funnel, diam. 3"
- k. filterpaper, diam. 5"

B. Chemicals

- a. 1N hydrochloric acid (HCl)
To make up one litre of 1N HCl take 100 ml of the standard 35,4% HCl and add 900 ml of demineralized water.
 - b. 1N sodium hydroxide (NaOH)
To obtain one litre of 1N NaOH dissolve 40 grams of dry NaOH pellets in demineralized water to make a litre solution.
 - c. methyl-orange
 - d. 100% CaCO_3
- N.B. Keep both NaOH pellets and 100% CaCO_3 stored in a dessicator.

2. PROCEDURE

It is advisable to work with six samples at a time. Crush the sample in a mortar to eliminate the effect of granular variation. By sieving through sieves mesh 30 and 120 the fraction $125-500\ \mu$ is obtained. From this take one gram (analytical balance) and put it in a 100 ml beaker. Add 20 cc (pipette) 1N HCl and 20 to 25 cc of demineralized water. Shake the beaker and put it on a hotplate (in fume cupboard) for 10 minutes at $60^\circ-70^\circ\text{C}$.

After cooling filter the solution into a 250 ml Erlenmeyer and add a drop of methyl orange as indicator. The amount of HCl used is now estimated by titration with 1N NaOH solution.

As the volume of NaOH required to neutralise the superfluous HCl is directly proportional to the carbonate percentage of the sample a simple nomogram can be used to estimate the carbonate concentrations. The nomogram (Fig. 6) is based on the analyses of pure (100%) calcium carbonate and of a blank. These analyses provide two endpoints on the graph which are joined by a straight line. The scale of the graph should be selected so that the volume of NaOH can be entered to the nearest 0.05 ml and the CaCO_3 percentages read to the nearest 1% (approx. 1 cm \equiv 1 ml; 1 cm \equiv 10%). An extra advantage of the nomogram is that the normality of the reagents is not too critical. Naturally a new nomogram must be constructed every time new reagents (HCl or NaOH) are used.

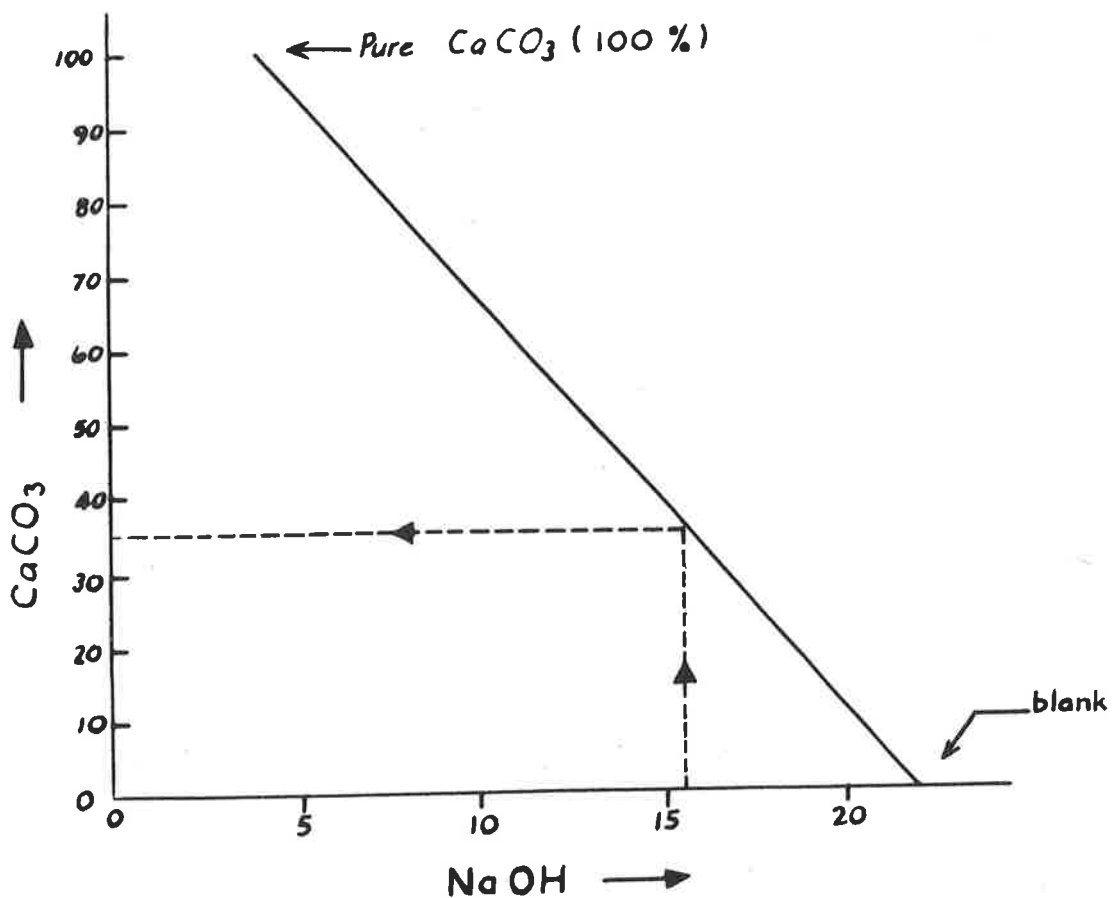


Fig. 6 Nomogram for the determination of carbonate percentages.

REFERENCE

Dulemba, J. L. 1963: Methodes d'Analyse des carbonates dans les Sediments. Révue Géomorph. dyn. 4-6: 62-71

HEAVY MINERAL ANALYSIS

1. REQUISITES

A. Instruments and Apparatus

- a. 1 x precision balance (Mettler K4)
- b. 6 x beakers, 600 ml + 6 x watch glasses, diam. 5"
- c. 1 x sieve mesh no. 30 (500 microns), diam. 4"
- d. 1 x sieve mesh no. 240 (64 microns), diam. 4"
- e. 1 x porcelain wash basin, diam. 8"
- f. 1 x wooden pestle
- g. thermostatically controlled hot plates or water bath
- h. 6 x nickel evaporation dishes, 50 ml
- i. 1 x drying oven (temp. up to 120°C)
- j. 1 x dessicator
- k. separation unit -
 - 1 x funnel-battery or retort stand with 2 x clamps and bossheads
 - 6 x separation funnels, 50 cc (Pyrex B 19/28)
 - 6 x glass funnels, diam. 3"
 - 12 x coloured glass bottles, 500 cc
 - 6 x porcelain dishes, diam. 2"
 - filter paper, diam. 4"
 - 1 x hydrometer (2.6-3.0) or 1 x pycnometer, 50 cc
- l. FRANTZ Isodynamic Magnetic Separator
- m. mounting set-up -
 - 1 x thermostatically controlled hot plate
 - 1 x thermometer (0°-200°C)
 - 1 x copper thermometer holder
 - object glasses + cover glasses
 - match sticks
- n. squeeze bottles, spatulas, stirring rods, marking ink, diamond pencil.
- o. 1 x 250 cc separation funnel

B. Chemicals

- a. 10% peroxide (H_2O_2)
To make up one litre of 10% H_2O_2 add 250 ml of the standard 130 Vol. O. H_2O_2 (\pm 39%) to 750 ml of demineralized water.
- b. concentrated hydrochloric acid (HCl)
- c. bromoform (sp. gr. 2.9)
- d. 99% alcohol (methylated spirits)
- e. canada balsam
- f. xylol (xylene)

2. PROCEDURE

It is advisable to work with six samples at a time.

A. Preparation

Homogenise the sample by carefully mixing with a spatula. Put approximately 50 grams of sample (100 grams if predominantly silt and clay) in a 600 ml beaker and add 50 cc of 10% H_2O_2 solution to remove organic material. Cover the beaker with a watchglass and leave standing overnight in a fume cupboard.

Next add water and stir thoroughly. Remove all material finer than 64μ and coarser than 500μ by wet sieving through sieves mesh nos 30 and 240. To remove excessive light fraction wash the 64 - 500μ fraction in a porcelain wash basin with tap water at the same time breaking down aggregates with a wooden pestle. Leave the suspension to settle for 30 seconds and decant. Repeat the procedure until the water stays clear.

Return the sample to the 600 ml beaker and add 50 cc of concentrated HCl. Put this on the waterbath in the fume cupboard for 20 minutes.

After adding cold water to the suspension to prevent the escape of fumes outside the cupboard wash the sample repeatedly in the porcelain wash basin as before.

N.B. The treatment with concentrated HCl will attack and dissolve the following heavy minerals: apatite, siderite, olivine, monazite and glauconite.

Next put the sample in nickel evaporation dish, dry it on the water bath or hotplate (temp. lower than $100^\circ C$) and later on stove at $120^\circ C$ for 1 hour. Store the sample in a dessicator.

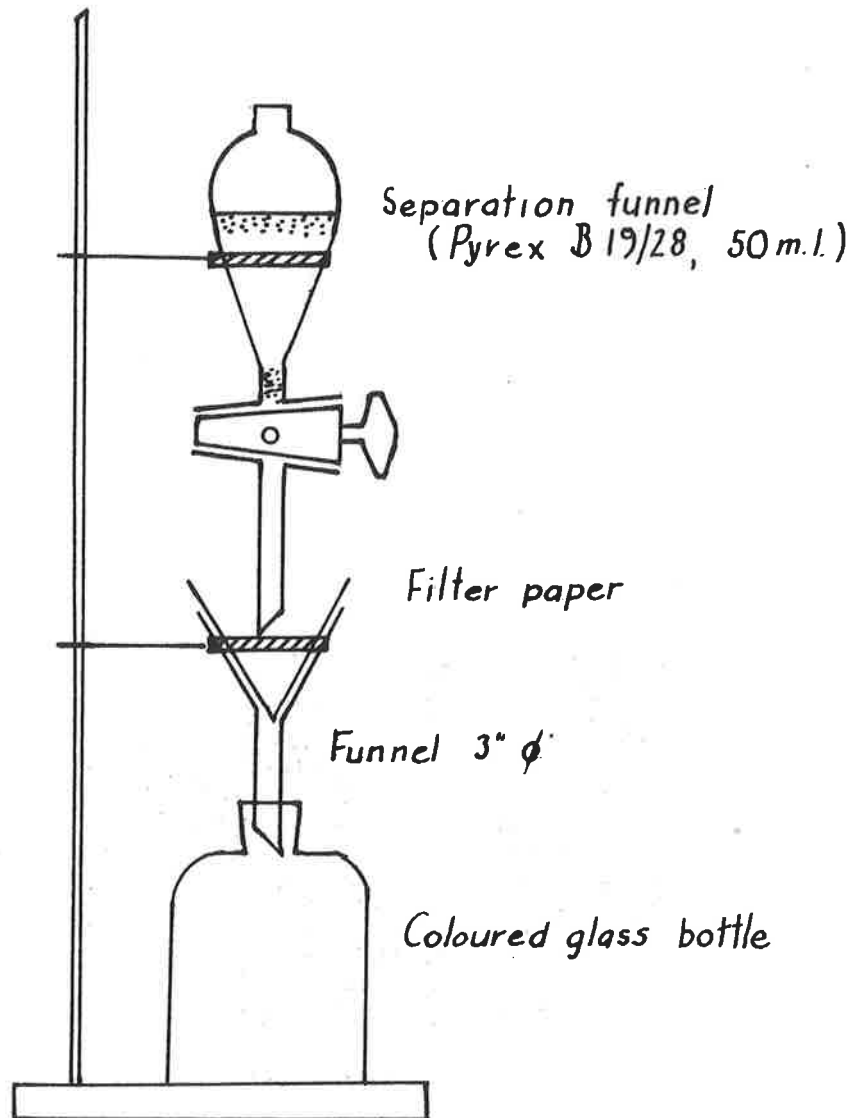


Fig. 7 Heavy mineral separation unit.

B. Separation of the Heavy Fraction with Bromoform (Fig. 7)

Care should be taken with the handling and use of bromoform as its vapours are toxic if breathed in quantity. The use of bromoform outside a fume cupboard should be restricted to a minimum. Bromoform must be kept in the dark and separation of minerals with bromoform should be carried out in subdued light to avoid disintegration of the fluid and consequent decrease in density. As bromoform is also expensive every effort should be taken to avoid spilling.

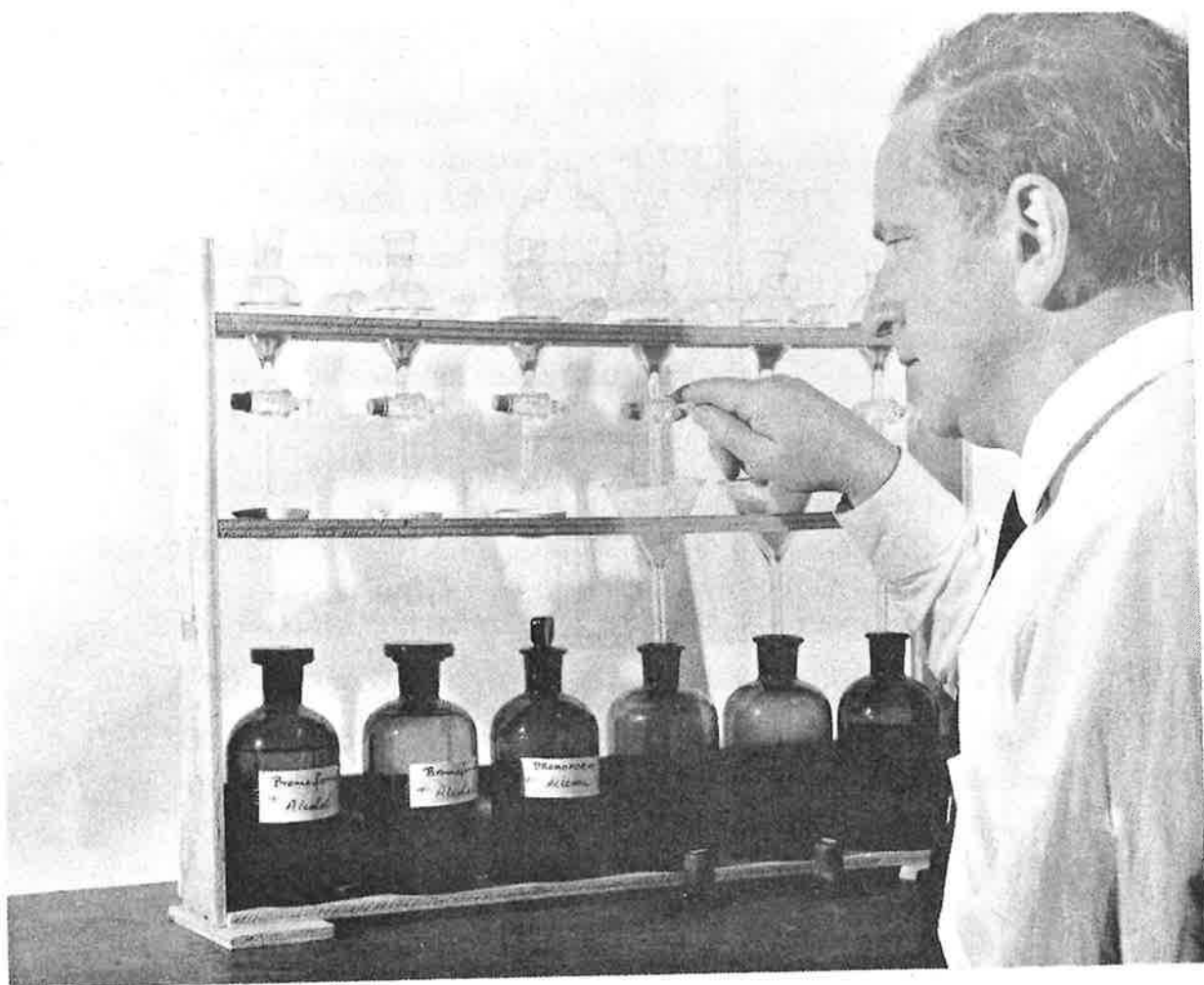


Fig. 8 Funnel battery for the separation of heavy minerals.

The use of a funnel battery enables a number of separations to be carried out at the same time (Fig. 8). First of all check the density of the bromoform (2.89) directly with a hydrometer (calibrated for densities between 2.6 and 3.0) or indirectly by using a pycnometer (50 cc). Three-quarters fill the separation funnel with bromoform. Add a spoonful of thoroughly mixed sample and stir carefully with a clean glass rod. Take care the fluid is not disturbed in the lower narrow part of the funnel. If the amount of heavy mineral that settles down is not sufficient add another spoonful of sample and stir again carefully.

By opening the tap slightly collect the heavies in a porcelain dish. Decant excessive bromoform through a filter back into the bromoform bottle. Empty the separation funnel by opening the tap also through a filter into the bromoform bottle and leave the tap open for 15 minutes.

To clean the separation funnel rinse it with wash fluid, a mixture of bromoform and 95% alcohol, and empty the contents through a filter into a wash bottle.

Clean the sample with 95% alcohol and decant supernatant through a filter into the wash bottle. Repeat this last procedure three times.

Dry the heavy mineral sample in a stove at 120°C. Wash the light fraction in the same way as the heavy fraction, dry and store with sample no. in sample tube.

C. Magnetic Separation

This method separates the heavy mineral association in six groups according to their magnetic susceptibilities. This separation makes later microscopic identification much easier especially for inexperienced staff. The procedure described is the one for the FRANTZ isodynamic separator (Fig. 9).

First separate the ferro-magnetic minerals with a hand magnet. Minerals with lower susceptibilities are fed in the hopper and separation is carried out in successive steps with side inclination of the magnet and field strength set as indicated in Table 3. The inclination of the magnet in the direction of the chute (forward slope) is set at 30° for all steps. After each step the grains with higher susceptibilities are stored ready for mounting and the grains with lower susceptibilities are put through the separator for the next step.

D. Mounting of Specimens

Set the hotplate for a temperature of 125°C some time prior to mounting. N.B. This temperature is critical. If the temperature is too low the balsam will not set, if too high the balsam becomes brittle and turns yellow-brown. Put an object glass on the plate and put some Canada balsam on the slide with a glass rod. Leave for a few minutes to permit evaporation of volatiles. Mix the dry heavy mineral sample carefully and sprinkle an adequate amount of sample on the balsam. Spread the grains evenly over the slide and ensure that no air bubbles develop. With the help of two match sticks mount a cover glass in the following way :-

TABLE 3

Heavy minerals arranged in groups based
on mass magnetic susceptibility
(after Hess, 1959)

Handmagnet	Side Slope 20°			Side Slope 5°	
	Magnetic at 0.4 A	Magnetic at 0.8 A	Magnetic at 1.2 A	Magnetic at 1.2 A	Non- magnetic
magnetite	ilmenite	hornblende	diopside	titanite	zircon
	garnet	hypersthene	tremolite	apatite	rutile
	olivine	augite	enstatite	andalusite	anatase
	chromite	actinolite	spinel	monazite	brookite
	chloritoid	staurolite (light)	staurolite (dark)	xenotime	corundum
		epidote	muscovite		topaz
		biotite	zoisite		fluorite
		chlorite	clinozoi- site		kyanite
		tourmaline (dark)	tourmaline (light)		sillimanite
					beryl

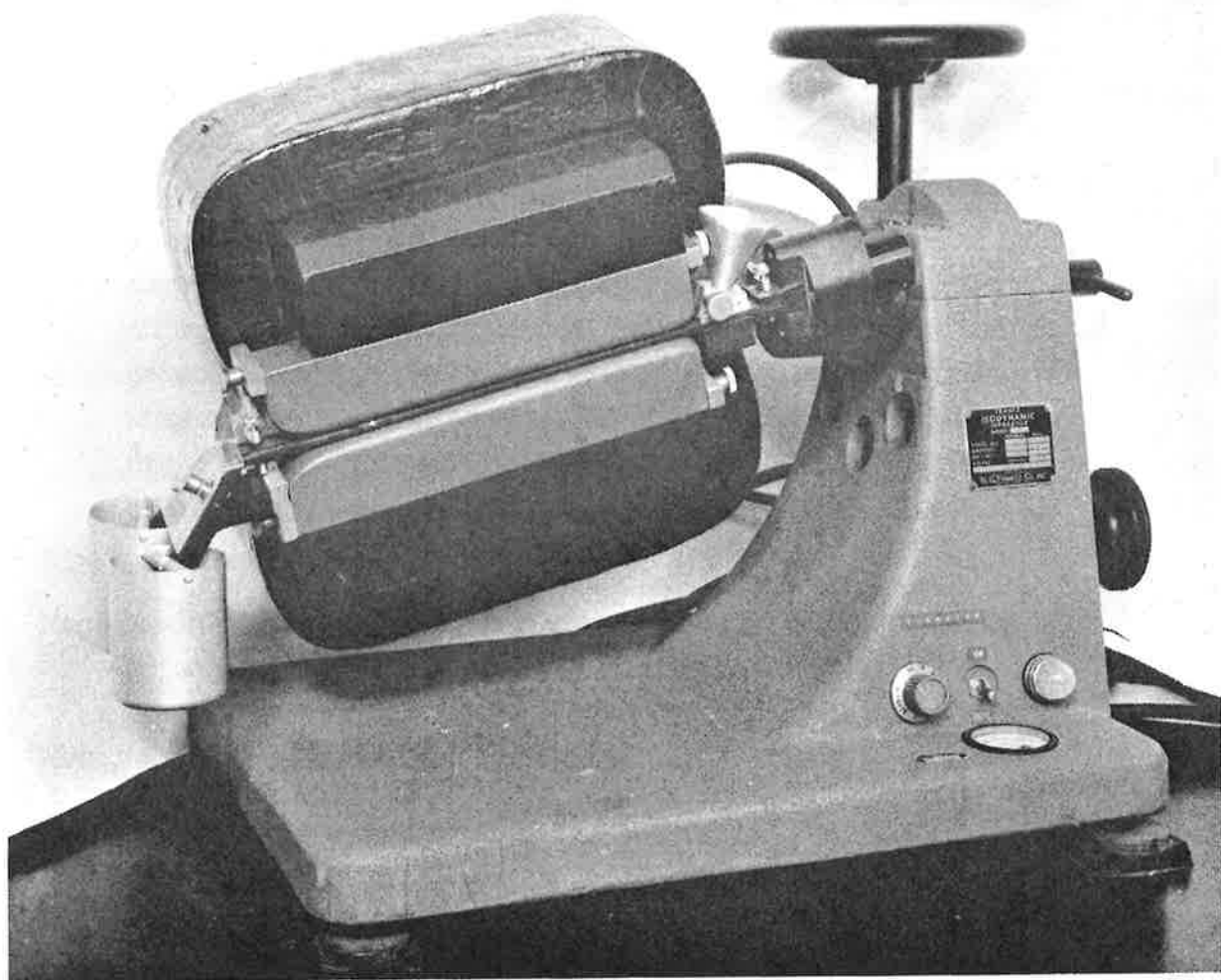


Fig. 9 FRANTZ Isodynamic Magnetic Separator.

Dip one match in canada balsam and stick the match to the cover glass. Now carefully bring the cover glass on the preparate supporting it on one side with another match. Gently let the cover glass drop down from one end (Fig. 10). Press the cover glass down firmly, put the slide aside and let it cool. After fifteen minutes the excessive balsam can be split off with a knife and the slide cleaned with xylene. Scratch the sample no. (and magnetic fraction) in the object glass with a diamond pencil.

E. Bromoform Recovery from Wash Fluid

If, after some time, the fluid turns brown and its density decreases below 2.89 shake it with charcoal (e. g. medicinal tablets) and then filter the suspension.

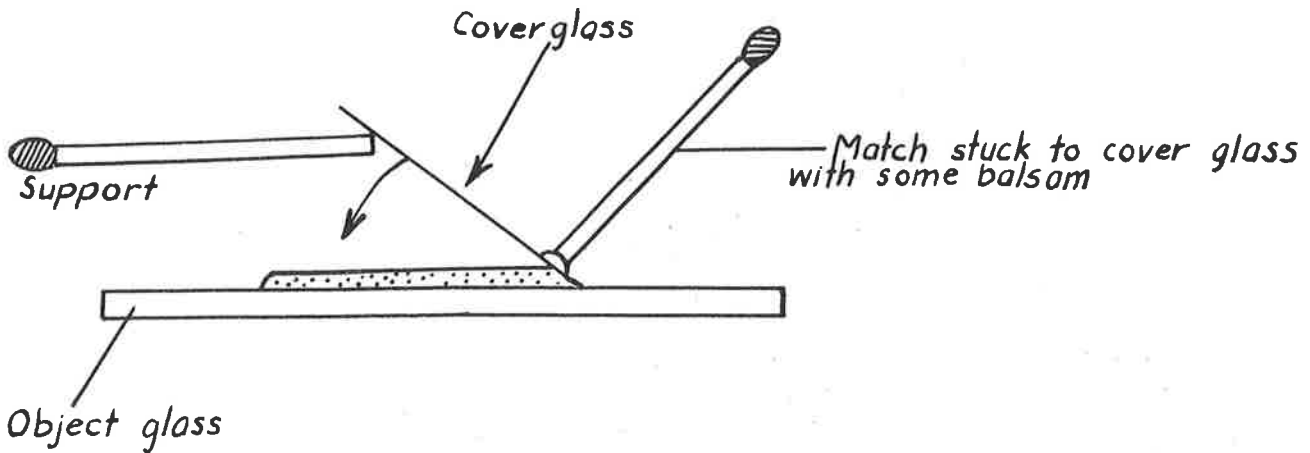


Fig. 10 Techniques for mounting mineral specimens for microscopic examination.

The bromoform can be recovered from the wash fluid as follows:-
 add to half a bottle of wash fluid the same amount of water and shake thoroughly. Leave the contents for a few hours. The bromoform will separate to the bottom, the alcohol-water mixture to the top. Now bring a glass tube attached to a water tap deep in the bottle and leave water percolating gently overnight. The water will remove all alcohol left in the bromoform. Carefully decant excess water and do the final separation in a 250 cc separation funnel. Filter the contents back into a bromoform bottle.

F. Identification of Heavy Minerals with the Polarizing Microscope

Tables 4 and 5 are only meant as an aid for rapid identification. The use of the petrographic microscope and a working knowledge of crystallography is assumed. Table 4 provides a means of identification of the most common heavy minerals based on the following optical properties:-

- a. Isotropism or anisotropism
- b. Extinction
- c. Colour and pleochroism
- d. Optic sign and optical character
- e. Elongation
- f. Birefringence

Table 5 is a check list with description of the optical characteristics of the various minerals. It is advisable to use this check list in combination with a handbook providing a more detailed description of the diagnostic properties such as Milner, H. B. (1962); Kerr, P. F. (1959); Tickell F. G. (1965); Winchell, A. M. (1951).

For every slide the ratio opaques and alterites versus transparent minerals should be estimated as well as the percentages of the various transparent minerals. In practice an identification of 100 minerals is needed to establish the ratio opaques, alterites/transparent minerals followed by a further identification of transparent minerals until the latter add up to 100. Identification should be carried out systematically by using a mechanical stage or point counter.

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TABLE 4

Identification of heavy minerals based on
their optic characteristics.

(modified after Tickell, 1965)

* Minerals partly or completely
dissolved in HCl.

	Extinction	Colour	Pleochroism	Interference	Optical Sign	Elongation	Mineral	Birefringence	2 V	
Isotropic							Garnet			
							Spinel			
							Diamond			
							Chlorite group			
Anisotropic	Straight	Colourless		1	+	+	Zircon	0.055-0.062		
						+	Cassiterite	0.097		
					-	+	Corundum	0.008-0.009		
						-	Apatite	* 0.003-0.005		
					-	Beryl	0.004-0.008			
					-	Vesuvianite	0.004-0.008			
					2	+	Brookite	0.158	0°-30°	
						+	Enstatite	0.008-0.009	54°-80°	
						+	Sillimanite	0.020-0.023	21°-30°	
						+	Zoisite	0.006-0.018	0°-60°	
	+	Monazite	* 0.049-0.051	6°-19°						
	-	Topaz	0.008-0.010	44°-66°						
		(Titanite)	0.092-0.141	23°-37°						
	+	Hypersthene	0.010-0.016	45°-90°						
	+	Epidote	0.014-0.045	65°-90°						
	-	Andalusite	0.007-0.011	83°-85°						
	-	Dumortierite	0.011-0.020	20°-40°						
	-	(Beryl)	0.004-0.008							
			Coloured	Non pleochroic	1	+	+	Rutile	0.287	
							+	Xenotime	0.095-0.107	
+							Zircon	0.055-0.062		
+							Cassiterite	0.097		
+							Anatase	0.061		
-						-	Apatite	* 0.003-0.005		
						-	Vesuvianite	0.004-0.008		
						-	(Beryl)	0.004-0.008		

	Extinction	Colour	Pleochroism	Interference	Optical Sign	Elongation	Mineral	Birefringence	2 V					
Anisotropic	Straight	Coloured	Non pleochroic	2	+		+	Barite	0.012	36°-38°				
							+	Brookite	0.158	0°-30°				
							+	Monazite	*	0.049-0.051	6°-19°			
							+	Sillimanite		0.020-0.023	21°-30°			
							+	Olivine	*	0.037-0.041	53°-90°			
							-	Topaz		0.008-0.010	44°-66°			
							+	(Olivine)	*	0.037-0.041	53°-90°			
							-	(Beryl)		0.004-0.008				
							1	+	+	Rutile		0.287		
								+	+	Anatase		0.061		
								+	+	Corundum		0.008-0.009		
								-	+	Apatite	*	0.003-0.005		
								-	+	Tourmaline		0.015-0.040		
								2	+	+	Brookite		0.158	0°-30°
									+	+	Enstatite		0.008-0.009	54°-80°
	+	+	Sillimanite		0.020-0.023	21°-30°								
	+	+	Staurolite		0.010-0.015	79°-90°								
	+	+	Anthophyllite		0.016-0.025	70°-90°								
	+	+	Olivine	*	0.037-0.041	53°-90°								
		+	(Titanite)		0.092-0.141	23°-37°								
	+	+	Hypersthene		0.010-0.016	45°-90°								
	+	+	Basaltic Hornblende		0.023-0.072	64°-80°								
	+	+	Glaucophane		0.013-0.018	0°-68°								
	-	+	+	(Olivine)	*	0.037-0.041	53°-90°							
		+	+	Epidote		0.014-0.045	65°-90°							
		-	+	Dumortierite		0.011-0.020	20°-40°							
		-	+	Andalusite		0.007-0.011	83°-85°							
		2	+	+	Monazite	*	0.049-0.051	6°-19°						
			+	+	Spodumene		0.013-0.027	54°-60°						
			+	+	Clinozoisite		0.005-0.011	65°-90°						
				+	Augite		0.043	58°-62°						
				+	Titanite		0.092-0.141	23°-37°						
			+	+	Kyanite		0.016	82°						
+	+		Muscovite		0.037-0.041	30°-40°								
+	+		Epidote		0.014-0.045	65°-90°								
+	+		Wollastonite		0.014	36°-42°								
	+		Axinite		0.010-0.012	70°-75°								

Anisotropic	Extinction	Colour	Pleochroism	Interference	Optical Sign	Elongation	Mineral	Birefringence	2 V
Anisotropic	Oblique	Coloured	Non pleochroic	2	+	+	Monazite	0.049-0.051	6°-19°
						-	Clinochlore	0.004-0.011	0°-50°
							Diopside	0.029-0.031	56°-61°
							Augite	0.043	58°-62°
							Titanite	0.092-0.141	23°-37°
						+	Tremolite-Actinolite	0.022-0.027	79°-82°
							Kyanite	0.016	82°
					-	+	Epidote	0.014-0.045	65°-90°
						-	Clinochlore	0.004-0.011	0°-50°
						+	Monazite *	0.049-0.051	6°-19°
						+	Spodumene	0.013-0.027	54°-60°
						-	Riebeckite	0.004	80°-90°
						-	Clinochlore	0.004-0.011	0°-50°
						-	Chloritoid	0.011-0.016	36°-63°
			Pleochroic	2	+		Augite	0.043	58°-62°
							Titanite	0.092-0.141	23°-37°
						+	Hornblende	0.019-0.026	52°-85°
						+	Basaltic Hornblende	0.023-0.072	64°-80°
						+	Glauconite *	0.020-0.032	16°-30°
						+	Kyanite	0.016	82°
						+	Tremolite-Actinolite	0.022-0.027	79°-82°
					-	+	Glaucophane	0.013-0.018	0°-68
						+	Epidote	0.014-0.045	65°-90°
						-	Riebeckite	0.004-0.006	80°-90°
						-	Aegirine-Augite	0.029-0.037	60°-81°

TABLE 5

Description of Determinative Optical Characteristics of
the Most Common Heavy Minerals

Mineral	Colour	Pleochroism	Relief	Δ	Extinction	Opt. sign and axial angle	Elonga- tion	Remarks
Alterite	Dirty, grey brown	Absent						Often well rounded dirty grains. Alteration products of minerals (e. g. Epidote). Some- times on the edges the original mineral visible.
Aegirine- Augite	Green - greenish black (opaque)	Moderate, yellow- green - greenish	Very high $n = +1.75$	Strong 0.029- 0.037	Oblique 15°-38°	2 + 2 - 60°-81°	Fast -	Resembles aegirine but is distinguished by larger extinction angle. Most easily distinguish- ed from hornblende by pyroxene cross sections and cleavage.
Anatase	Yellow, brown, colourless, blue (trans- parent- opaque)	Absent, except in very thick grains pale blue or yellow, dark blue or orange	Extremely high $n = +2.5$	Strong 0.061	Straight	1 -	Slow +	Basal sections:isotropic. Idiomorphic rounded form. Often dirty grains with clear, straight edged rims, sometimes stria- tions. Dark coloured grains almost metallic- opaque:sometimes ano- malous bi-axial.

Mineral	Colour	Pleochroism	Relief	Δ	Extinction	Opt. sign and axial angle	Elongation	Remarks
Andalusite	<u>Colourless</u> , pale hues of red, green brown, violet	<u>Strong</u> (often absent); colourless (greenish), pink or blood-red	High $n = +1.64$	Weak 0.007- 0.011	Straight	2 - 83°-85°	Fast -	Mostly transparent. Irregular form. Axial figure seldom observed. Different from topaz by optical sign and pleochroism and also by inclusions of graphite or carbonaceous material, furthermore often alterations which make the grains dirty.
Apatite	<u>White</u> , colourless sometimes greenish	<u>Absent</u> , weak in some coloured var. red	High $n = +1.63$	Weak 0.003- 0.005	Straight	1 -	Fast -	Transparent, often small grains, Habit: rounded elongated prisms or egg-shaped. Solution features because of HCl treatment. (Mostly not present).
Augite	Transparent bottle green (silver beet colour) yellow green, dark green brown, violet	<u>Absent</u> or weak (with violet or red)	Very high $n = +1.72$	Strong 0.043	Oblique ± 45	2 + 58°-62°		Rounded prismatic or irregular fragments with coarse ragged teeth (in the last case a good axial figure is usually obtainable. Dispersion $r > v$
Basaltic Hornblende, Lamprobolite Basaltine Oxyhornblende	<u>Brown</u> , brownish black, olive green	Moderate, dark olive green or brown, dark brown pale yellow	High $n = +1.68$	Moderate to strong 0.023- 0.072 own colour often dominant	Straight to oblique 0°-12°	2 - 64°-80°	Slow +	Inclusions more common than in hornblende. Often elongate large grains.

Mineral	Colour	Pleochroism	Relief	Δ	Extinction	Opt. sign and axial angle	Elongation	Remarks
Brookite	Brown and yellow	Sometimes, light yellow brown - dark (red) brown	Extremely high $n = \pm 2.6$	Very strong 0.158	Sometimes straight (often no extinction)	2 + $0^\circ - 30^\circ$	Slow +	Anomalous optical properties. Prismatic form, striation parallel, "dirty" through inclusions.
Chloritoid	<u>Olive green-</u> blue, grey yellow	Weak-strong; olive green, indigo-blue yellow green	High $n = \pm 1.72$	Moderate-weak 0.011-0.016	Straight to oblique $0^\circ - 20^\circ$	2 + $36^\circ - 63^\circ$	Fast -	Mostly rounded, flaky grains (cleavage // 001 perfect). Good axial figure. Dispersion $r > v$
Clinzoisite	Colourless, yellow, pale green, red brown	<u>Absent -</u> weak green, pink, red	High $n = \pm 1.72$	Weak 0.005-0.011	Oblique $2^\circ - 12^\circ$	2 + $65^\circ - 90^\circ$	Slow + Fast -	Differs from zoisite in its oblique extinction and larger optical angle. "Ultra blue" anomalous birefringence colours occasionally exhibited.
Diopside	<u>Colourless,</u> pale green white, grey	<u>Absent</u>	High $n = \pm 1.67$	Strong 0.029-0.031	Oblique $38^\circ - 45^\circ$	2 + $56^\circ - 63^\circ$		In contrast to kyanite, Diopside shows often good cleavage and fracture patterns.
Enstatite	<u>Colourless,</u> yellow, green	Moderate, increasing with higher Fe content yellow brown-green	High $n = \pm 1.65$	Weak 0.008-0.009	Straight	2 + $54^\circ - 80^\circ$	Slow +	Irregular, prismatic grains. "Dirty" colour often characteristic (Bronzite:intermediate in optical properties between Enstatite and Hypersthene)

Mineral	Colour	Pleochroism	Relief	Δ	Extinction	Opt. sign and axial angle	Elongation	Remarks
Epidote	<u>Colourless</u> , lemon, <u>yellow</u> , dark-green, hues of brown, grey	<u>Weak or absent</u> colourless, yellow green	High $n = \pm 1.74$	Moderate-strong 0.014-0.045	Straight-oblique 0°-5°	2 - 65°-90°	Some + Some -	Irregular (equidimensional ?) angular grain. Clear to dirty. Characteristic bright colours (green, violet red rings on the edges). Strong dispersion $r > v$
Garnet	Colourless, pink, red, yellow-brown, green	Isotropic	High - very high $n = \pm 1.7-2.0$					Irregular form, high relief. No cleavages.
Glauco-phane	<u>Colourless-blue</u>	Moderate-strong blue, violet, colourless yellow	High $n = \pm 1.63$	Moderate 0.013-0.018	Oblique 4°-6°	2 - 0°-68°	Slow +	Pleochroic, often oblate grains characteristic. Inclusions common.
Hornblende	<u>Green-brown</u> transparent	Moderate - weak yellow, straw yellow pale green brown or dark green	High $n = \pm 1.66$	Moderate 0.019-0.026	Oblique 12-30° (sometimes straight)	2 - 52°-85°	Slow +	Prismatic cleavage parallel length or crossing at 124°, sometimes solution marks. Inclusions uncommon.
Hypersthene	<u>Yellow-brown</u> , green, pink (transparent)	<u>Weak-moderate</u> (in ferriferous varieties) yellow green, pink or red yellow. (traffic-light)	High $n = \pm 1.7$	Moderate 0.010-0.016	Straight	2 - 45°-90°	Slow +	Normally ragged, prismatic form. Often small inclusions (Schiller structure)

Mineral	Colour	Pleochroism	Relief	Δ	Extinction	Opt. sign and axial angle	Elongation	Remarks
Kyanite	<u>Colourless</u>	<u>Absent</u> , weak in dark coloured grains, colourless, violet-blue, cobalt-blue	High $n = \pm 1.72$	Moderate 0.016	Oblique max. 32° ($0^\circ-32^\circ$)	2 - 82°	(Slow +)	Mostly angular prismatic grains with sometimes cleavage parallel the length.
Olivine	<u>Colourless</u> , light, yellow green	<u>Absent</u>	High $n = \pm 1.67$	Strong 0.037- 0.041	Straight	2 + $53^\circ-90^\circ$	Slow +	Often irregular formed, broken grains. Solution marks.
Rutile	Red brown golden-yellow yellow, red	Weak, darkest colour // length of x, red brown, brown/yellow	Very high $n = \pm 2.8$	Extreme 0.287	Straight	1 +	Slow +	Often well formed prismatic grains or also broken grains. Sometimes characteristic oblique striation.
Sillimanite	<u>Colourless</u> , yellow pale hues of brown, green, grey	Moderate or absent pale brown-yellow brown or green <u>dark brown</u> or <u>blue</u>	High $n = \pm 1.66$	Moderate 0.020- 0.023	Straight	2 + $21^\circ-30^\circ$	Slow +	Mostly elongated prisms or fibres with distinct, sometimes irregular cleavage parallel the length. If equidimensional grain: low interference colours and cleavage less obvious.
Staurolite	Straw yellow orange yellow, brown, red-brown	<u>weak</u> , colourless pale yellow, yellow reddish yellow-brown	High $n = \pm 1.74$	Moderate 0.010- 0.015	Straight	2 + $79^\circ-90^\circ$	Slow +	Irregular form, determined by cleavage, haphazard boundaries. In a few cases perfect euhedra are seen. Inclusions common especially in dark varieties.

Mineral	Colour	Pleochroism	Relief	Δ	Extinction	Opt. sign and axial angle	Elongation	Remarks
Titanite (Sphene)	<u>Brown, yellow-</u> brown, orange, yellow-green, olive green	Absent, sometimes weak in strongly coloured varieties. Yellow or colourless, greenish pink or brownish yellow, pink or pale yellow.	Very high $n = +1.91$	Very strong 0.092- 0.141	Oblique, total extinction seldom observed	2 + 23°-37°		Mostly, small irregular angular grains, sometimes dirty. Dispersion strong $r > v$ <u>Ultra blue</u> - Yellow and red polarization colours.
Topaz	<u>Colourless</u> yellow, blue, red, green	<u>Absent</u> apart from some thick grains brownish-yellow, yellowish pink, violet pink	High $n = +1.62$	Weak 0.008- 0.010 (0.003)	Straight	2 + 44°-66°	Fast -	Irregular glassy grain. To distinguish from Andulalite by absence of pleochroism, optical sign and transparency.
Tourmaline	<u>Yellow-</u> brown, pink, yellow, orange, green blue, grey	<u>Very strong</u> (brown var.) - weak (blue var.). green, yellow brown, blue or black, yellow violet or colourless	High $n = +1.65$	Strong 0.015- 0.040	Straight	1 -	Fast -	Mostly well rounded, no alterations, no fracturing or cleavage. Good axial figure only in grains without pleochroism.
Tremolite-Actinolite	<u>Colourless-</u> pale green	<u>Absent</u> - weak (in green varieties)	High $n = +1.67$	Moderate-strong 0.022- 0.027	Oblique 10°-20°	2 - 79°-82°	Slow +	Amphibole character, fibrous, ragged ends. Frequently alteration to chloritic matter. Inclusions of iron ore and carbonaceous matter.

Mineral	Colour	Pleochroism	Relief	Δ	Extinction	Opt. sign and axial angle	Elongation	Remarks
Vesuvianite (Idocrase)	<u>Brown, green-brown, red, green, pale-blue, yellow</u>	Moderate or absent, variable, yellow green-colourless; yellow brown-brownish-grey; dark blue-colourless; red-colourless or grey	High $n = \pm 1.71$	Weak 0.004- 0.008	Straight	1 - often anomalous 2 + 17°-33°	Fast -	Prismatic, clear grains, characterised by colour and low birefringence.
Xenotime	<u>Pale yellow - brown, yellow, orange, pink</u>	Moderate, yellow, green; pale yellow	Very high $n = \pm 1.75$	Strong 0.095- 0.107	Straight	1 +	Slow +	Normally idiomorphic grains. A strong resemblance to coloured zircon, however less often inclusions.
Zircon	<u>Colourless or pale hues of yellow, brown pink etc.</u>	In thick grains and strongly coloured varieties	Very high $n = 1.95$	Strong 0.55- 0.62	Straight	1 +	Slow +	Clear, mostly small grains; prismatic with pyramidal terminations. Idiomorphic mostly showing a certain degree of rounding. Sometimes zoning. Inclusions common.
Zoisite	<u>Colourless grey</u>	<u>Absent, sometimes moderate</u>	High $n = \pm 1.70$	Weak-moderate 0.006- 0.018	Straight, sometimes no extinction	2 + 0°-66°	Slow +	Prismatic. Often green rod-like (amphibole) inclusions. Var. thulite (pink-red pleochr.) resembles andalusite. Pol. col. deep blue ("ultra blue") characteristic.