THESIS

by

JOSEPH B. ALEXANDER

(Geological Survey of Malaya)

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HEAVY MINERALS OF CERTAIN QUARTZITES FROM MALAYA:

A STUDY IN DIFFERENTIATION AND CORRELATION

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Joseph B. Alexander,

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ABSTRACT

This paper has a three-fold aim.

Firstly, it demonstrates the practicability of a mechanical method alternative to panning for the preliminary concentration, prior to final bromoform separation, of arenaceous materials carrying only very small percentages of heavy mineral residues. This method utilizes the laboratory Wilfley concentrating-table and the Haultain superpanner, with crushed calcite stained green by basic cupric nitrate for visual control to ensure reasonable recovery.

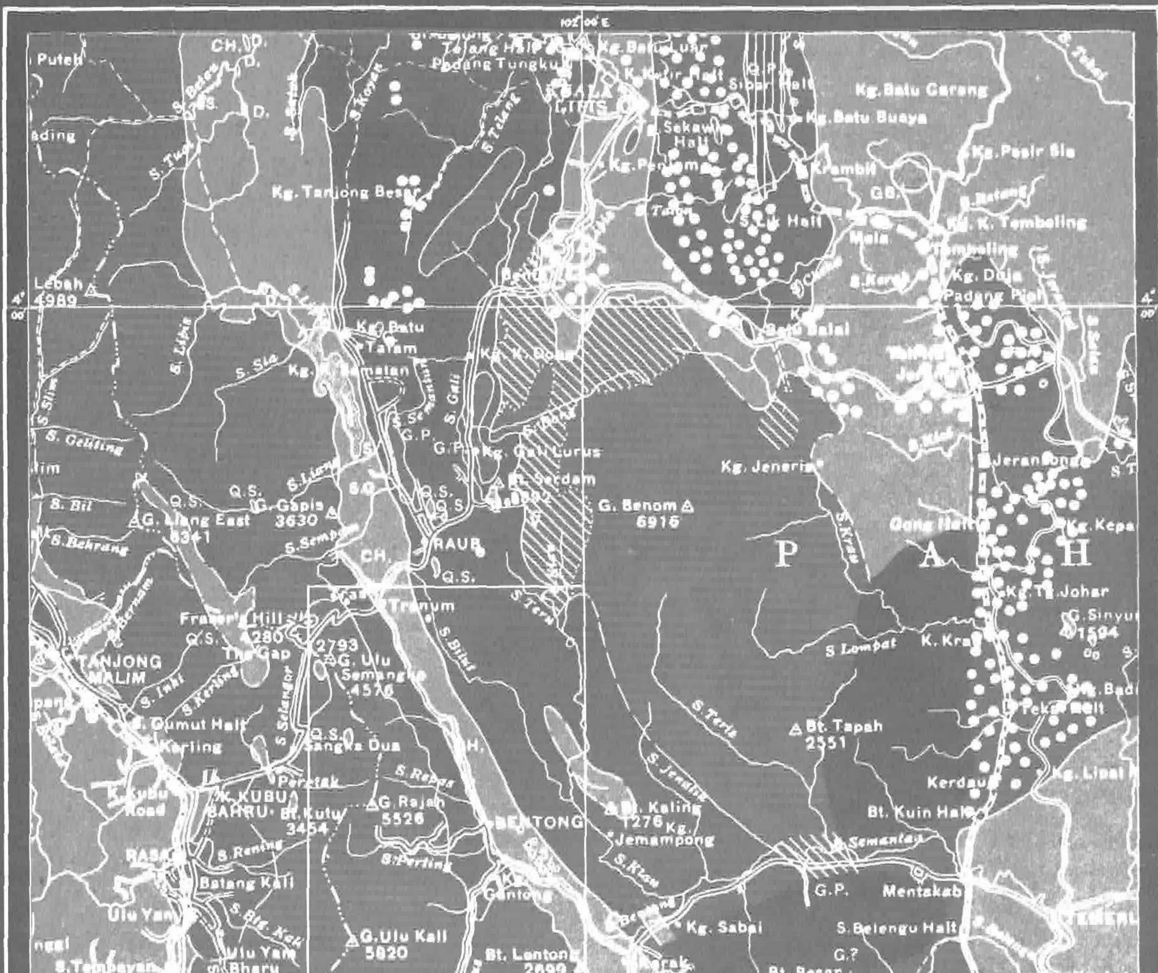
Secondly, it serves to present some fresh ideas for the computation of comparative indices and for the illustrative graphical representation of statistical data. Empirical colour ratios and roundness ratios are calculated, in addition to volume frequency ratios of tourmaline, rutile, and zircon, for each grade size of concentrate obtained, and corresponding coefficients are derived for each sample over a common range of grade sizes.

Thirdly, it records the results obtained in conjunction with an optical examination of the heavy minerals separated from various quartzites occurring in certain areas of Malaya. The diagnostic feature of the data determined by this preliminary investigation indicate the possibilities of utilizing heavy mineral characteristics, as an alternative to fossil evidence, for the differentiation or correlation of these quartzites.

I N T R O D U C T I O N

A preliminary investigation has been made into the possibilities of differentiating, or correlating, lithologically similar quartzites occurring in Malaya. Some of these quartzites, in certain localities, have been found by fossil evidence to be of Triassic age. Others, although believed to be of Carboniferous age on structural grounds

Fig. 1. – GEOLOGICAL MAP of PART of MALAYA



Quartzite and Shale	Q.S.	*The shale has been altered to schist or phyllite. In the weathered zone, quartzite and schist have been reduced to sandstone and a laminated rock resembling shale. Some rocks mapped as Trias, including the foothills of Main Range in Pahang may be Carboniferous.*

(Annual Report Geological Survey Malaya, 1940) by the writer, and independently by some of his co-workers, are still unproven because the palaeontological approach has been consistently unsuccessful. In the absence of suitable fossil evidence, therefore, no distinction between the definitely proved Triassic beds and the other quartzites has hitherto been possible. The present thesis was developed in order to see whether or not the optical examination of their heavy mineral residues would yield any diagnostic information.

In greater detail it may be stated briefly that the primary objects of this investigation were to find out whether or not:

(1) any significant features are consistently displayed by the heavy minerals contents of,
  (a) the Triassic fossiliferous quartzites;
  (b) the quartzites of unknown age;

(2) any characteristics so displayed would be sufficiently striking to enable the various quartzite series to be differentiated from, or correlated with, each other, and so serve as a reliable age guide.

F I E L D W O R K

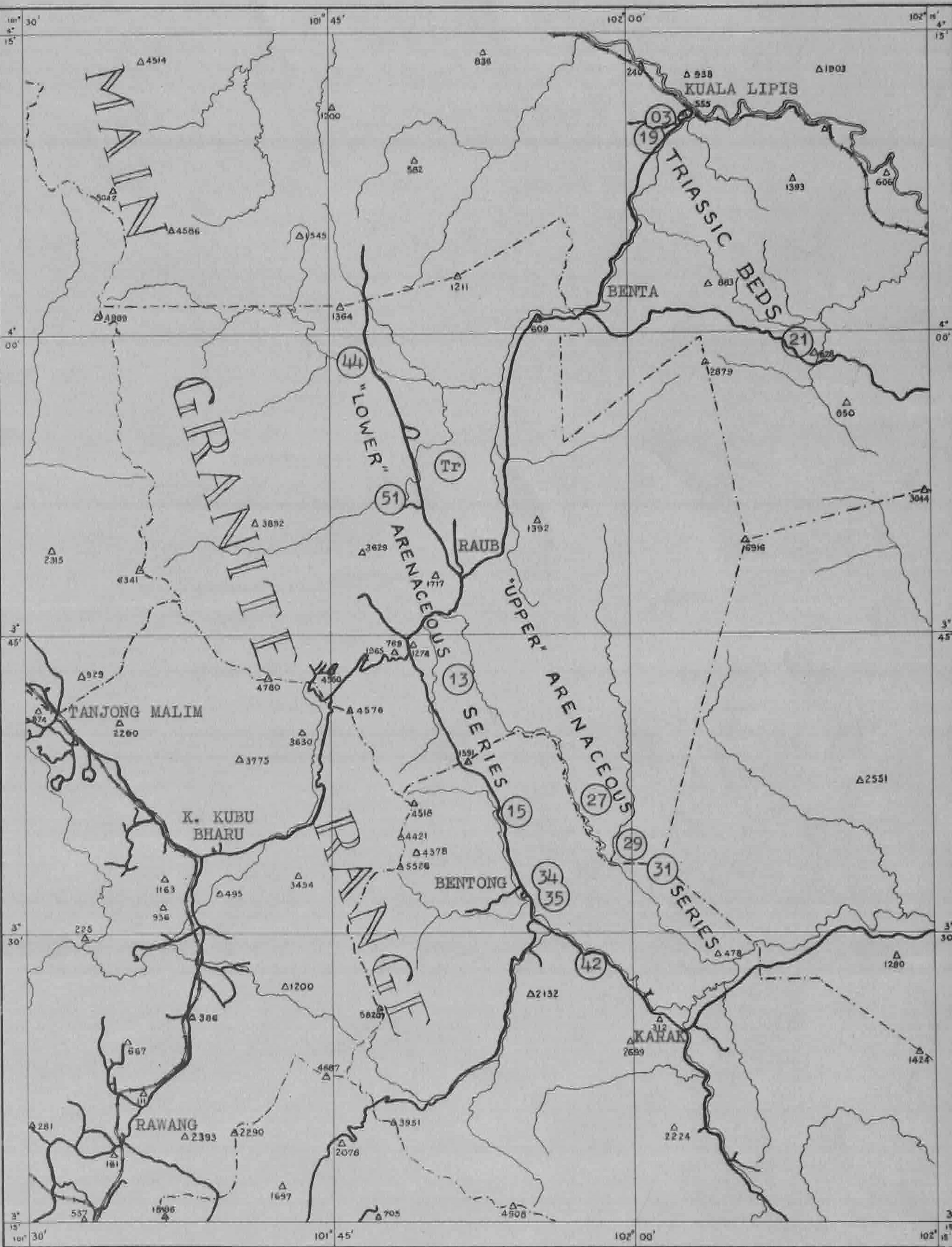
GENERAL MAPPING.

Detailed routine field mapping was carried out east of the Main Range of Malaya, in the southwestern portion of the State of Pahang covered by topographic quadrangle sheets 3 B/8 and 3 B/12. This area is bounded by lines of latitude 3° 15' and 3° 45' north, and between lines of longitude 101° 45' and 102° 00' east. It was geologically surveyed by the writer during 1939-41, this work being interrupted by the Japanese occupation when most of the records were lost, but was resumed in 1946-47, and was completed in 1948-49. Progress reports on the area (Alexander, 1940, 1947-49) have been published in the Annual Reports of the Geological Survey of Malaya, and a complete account of the Bentong neighbourhood is now in the process of final preparation by the writer. The quadrangle lying immediately to the north, covering the neighbourhood of Raub, has been described in a separate memoir (Richardson, 1939), while yet another memoir is being prepared by H. Service on the Lipis neighbourhood, which lies to the northeast. The relative positions and general geology surrounding all these localities are indicated on figure 1, which represents a portion of the 1948 Geological Map of Malaya.

GEOLOGICAL SETTING.

Eastern foothills, flanking the Main Range granite backbone of Malaya, trend north-northwest to south-southeast and are composed of a series of variably metamorphosed sediments predominantly arenaceous in character, but with argillaceous bands and lenticular rudaceous developments. These rocks comprise a great variety of pebbly types, quartzite-conglomerates, grits, quartzites, sandstones, sandy phyllites, sandy shales, schists, and some intercalated cherts. They have been referred to in previous publications (Richardson, 1946) as the "Arenaceous Formation of the Main Range foothills" more simply as the "Foothills Formation", but the writer prefers

FIGURE 2 - INDEX PLAN SHOWING LOCALITIES FROM WHICH QUARTZITES SAMPLES WERE COLLECTED.



SCALE: 1 Inch to 8 Miles.

Miles 5 4 3 2 1 0 5 10 15 20 25 Miles

the term "Lower" or "Older Arenaceous Series". These are believed, on structural grounds alone, to be the oldest rocks occurring in the area and of Carboniferous age.

Abruptly to the east of the foothills lies a broad bordering lowland belt of calcareo-argillaceous sediments referred to as the "Calcareous Formation" or, more recently, as the "Calcareous Series". These comprise phyllites, shales, calcareous mudstones, and limestones and are considered, on account of evidence in the Raub area and elsewhere along the general strike, to be of late Carboniferous or Permian age. In turn these strata are succeeded still further to the east by an infolded series of mixed argillaceous and arenaceous rocks lithologically similar to those exposed in the foothills. In the Kuala Lipis area these rocks are known to be of Triassic age on palaeontological evidence, but their occurrence is separated from other arenaceous strata found in the Bentong area where no fossils have been discovered. Pending further evidence, therefore, the latter have been referred to provisionally as the "Upper" or "Younger Arenaceous Series" of the Bentong area.

Contemporaneous pyroclastic rocks and lavas of the Pahang Volcanic Series (Willbourn, 1917), principally rhyolite tuffs, are abundantly interstratified in the later part of the Carboniferous-Permian sequence and in the Triassic rocks, also in the "Upper" arenaceous series, but are a comparative rarity within the "Lower" arenaceous sequence. The close of the Triassic or ensuing Rhaetic period appears to mark the cessation of sedimentation and the commencement of a prolonged phase of terrestial conditions.

Although the Arenaceous Formation of the Main Range foothills has hitherto been mapped as of Triassic age, it had only been left as such on account of the absence of palaeontological evidence to prove it otherwise. No fossils have been found anywhere in these rocks and consequently its age is not known. This had only been inferred previously on lithological grounds because both the foothills and the Triassic beds are predominantly arenaceous.

STRUCTURAL RELATIONS.

Structurally, with a general strike parallel to the Main Range granite, the foothills strata display dips which are very variable, and although they may locally be steeply west or vertical over a considerable width of outcrop, they are more commonly found inclined steeply towards the east with an average dip of 70°-80°. Along its eastern margin, therefore, this "Lower" arenaceous series thus dips below the calcareo-argillaceous sequence of late Carboniferous or Permian aged rocks lying to the east. This fact has been commented upon by early workers (Scrivenor, 1911, 1931), but as these arenaceous rocks had been ascribed elsewhere to the Triassic on lithological grounds, so it has hitherto been assumed, as a natural corollary, that the normal stratified succession has been inverted along the eastern flank of the Main Range. There is little evidence to substantiate this assumption. In fact the careful study of the minor flexures, folds, and contortions, locally acute, often isoclinal, and commonly steeply inclined eastwards, has tended to the conclusion that the succession is not otherwise than normal, although it is possible that a degree of unconformity or disconformity may exist between the two series.

TABLE 1.

DETAILS OF QUARTZITES SAMPLES FROM PAHANG

FORMATION	DISTRICT	TOPO REF:	LOCALITY	SAMPLE NUMBER	TYPE OF SAMPLE	DESCRIPTIVE REMARKS
TRIASSIC	Lipis.	2 0/13	K.Lipis-Benta road, near milestone 3.	03	selected typical;	fossiliferous, medium-grain, light iron-stain.
TRIASSIC	Lipis.	2 0/13	K.Lipis-Benta road, near milestone 3-1/2.	19	local average;	fossiliferous, medium-grain, light iron-stain.
TRIASSIC	Lipis.	3 C/1	Benta-Kuantan road, near milestone 33-1/2.	21	local average;	fossiliferous, argillaceous, light iron-stain.
"UPPER"	Bentong.	3 B/ 8	Bukit Bajang.	27	local average;	medium-grain, light iron-stain.
"UPPER"	Bentong.	3 B/ 8	Lakum Forest Reserve.	29	local average;	medium-grain, carbonaceous.
"UPPER"	Bentong.	3 C/ 5	Bukit Kaling.	31	local average;	medium-grain, carbonaceous.
"LOWER"	Raub.	3 B/ 4	Sungei Lipis, near Batu Malim.	44	local average;	medium-grain, light iron-stain.
"LOWER"	Raub.	3 B/ 4	Sungei Mas Estate.	51	local average;	medium-grain, light iron-stain.
"LOWER"	Raub.	3 B/ 8	North of Bukit Jinjong.	13	areal composite;	medium-grain, light iron-stain.
"LOWER"	Bentong.	3 B/ 8	South of Bukit Jinjong.	15	areal composite;	medium-grain, light iron-stain.
"LOWER"	Bentong.	3 B/ 8	Bukit Raka.	34	local average;	gritty, light iron-stain.
"LOWER"	Bentong.	3 B/ 8	Bukit Raka.	35	local average;	medium-grain, light iron-stain.
"LOWER"	Bentong.	3 B/12	Bentong-Karak road, near milestone 72.	42	selected typical;	gritty, light iron-stain.

TABLE 2.

COMPLETE MECHANICAL ANALYSIS OF SAMPLES

SAMPLE NUMBER	+ 35 mesh	+ 45 mesh	+ 60 mesh	+ 80 mesh	+120 mesh	+170 mesh	+230 mesh	-230 mesh	TOTAL %
03	31.2	14.9	12.6	10.9	12.9	5.6	4.8	6.9	99.8
19	3.4	10.9	11.5	11.5	17.8	11.7	21.8	11.5	100.1
21	17.9	11.3	8.8	7.9	13.1	8.0	16.3	16.4	99.7
Average	17.5	12.4	11.0	10.1	14.6	8.4	14.3	11.6	99.9
27	6.0	23.6	20.2	12.0	11.2	4.6	4.2	18.2	100.0
29	27.9	20.4	11.1	8.2	9.3	4.7	8.5	10.0	100.1
31	24.6	19.4	12.4	7.6	8.7	4.9	5.2	17.2	100.0
Average	19.5	21.1	14.6	9.3	9.7	4.7	6.0	15.1	100.0
44	9.0	10.3	13.1	13.6	18.2	10.9	16.1	8.7	99.9
51	2.0	11.5	19.0	13.6	16.3	9.4	15.1	12.8	99.7
13	4.9	14.9	17.9	16.0	17.3	9.2	7.8	11.8	99.8
Average	5.3	12.2	16.7	14.4	17.3	9.8	13.0	11.1	99.8
15	6.9	12.6	16.5	14.3	16.4	8.8	11.1	13.7	100.3
34	0.3	6.9	17.9	19.1	22.7	11.3	12.0	9.6	99.8
35	17.1	17.4	15.6	12.4	14.3	7.1	5.7	10.6	100.2
42	1.8	13.7	18.2	14.2	14.9	9.6	17.5	10.1	100.0
Average	5.8	12.8	17.1	14.7	16.6	9.2	12.5	11.3	100.0

SEDIMENTOLOGICAL SAMPLING.

The various types of samples collected for this study all reveal the average characteristics of the selected occurrences. It was neither desired nor possible to deal with a single sedimentation unit, defined (Otto, 1938) as that thickness of sediment which was deposited under essentially constant physical conditions. Insufficient exposures were available to trace such a unit in the first place, but even had this been possible it would not have served to test, satisfactorily, the general heavy mineral distribution of the series, and so provide data on the average load deposited under varying conditions at any one point over a wide range of time.

Localities selected for sampling were chosen where intrusive veins of igneous material were absent and, as far as possible, badly limonitized material was avoided. Unfortunately the severe weathering of the quartzites in these tropical regions has resulted in severe iron-staining. The sandy rocks formed from the unweathered greyish quartzites are sometimes bleached to a light buff colour, but are commonly rusty purplish-brown or deep reddish-purple with iron oxides. The more lightly stained softened material, which was used wherever possible, was found to be most suitable from the view of successful disaggregation with the least possible damage to heavy mineral constituents. Even the hard, tough, relatively unweathered quartzite, however, could be treated with reasonable success.

Where possible in any one locality a channel sample was taken through the greatest thickness of strata exposed, in no case more than 10 feet, and has been termed a "local average" sample. When this was not possible, as with many cases of inadequate exposures, fragments of moderate size were taken from a minimum of four different portions of the same exposure to form a "selected typical sample. A mixed group of such samples of the latter type, collected during the course of routine mapping over a large area of the same formation series, provided a compound sample designated as "areal composite". All these varieties of samples are in contrast to those of the successive hand-specimen type used for certain statistical methods (Smithson, 1939).

Particulars of the samples collected from the different areas mentioned are given in table 1 and their relative positions are shown in figure 2. Originally 37 samples of fine-, medium-, and course-grained quartzites had been accumulated, but in view of the preliminary nature of the investigation and the time involved in crushing and separation, only 13 of the medium-grained quartzites were finally selected for detailed examinations. One of the selected quartzites was used for pilot tests when working out the separation process, while the remaining 12 were chosen in batches of three to represent:-

(a) those fossiliferous localities in the Triassic quartzite sequence of the Kuala Lipis area (samples numbered 03, 19, 21);
(b) those non-fossiliferous localities in the "Upper" quartzite series of the Bentong area believed on structural grounds to be correlative with the Triassic quartzites (samples numbered 27, 29, 31);
(c) those non-fossiliferous localities in the "Lower" (foothills) quartzite series of the Raub area, believed on structural grounds to be of a different age, possibly as old as Middle or Lower Carboniferous (samples numbered 44, 51, 13);

(d) those non-fossiliferous localities in the "Lower" (foothills) quartzite series of the Bentong area, known to occur along the same strike and to be the same formation as the Raub quartzites (samples numbered 15, 34, 35, 42).

Possible sampling errors which may have occurred fall into two categories, those due to the size of the sample, and those due to local variations in the formation. In determining the size of the samples for the coarser-grained gritty materials with pebbles, the empirical rule (Wentworth, 1926) was adopted which required that a sample be large enough to include several fragments of the largest sizes present. From probability considerations the number of such fragments should be at least four in number. No difficulty was experienced with the medium- and finer-grained quartzites, and nominal amounts, averaging 2 to 4 kilograms (5 to 9 pounds) weight, were usually obtained.

It is not possible to entirely eliminate errors due to variations in the deposit. These are much more difficult of correction, but were reduced as far as practicable with local variations by taking samples of the types described. A minimum of four discrete samples combined into a single composite from each locality is probably the most satisfactory type. Only by investigating a sufficiently large number of such samples gathered from widely scattered portions of the same formation, however, will it be reasonably safe to assume the validity of any consistent results obtained.

L A B O R A T O R Y   T E C H N I Q U E

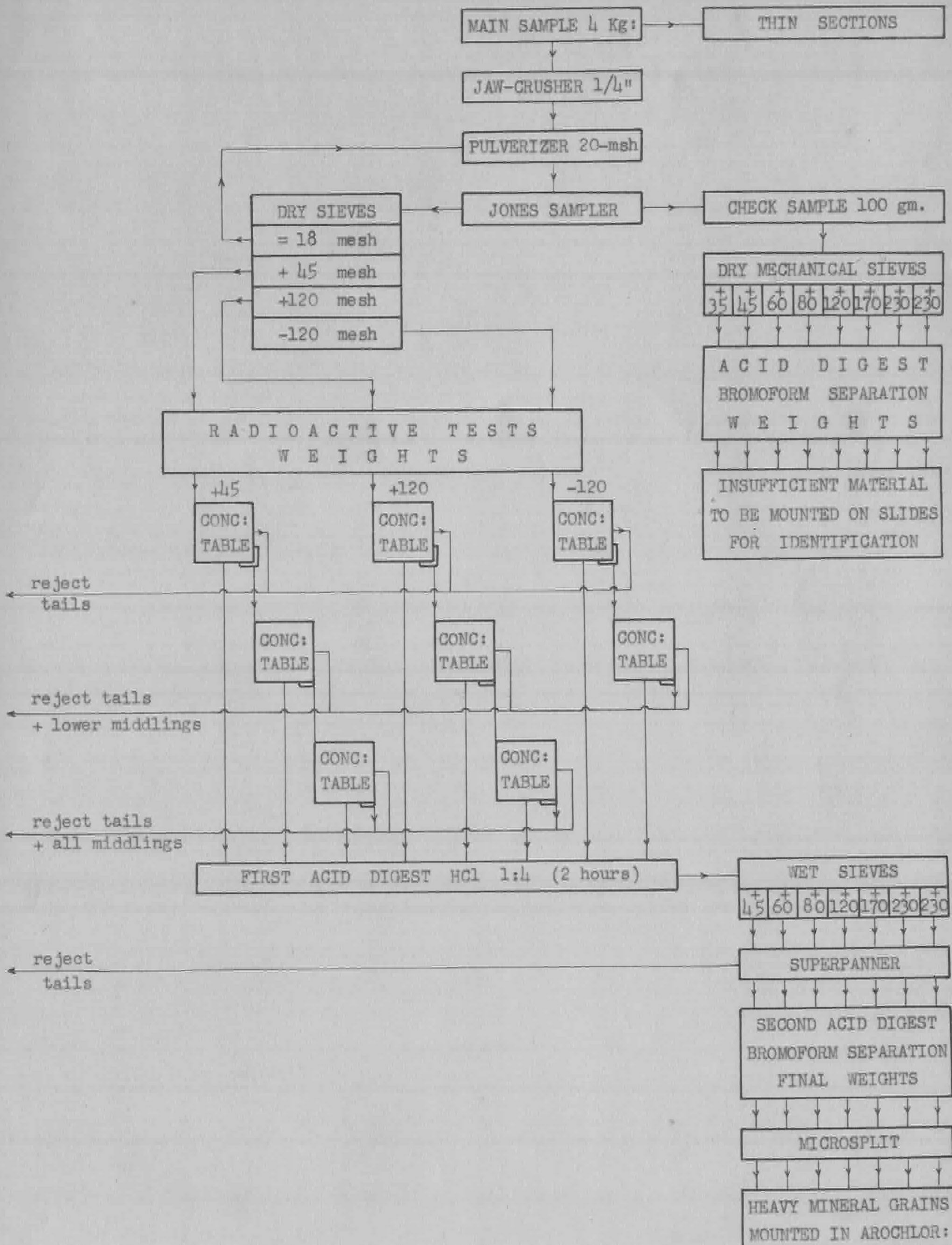
Krumbein and Pettijohn (1938) stress the primary importance of not employing, without an evaluation of the errors introduced, any methods which alter or destroy any of the data to be obtained in subsequent analysis. Since the preparation of the samples involves distinct steps of disaggregation, sizing, concentration, and mounting, appropriate precautions must be taken at each stage. The process sequence finally adopted is shown in the operations flowsheet depicted by figure 3.

DISAGGREGATION AND SIZING.

Since the quartzitic materials sampled have a fairly high degree of induration compared with sandstones which are usually more loosely consolidated, so has the likelihood increased that some of their characteristics may be modified by any disaggregation process. Such coherent material is unaffected by weak acid, which is only useful in this case for removing iron-stains and clarifying the grains prior to optical examination. The choice of partially weathered material for sampling has tended to reduce this effect to a practical minimum, but it was realized that, as a consequence, only the ultra-stable allogenic heavy minerals could then be relied upon for diagnostic purposes. Authigenic heavy minerals such as limonite, leucoxene, and possibly anatase, might be present in disproportionate amounts in such material, but the statistical comparision of mineral frequency counts is not considered to have been seriously affected for allogenic minerals such as tourmaline,

FIGURE 3.

OPERATIONAL FLOWSHEET FOR SEPARATION OF HEAVY MINERALS



rutile, and zircon, on which the conclusions ultimately derived have been based.

A small piece was cut from one of the fragments from each sample and reserved for preparation of thin sections. Disaggregation of the remaining portion of each sample in turn was then effected by its passage through a jaw-crusher set to ¼ inch opening, followed by a Braun pulverizer set to 1 millimetre. The precaution observed at this stage was the utilization of a pulverizer working by cracking rather than a grinder by rubbing. Twenhofel and Tyler (1941) recommend that particle sizes be reduced so that they will pass openings of 0.5 millimetre, and work on the pilot sample indicated that the heavy mineral constituents did not usually occur in sizes greater than this amount, so that the larger setting for the pulverizer opening was considered reasonably safe in reducing the possible breakage of heavy mineral grains to a minimum, whilst effectually breaking up the quartzite with the greatest consistent efficiency. The usual precautions of cleaning were observed in order to reduce possible "salting" to a minimum.

After splitting off a check sample of about 100 grams by means of a modified Jones-type splitter (Otto, 1937), the crushed product was passed through a series of dry sieves (18, 45, & 120 American Standard Tyler Mesh), oversize being returned to the pulverizer. The main size fractions were subjected to routine tests for radio-activity with a supersensitive Geiger counter, and then weighed prior to concentration procedure. The check samples were mechanically analysed for size by means of a nested-sieve shaking-machine operated, with each sample, for a nominal period of ten minutes. Standard sieves 35, 45, 60, 80, 120, 170, & 230-mesh (A.S.T.M.), were used, and the results obtained are given in table 2.

PRELIMINARY CONCENTRATION.

As already stated the auxiliary purpose of this thesis was, in addition to an investigation of the quartzites concerned, also an experimentation on alternative methods for heavy mineral separation. (Smithson, 1930; Ewing, 1931). The quartzites examined carry less than 0.1 percent of heavy minerals, so that direct bromoform separation in order to yield a sufficient quantity for satisfactory optical examination would be both laborious and expensive. Some form of preliminary concentration is desirable before a final bromoform separation. Such a process was successfully worked out, instead of panning, by utilizing the laboratory Wilfley concentrating-table and the Haultain superpanner. Reasonable relative recoveries of the order of 60-70 percent were secured, and since all the samples were treated in exactly the same manner the results obtained can be safely used for comparative purposes.

In effecting this preliminary concentration the pilot sample was used in order to determine, for each main size fraction, the best setting of the laboratory Wilfley table as regards rate of feed, tilt, speed of oscillation, wash-water supply, and tailings cut-off. When these had been determined satisfactorily the samples were treated in successive batches according to size fractions, each sample then requiring only the minimum of individual attention and occasional adjustment in order to maintain the best recovery. It was found that the separation for the under 120-mesh was fairly clean, was quite good for the over 120-mesh, but only fair in the case of the

TABLE 3.

CONCENTRATION STATISTICS - MAIN SAMPLES - WILFLEY TABLE SEPARATION

SAMPLE	NUMBER	03	19	21	27	29	31	44	51	13	15	34	35	42	AVERAGE
WEIGHT SAMPLE grams:	+ 45 mesh	1954	618	747	1243	2453	2285	794	782	752	692	1223	1563	755	1220
	+120 mesh	1432	1243	1229	1317	1548	1292	2024	2235	1433	1566	2421	1963	1943	1665
	-120 mesh	255	160	136	337	244	393	349	346	230	265	120	308	643	291
	TOTAL	3641	2021	2112	2897	4245	3970	3167	3363	2415	2523	3764	3834	3341	3176
WEIGHT CONCS: grams:	+ 45 mesh	59.6	23.7	22.1	18.0	20.4	16.2	0.2	2.4	46.9	6.1	63.2	15.5	2.3	22.8
	+120 mesh	26.5	6.1	12.6	12.7	29.0	17.4	6.1	12.4	11.1	12.7	42.2	77.1	17.2	21.8
	-120 mesh	20.3	2.8	2.7	6.8	6.2	7.3	9.9	1.5	22.5	4.9	1.9	1.1	7.1	7.3
	TOTAL	106.4	32.6	37.4	37.5	55.6	40.9	16.2	16.3	80.5	23.7	107.3	93.7	26.6	51.9
WEIGHT CONCS: %	+ 45 mesh	3.05	3.84	2.96	1.45	0.83	0.71	0.03	0.31	6.24	0.86	5.17	0.99	0.31	2.06
	+120 mesh	1.85	0.49	1.03	0.96	1.87	1.35	0.30	0.56	0.78	0.81	1.74	3.93	0.89	1.27
	-120 mesh	7.96	1.75	1.99	2.02	2.54	1.86	2.84	0.43	9.78	1.85	1.62	0.36	1.10	2.78
	TOTAL	2.92	1.61	1.77	1.30	1.31	1.03	0.51	0.49	3.33	0.94	2.85	2.45	0.80	1.64
RATIO OF CONCN:	+ 45 mesh	33:1	26:1	34:1	69:1	120:1	141:1	3970	330:1	16:1	113:1	19:1	101:1	328:1	49:1
	+120 mesh	54:1	204:1	98:1	104:1	53:1	74:1	332:1	180:1	129:1	123:1	57:1	25:1	113:1	79:1
	-120 mesh	13:1	57:1	50:1	50:1	39:1	54:1	35:1	231:1	10:1	54:1	63:1	280:1	91:1	36:1
	OVERALL	34:1	62:1	56:1	77:1	76:1	97:1	195:1	206:1	30:1	104:1	35:1	41:1	126:1	61:1

TABLE 4.

ACTUAL WEIGHTS OF FINAL HEAVY MINERAL CONCENTRATES - MAIN SAMPLES

SAMPLE NUMBER	+ 45 mesh	+ 60 mesh	+ 80 mesh	+120 mesh	+170 mesh	+230 mesh	-230 mesh	TOTAL grams	% OF INT: TABLE CS:	RATIO CONC:
03	0.8682	1.1187	0.3840	1.4514	1.0516	0.7173	0.2930	5.8842	5.54	18:1
19	0.6495	0.0362	0.0594	0.0921	0.1126	0.0649	0.0811	1.0958	3.36	30:1
21	0.1225	0.1101	0.0695	0.1100	0.1017	0.0661	0.0138	0.5937	1.59	63:1
27	0.1604	0.9902	0.8391	0.6253	0.1809	0.1018	0.0271	2.9248	7.80	13:1
29	0.0845	0.1536	0.1349	0.1378	0.0842	0.0664	0.0173	0.6787	1.22	82:1
31	0.1081	0.2329	0.2218	0.1945	0.0930	0.0758	0.0227	0.9488	2.32	43:1
44	0.0146	0.0178	0.0333	0.0697	0.0590	0.0561	0.0278	0.2783	1.72	58:1
51	0.0042	0.0235	0.0200	0.0661	0.0192	0.0351	0.0101	0.1782	1.09	92:1
13	0.0321	0.0782	0.0411	0.1110	0.1180	0.1328	0.0565	0.5697	0.71	141:1
15	0.0207	0.0651	0.0477	0.0887	0.0873	0.0908	0.0522	0.4525	1.91	52:1
34	0.0541	0.2531	0.1806	0.2643	0.1418	0.1408	0.0550	1.0897	1.02	98:1
35	0.4287	0.5070	0.4490	0.3820	0.3389	0.2647	0.0609	2.4312	2.60	39:1
42	0.0292	0.0994	0.1487	0.1727	0.0792	0.0728	0.0207	0.6227	2.34	43:1
Average	0.1982	0.2835	0.2022	0.2897	0.1898	0.1450	0.0568	1.3652	2.555	39:1

TABLE 5 .

FINAL MAIN CONCENTRATES EXPRESSED AS PERCENTAGES OF SIZE FRACTIONS

SAMPLE NUMBER	+ 45 mesh	+ 60 mesh	+ 80 mesh	+120 mesh	+170 mesh	+230 mesh	-230 mesh	OVERALL %
03	0.052	0.246	0.092	0.310	0.518	0.417	0.116	0.162
19	0.224	0.017	0.026	0.028	0.043	0.014	0.035	0.054
21	0.021	0.057	0.038	0.038	0.063	0.018	0.006	0.028
27	0.017	0.168	0.242	0.198	0.130	0.095	0.005	0.101
29	0.004	0.027	0.037	0.032	0.043	0.024	0.010	0.016
31	0.007	0.048	0.066	0.058	0.041	0.039	0.006	0.024
44	0.003	0.004	0.007	0.011	0.018	0.012	0.011	0.009
51	0.000	0.005	0.004	0.012	0.005	0.007	0.000	0.005
13	0.005	0.017	0.013	0.029	0.054	0.077	0.017	0.024
15	0.005	0.018	0.014	0.018	0.034	0.036	0.015	0.018
34	0.021	0.034	0.026	0.031	0.035	0.033	0.016	0.029
35	0.032	0.083	0.097	0.070	0.127	0.123	0.014	0.063
42	0.006	0.017	0.035	0.034	0.026	0.011	0.010	0.019
Average	0.0305	0.0570	0.0536	0.0668	0.0875	0.0697	0.0201	0.0425

TABLE 6 .

FINAL MAIN CONCENTRATES EXPRESSED AS PERCENTAGES OF MAIN SAMPLES

SAMPLE NUMBER	+ 45 mesh	+ 60 mesh	+ 80 mesh	+120 mesh	+170 mesh	+230 mesh	-230 mesh	TOTAL %
03	0.024	0.031	0.010	0.040	0.029	0.020	0.008	0.162
19	0.032	0.002	0.003	0.005	0.005	0.003	0.004	0.054
21	0.006	0.005	0.003	0.005	0.005	0.003	0.001	0.028
27	0.005	0.034	0.029	0.022	0.006	0.004	0.001	0.101
29	0.002	0.003	0.003	0.003	0.002	0.002	0.001	0.016
31	0.003	0.006	0.005	0.005	0.002	0.002	0.001	0.024
44	0.0005	0.0005	0.001	0.002	0.002	0.002	0.001	0.009
51	0.0000	0.001	0.0005	0.002	0.0005	0.001	0.0000	0.005
13	0.001	0.003	0.002	0.005	0.005	0.006	0.002	0.024
15	0.001	0.003	0.002	0.003	0.003	0.004	0.002	0.018
34	0.0015	0.006	0.005	0.007	0.004	0.004	0.0015	0.029
35	0.011	0.013	0.012	0.010	0.009	0.007	0.0015	0.063
42	0.001	0.003	0.0045	0.005	0.0025	0.002	0.001	0.019
Average	0.0068	0.0085	0.0061	0.0088	0.0058	0.0046	0.0019	0.0425
MAIN	0.0068		0.0234			0.0123		0.0425
CHECK	0.0111		0.0323			0.0177		0.0611
RECOVERY	60.8 %		72.5 %			69.6 %		69.5 %

over 45-mesh. Only one retreatment of the middlings products was therefore sufficient in the case of under 120-mesh material, but it was considered that two retreatments were required in the case of each of the other two size fractions.

The table-concentration statistics are shown in table 3, from which it may be observed that the average concentration ratio was of the order of 50:1 for over 45-mesh material, 80:1 for over 120-mesh, and 36:1 for under 120-mesh, with an average overall ratio of 60:1. This was increased 2 to 3 times, to the order of 100-200:1, by subsequent cleaning up the rough table-concentrate on the Haultain superpanner, thus considerably reducing the bulk of material for bromoform separation.

The size fractions for each sample were given an acid digest for two hours with 1:4 HCl in order to remove iron-staining as far as possible, washed, re-grouped, and then re-sized by wet sieving to grade sizes +45, +60, +80, +120, +170, +230, and -230 mesh (A.S.T.M.). Each of these sizes was then separately treated on the superpanner, a novel method being used for visual control to ensure good recovery and no undue loss of heavy minerals. This was effected by adding a small quantity of the same grade size of crushed calcite which had been stained green with basic cupric nitrate. Such material was prepared by crushing a quantity of calcite to under 40-mesh, placing in a glass beaker, covering with a molar solution of cupric nitrate, boiling for five minutes, and fixing with cold concentrated ammonia for five minutes. This process yielded material with a bright emerald-green colour, a pinch of the appropriate grade size of which, added to the material being concentrated, was strikingly visible.

Separate tests performed on sized mixtures of 45 pereent white crushed quartz (specific gravity 2.65), 10 percent green stained calcite, and 45 percent purplish lepidolite (specific gravity varying 2.8 - 2.9), indicated that it was possible to effect a successful separation of quartz from the lepidolite, representing about 0.2 difference in specific gravity. In these experiments the purplish lepidolite formed a definite head and the white quartz a bedraggled tail, with the green-stained calcite in between. On the other hand, with a mixture composed of white quartz (sp. gr. 2.65), green-stained calcite, and red polyhalite (sp. gr. 2.77 - 2.78), both the quartz and the polyhalite form a tail to the stained calcite. Since pure calcite has a specific gravity of 2.71 - 2.72, and basic cupric nitrate is 3.43, it would thus appear that the stained calcite (in small sizes) has a specific gravity of 2.8 approximately. Probably this would vary slightly with grade size, due to the different ratios of surface area to volume, but there is no doubt that it can be used successfully as a means of visual control to ensure that most of the quartz is removed from a rough concentrate, and that heavy minerals having a specific gravity greater than 2.8 are retained. Actually, in order to be on the safe side, no attempt was made to remove all the quartz and a concentration ratio of only 2, 3, or 4:1 was effected, leaving a remaining concentration by bromoform separation of the order of 10:1.

As with the Wilfley table, the fractions of the pilot sample were used for determining the best adjustment on the superpanner before successively treating each sample. It was noticeable that sizes above 45-mesh did not separate so well as those less than 120 mesh. Each fraction obtained was subsequently separately given a second acid treatment in an endeavour to remove as much as possible

TABLE 7.

ACTUAL WEIGHTS OF DIRECT BROMOFORM CONCENTRATES - CHECK SAMPLES

SAMPLE NUMBER	+ 35 mesh	+ 45 mesh	+ 60 mesh	+ 80 mesh	+120 mesh	+170 mesh	+230 mesh	-230 mesh	TOTAL grams
03	0.0556	0.0211	0.0232	0.0400	0.0765	0.0798	0.0393	0.0070	0.3425
19	0.0015	0.0007	0.0015	0.0013	0.0032	0.0009	0.0008	0.0007	0.0106
21	0.0028	0.0004	0.0016	0.0029	0.0037	0.0006	0.0005	0.0004	0.0129
27	0.0052	0.0094	0.0306	0.0491	0.0462	0.0156	0.0076	0.0005	0.1642
29	0.0087	0.0046	0.0084	0.0042	0.0050	0.0030	0.0020	0.0019	0.0378
31	0.0045	0.0034	0.0092	0.0073	0.0075	0.0033	0.0019	0.0011	0.0382
44	0.0005	0.0018	0.0028	0.0014	0.0077	0.0043	0.0022	0.0013	0.0220
51	0.0000	0.0004	0.0013	0.0012	0.0038	0.0024	0.0031	0.0005	0.0127
13	0.0007	0.0007	0.0016	0.0029	0.0038	0.0039	0.0028	0.0008	0.0172
15	0.0004	0.0002	0.0022	0.0029	0.0046	0.0017	0.0051	0.0005	0.0176
34	0.0013	0.0011	0.0031	0.0060	0.0097	0.0073	0.0073	0.0017	0.0375
35	0.0062	0.0077	0.0107	0.0109	0.0047	0.0053	0.0022	0.0032	0.0509
42	0.0018	0.0041	0.0030	0.0072	0.0070	0.0041	0.0016	0.0017	0.0305
Average	0.0068	0.0043	0.0076	0.0106	0.0141	0.0102	0.0059	0.0016	0.0611

TABLE 8.

DIRECT BROMOFORM CONCENTRATES EXPRESSED AS PERCENTAGES OF CHECK SAMPLES

SAMPLE NUMBER	+ 35 mesh	+ 45 mesh	+ 60 mesh	+ 80 mesh	+120 mesh	+170 mesh	+230 mesh	-230 mesh	TOTAL %
03	0.056	0.021	0.023	0.040	0.077	0.080	0.039	0.007	0.343
19	0.0015	0.001	0.0015	0.001	0.003	0.001	0.001	0.001	0.011
21	0.003	0.0005	0.0015	0.003	0.0035	0.0005	0.0005	0.0005	0.013
27	0.005	0.009	0.031	0.049	0.046	0.016	0.0075	0.0005	0.164
29	0.009	0.005	0.008	0.004	0.005	0.003	0.002	0.002	0.038
31	0.005	0.003	0.009	0.007	0.008	0.003	0.002	0.001	0.038
44	0.0005	0.002	0.003	0.0015.	0.008	0.004	0.002	0.001	0.022
51	0.0000	0.0005	0.001	0.001	0.004	0.0025	0.003	0.0005	0.013
13	0.0005	0.0005	0.0015	0.003	0.004	0.004	0.003	0.001	0.017
15	0.0005	0.0005	0.002	0.003	0.0045	0.0015	0.005	0.0005	0.018
34	0.0015	0.001	0.003	0.006	0.010	0.007	0.007	0.002	0.038
35	0.006	0.008	0.011	0.011	0.005	0.005	0.002	0.003	0.051
42	0.002	0.004	0.003	0.007	0.007	0.004	0.002	0.002	0.031
Average	0.0068	0.0043	0.0076	0.0106	0.0141	0.0102	0.0059	0.0016	0.0611
	0.0111		0.0323			0.0177			0.0611

TABLE 9.

COMPLETE MECHANICAL ANALYSIS OF MAIN CONCENTRATES

SAMPLE NUMBER	+ 45 mesh	+ 60 mesh	+ 80 mesh	+120 mesh	+170 mesh	+230 mesh	-230 mesh	TOTAL %
03	14.7	19.0	6.5	24.7	17.9	12.2	5.0	100.0
19	59.3	3.3	5.4	8.4	10.3	5.9	7.4	100.0
21	20.6	18.5	11.7	18.5	17.1	11.1	2.3	99.8
Average	31.5	13.6	7.9	17.2	15.1	9.7	4.9	99.9
27	5.5	33.9	28.7	21.4	6.2	3.5	0.9	100.1
29	12.5	22.6	19.9	20.3	12.4	9.8	2.5	100.0
31	11.4	24.5	23.4	20.5	9.8	8.0	2.4	100.0
Average	9.8	27.0	24.0	20.7	9.5	7.1	1.9	100.0
44	5.2	6.4	12.0	25.0	21.2	20.2	10.0	100.0
51	2.4	13.2	11.2	37.1	10.8	19.7	5.7	100.1
13	5.6	13.7	7.2	19.5	20.7	23.3	9.9	99.9
Average	4.4	11.1	10.1	27.2	17.6	21.1	8.5	100.0
15	4.6	14.4	10.5	19.6	19.3	20.1	11.5	100.0
34	5.0	23.3	16.6	24.3	13.0	12.9	5.0	100.1
35	17.6	20.9	18.5	15.7	13.9	10.9	2.5	100.0
42	4.7	16.0	23.9	27.7	12.7	11.7	3.3	100.0
Average	6.9	17.5	17.3	22.4	15.2	14.6	6.2	100.1

TABLE 10.

COMPLETE MECHANICAL ANALYSIS OF CHECK CONCENTRATES

SAMPLE NUMBER	+ 35 mesh	+ 45 mesh	+ 60 mesh	+ 80 mesh	+120 mesh	+170 mesh	+230 mesh	-230 mesh	TOTAL %
03	16.2	6.2	6.8	11.7	22.3	23.3	11.5	2.1	100.1
19	14.0	6.3	14.0	12.6	30.1	8.4	7.7	7.0	100.1
21	21.6	2.9	12.3	22.8	28.7	4.7	4.1	2.9	100.0
Average	17.3	5.1	11.0	15.7	27.0	12.1	7.8	4.0	100.0
27	3.2	5.8	18.6	29.9	28.2	9.5	4.6	0.3	100.1
29	23.0	12.3	22.2	11.1	13.3	7.9	5.3	4.9	100.0
31	11.7	8.8	24.1	19.2	19.6	8.6	5.1	2.9	100.0
Average	12.6	9.0	21.6	20.1	20.4	8.7	5.0	2.7	100.1
44	2.4	8.1	12.8	6.4	34.8	19.3	10.1	6.1	100.0
51	–	2.9	10.0	9.4	30.0	18.8	24.7	4.1	99.9
13	3.9	4.3	9.1	16.9	22.1	22.5	16.4	4.8	100.0
Average	2.1	5.1	10.6	10.9	29.0	20.2	17.1	5.0	100.0
15	2.1	1.3	12.3	16.6	26.0	9.8	28.9	3.0	100.0
34	3.6	3.0	8.2	16.0	25.7	19.6	19.4	4.6	100.1
35	12.2	15.2	21.0	21.3	9.3	10.4	4.3	6.3	100.0
42	5.9	13.5	9.8	23.6	22.9	13.5	5.2	5.6	100.0
Average	5.3	8.0	12.2	19.6	22.1	12.8	15.3	4.7	100.0

of any iron-staining present, together with any fragments of stained calcite.

SEPARATION OF HEAVY MINERALS.

The main concentrates resulting after the above treatment were individually washed, dried, and subjected to bromoform separation using separating funnels and beakers. The heavy mineral separates were not collected on filter paper, but run direct from the separating funnels into the beakers and washed twice by decantation. The dried residues were then weighed, passed through an Otto microsplit (Otto, 1933), and a sufficient quantity of each size fraction of each sample concentrate obtained for making individual mounts in Arochlor 4465 (refractive index 1.66) (Keller, 1934).

The size fractions resulting from the mechanical analysis of the check samples were also each digested in acid before carrying out bromoform separation in a similar manner. The dried check separates thus obtained were then found, unfortunately, to be insufficient in quantity to allow for reliably statistical optical examination.

The actual weight of final heavy mineral concentrates obtained from the main samples are given in table 4, while these amounts expressed as percentages of the size fractions treated on the concentrating tables, and as percentages of the correspond main samples, have been calculated and are shown respectively in tables 5 and 6. In the case of the direct bromoform concentrates obtained from the check samples, the actual weights are given in table 7, and the amounts expressed as percentages of the corresponding check samples, in table 8. The average overall percentage recoveries were determined by computing the ratio of the average weights of material recovered in the main concentration to those obtained in the corresponding sizes of the check concentrates, and are indicated in table 6. The mechanical size analyses of the concentrates, calculated from the weights obtained, are shown in table 9 for the main concentrates, and in table 10 for the check concentrates.

OPTICAL EXAMINATION.

In order to aid identification the slide mounts were marked individually, not only by diamond-point pencil to show number of sample and Tyler mesh grade size, but also by colouring the slide edges with paint. The long sides were so coloured red for samples 03, 19, 21; white for samples 27, 29, 31; yellow for samples 44, 51; green for samples 13, 15; and blue for samples 34, 35, 42. The short top edges were likewise coloured:

red	for + 40	Tyler mesh	(= + 45	A.S.T.M.	= +0.351 mm);
orange	for + 60	" "	(= + 60	"	= +0.250 mm);
yellow	for + 80	" "	(= + 80	"	= +0.175 mm);
white	for +115	" "	(= +120	"	= +0.125 mm);
green	for +170	" "	(= +170	"	= +0.088 mm);
blue	for +250	" "	(= +230	"	= +0.062 mm);
black	for −250	" "	(= −230	"	= −0.062 mm).

The optical examination was carried out by moving each mount in turn across the field of vision and counting all the grains seen in this representative band of the slide. Although an average count of 300 to 400 grains was aimed at, this was not always possible.

TABLE II.

MINERAL NUMBER FREQUENCY PERCENTAGES - Grade size +0.351 mm.

SAMPLE NUMBER	03	19	21	27	29	31	44	51	13	15	34	35	42
Ilmenite (+ mag.)	1	1	-	8	4	13	4	7	3	9	5	3	2
Leucoxene(+wh.ct.)	3	1	2	7	-	4	-	-	2	2	4	1	12
Limonite (+br.ct.)	8	7	6	2	1	7	-	7	3	3	1	1	4
Compound (+pt.ct.)	16	82	78	31	4	3	7	7	35	59	41	1	2
Pyrite	-	-	-	-	-	-	-	-	-	-	-	-	-
Garnet	1	1	2	6	36	34	32	21	5	7	9	11	22
Apatite	-	-	-	-	-	-	-	-	-	-	-	-	-
Lepidolite	1	1	3	29	7	10	18	21	22	6	26	28	24
Chlorite	-	-	-	-	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	1	1	-	4	7	-	-	-	2	-
Tourmaline	-	-	-	-	-	-	-	-	-	-	-	-	-
Anthophyllite	-	-	1	2	-	-	-	-	-	-	-	-	-
Tremolite	1	1	2	1	4	4	25	14	6	6	2	37	24
Actinolite	1	1	1	-	-	-	-	-	-	-	-	-	-
Hornblende	3	-	1	-	1	-	-	-	-	-	-	1	2
Glaucophane	-	-	-	-	-	-	-	-	-	-	-	-	-
Enstatite	-	-	-	-	-	-	-	-	-	1	2	-	-
Hypersthene	-	-	-	-	-	-	-	-	-	-	1	-	-
Epidote	63	2	3	9	34	21	4	14	21	5	5	12	2
Monazite	-	-	-	-	-	-	-	-	-	-	-	-	-
Titanite	-	-	-	-	-	-	-	-	-	-	-	-	-
Zircon	-	-	-	-	-	-	-	-	-	-	-	-	-
Anatase	-	-	-	-	-	1	-	-	2	1	-	1	4
Spinel	-	-	-	-	-	-	-	-	-	-	-	-	-
Rutile	-	-	-	1	3	1	4	-	-	-	1	1	-
Unidentified	0.7	1.2	1.7	1.0	2.9	1.4	3.6	-	1.6	1.0	2.1	1.3	2.0
GRAINS COUNTED (AVERAGE - 84)	152	83	117	96	70	71	28	14	63	99	95	150	50

TABLE 12.

MINERAL NUMBER FREQUENCY PERCENTAGES - Grade size +0.250 mm.

SAMPLE NUMBER	03	19	21	27	29	31	44	51	13	15	34	35	42
Ilmenite (+ mag.)	3	3	4	63	38	61	8	16	10	18	24	17	24
Leucoxene (+wh.ct.)	35	23	19	23	2	9	34	22	39	29	16	1	19
Limonite (+br.ct.)	4	3	29	*	1	2	4	1	1	19	1	*	16
Compound (+pt.ct.)	41	32	21	4	1	3	1	2	7	7	5	1	20
Pyrite	-	-	-	-	-	-	-	-	-	-	-	-	-
Garnet	2	8	6	1	33	15	32	23	8	7	10	11	10
Apatite	-	-	-	-	-	-	-	-	-	-	-	-	-
Lepidolite	1	6	3	2	1	1	5	6	3	1	30	11	5
Chlorite	-	-	-	-	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	-	-	-	-	-	*	-	-	-
Tourmaline	1.3	0.9	-	0.4	0.3	0.3	1.0	0.9	9.2	7.0	5.2	0.7	-
Anthophyllite	-	-	-	-	-	-	-	-	-	-	-	-	-
Tremolite	*	11	8	*	9	3	8	10	5	5	3	34	3
Actinolite	-	1	-	-	-	-	-	-	-	-	-	-	-
Hornblende	*	*	2	*	1	-	1	1	*	-	*	1	-
Glaucophane	-	-	-	-	-	-	-	-	-	-	-	-	-
Enstatite	-	-	-	*	*	-	-	-	-	-	-	*	-
Hypersthene	-	-	-	-	-	-	-	-	-	-	-	-	-
Epidote	5	7	1	3	12	4	2	16	3	1	2	22	1
Monazite	-	-	-	-	-	-	-	-	-	-	-	-	-
Titanite	-	-	-	-	-	-	-	-	-	-	-	-	-
Zircon	4.3	2.8	2.8	1.2	1.1	1.0	-	-	5.7	4.3	1.5	0.3	-
Anatase	2	3	3	-	*	-	5	2	8	1	1	-	-
Spinel	*	-	-	-	-	-	-	-	1	-	-	*	-
Rutile	*	*	-	*	*	*	-	1	1	1	*	*	1
Unidentified	0.4	0.3	-	-	0.3	0.3	-	0.9	0.2	0.5	-	-	0.6
GRAINS COUNTED (AVERAGE - 299)	468	323	249	259	360	293	101	116	459	417	345	306	185

For samples 03-31; number frequency of zircon is greater than that of tourmaline.

For samples 44-42; number frequency of tourmaline is greater than that of zircon.

TABLE 13 .

MINERAL NUMBER FREQUENCY PERCENTAGES - Grade size +0.175 mm.

SAMPLE NUMBER	03	19	21	27	29	31	44	51	13	15	34	35	42
Ilmenite (+ mag.)	3	5	6	54	38	58	6	15	12	16	13	27	23
Leucoxene(+wh.ct.)	31	8	17	20	5	5	43	17	35	34	22	3	22
Limonite (+br.ct.)	9	39	16	3	1	4	3	1	3	5	30	4	22
Compound (+pt.ct.)	37	11	31	8	8	9	6	6	9	7	7	2	16
Pyrite	-	-	-	-	-	*	-	-	-	-	-	-	-
Garnet	3	4	4	2	16	8	13	30	9	7	9	9	6
Apatite	-	-	-	-	-	-	-	-	-	-	-	-	-
Lepidolite	4	16	12	8	16	8	16	18	8	8	8	28	7
Chlorite	-	-	-	-	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	*	-	*	-	-	*	-	-	-
Tourmaline	0.9	0.7	0.2	0.2	0.4	0.3	0.9	1.5	10.3	7.5	4.4	3.1	0.8
Anthophyllite	-	*	-	-	-	-	*	-	-	-	-	-	-
Tremolite	1	5	7	1	6	4	6	7	3	3	2	14	2
Actinolite	*	-	-	-	-	-	-	-	-	-	-	-	-
Hornblende	1	*	-	-	1	*	-	-	-	1	-	*	1
Glaucophane	-	-	-	-	-	-	-	-	-	-	-	-	-
Enstatite	-	-	-	-	-	-	*	-	-	-	-	-	-
Hypersthene	-	-	-	-	-	-	-	-	-	-	-	-	-
Epidote	7	4	1	3	4	3	*	4	2	1	1	9	*
Monazite	*	*	-	*	-	-	-	-	-	-	-	-	-
Titanite	-	-	-	*	-	-	-	-	-	-	-	-	-
Zircon	1.5	1.0	0.6	0.5	1.7	0.6	0.3	-	2.9	6.3	1.0	0.3	0.3
Anatase	1	4	5	-	-	-	3	-	4	3	2	-	-
Spinel	-	-	-	-	-	-	-	-	-	1	*	-	-
Rutile	*	-	-	-	1	-	*	1	1	*	1	-	-
Unidentified	0.4	1.0	0.6	0.5	0.8	0.6	0.3	1.0	1.0	0.6	0.2	0.6	0.6
GRAINS COUNTED (AVERAGE - 352)	550	305	535	415	238	331	321	195	204	335	433	357	361

For samples 03-31; number frequency of zircon is greater than that of tourmaline.

For samples 44-42; number frequency of tourmaline is greater than that of zircon.

TABLE 14.

MINERAL NUMBER FREQUENCY PERCENTAGES - Grade size +0.125 mm.

SAMPLE NUMBER	03	19	21	27	29	31	44	51	13	15	34	35	42
Ilmenite (+ mag.)	2	10	3	36	17	34	6	4	6	10	8	17	10
Leucoxene(+wh.ct.)	37	5	25	21	6	6	33	17	22	20	20	4	18
Limonite (+br.ct.)	1	15	5	*	1	2	*	1	2	2	20	1	13
Compound (+pt.ct.)	41	16	41	30	28	17	39	18	28	34	28	9	31
Pyrite	-	-	-	-	1	6	-	-	-	-	-	-	-
Garnet	2	4	5	2	22	13	5	17	5	4	4	13	11
Apatite	-	-	-	-	-	-	-	-	-	*	-	-	-
Lepidolite	4	5	3	4	11	8	6	16	6	5	4	10	5
Chlorite	-	-	-	-	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	*	*	*	1	-	*	-	-	-
Tourmaline	1.3	0.5	0.4	0.3	1.5	0.7	2.1	5.6	12.3	12.0	7.5	16.1	2.3
Anthophyllite	-	-	-	-	-	-	-	-	-	-	-	-	-
Tremolite	1	6	4	1	5	5	2	14	6	5	2	16	4
Actinolite	-	*	-	-	-	-	-	-	-	-	-	-	-
Hornblende	*	1	1	-	1	*	1	1	-	1	1	*	1
Glaucophane	-	-	-	-	-	-	-	*	-	-	-	*	-
Enstatite	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypersthene	-	-	-	-	-	-	-	-	-	-	-	-	-
Epidote	3	3	1	1	3	1	*	2	1	*	1	11	1
Monazite	-	*	*	-	-	-	-	-	1	1	-	-	-
Titanite	-	-	-	-	-	*	-	-	-	-	-	-	-
Zircon	3.4	4.2	1.2	4.3	2.5	3.1	1.0	1.6	2.9	3.9	3.3	1.3	2.0
Anatase	4	29	11	1	2	2	3	1	7	3	2	2	2
Spinel	-	*	*	-	-	-	-	-	-	-	*	*	*
Rutile	1	-	-	1	1	1	1	1	1	*	*	1	1
Unidentified	0.6	0.5	0.4	0.3	0.5	0.7	0.6	0.7	1.8	0.8	0.6	0.6	0.3
GRAINS COUNTED (AVERAGE - 414)	536	401	568	400	400	450	384	426	382	359	362	316	394

For samples 03-31; number frequency of zircon is greater than that of tourmaline.

For samples 44-42; number frequency of tourmaline is greater than that of zircon.

TABLE 15.

MINERAL NUMBER FREQUENCY PERCENTAGES - Grade size +0.088 mm.

SAMPLE NUMBER	03	19	21	27	29	31	44	51	13	15	34	35	42
Ilmenite (+ mag.)	1	1	1	1	3	1	2	2	*	*	-	5	-
Leucoxene (+wh.ct.)	41	4	26	24	3	4	23	18	24	21	24	6	18
Limonite (+br.ct.)	*	1	2	1	1	1	1	1	1	1	-	*	9
Compound (+pt.ct.)	38	2	28	25	23	13	29	12	28	24	23	2	24
Pyrite	-	-	-	-	-	3	-	-	*	-	-	-	-
Garnet	1	3	3	2	21	13	6	20	4	3	4	6	6
Apatite	-	-	-	-	-	-	-	-	-	-	-	-	-
Lepidolite	2	2	*	1	1	2	5	2	2	1	2	5	3
Chlorite	-	*	-	-	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	-	-	-	-	-	-	-	-	-
Tourmaline	1.3	1.1	0.6	0.4	0.8	0.9	3.9	3.8	6.2	16.3	11.7	10.4	2.3
Anthophyllite	-	-	-	-	-	-	-	-	-	-	-	-	-
Tremolite	1	1	2	1	2	3	2	10	1	2	1	7	3
Actinolite	-	-	-	*	-	-	-	-	-	-	-	-	-
Hornblende	*	*	*	*	*	*	1	1	-	-	-	*	*
Glaucophane	-	-	-	-	-	-	-	*	-	-	-	-	-
Enstatite	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypersthene	-	-	-	-	-	-	-	-	-	-	-	-	-
Epidote	2	*	1	*	1	1	-	-	-	-	-	3	1
Monazite	-	-	-	*	*	-	-	-	*	*	-	-	-
Titanite	-	-	-	-	-	-	-	-	-	-	-	*	-
Zircon	3.5	2.2	1.6	11.8	8.8	6.4	2.2	5.3	3.2	7.4	7.4	5.6	3.7
Anatase	9	81	35	30	32	48	22	19	27	23	25	46	27
Spinel	*	*	*	-	*	1	*	1	*	-	-	2	*
Rutile	1	*	*	1	2	1	2	4	1	2	2	1	3
Unidentified	0.1	0.2	0.2	0.2	0.4	0.7	0.4	0.4	0.6	-	0.6	0.6	0.7
GRAINS COUNTED (AVERAGE - 574)	750	450	500	500	500	450	540	450	500	350	350	520	300

For samples 03-31; number frequency of zircon is greater than that of tourmaline.

For samples 44-42; number frequency of tourmaline is greater than that of zircon except in case of # 51 & # 42.

TABLE 16.

MINERAL NUMBER FREQUENCY PERCENTAGES - Grade size +0.062 mm.

SAMPLE NUMBER	03	19	21	27	29	31	44	51	13	15	34	35	42
Ilmenite (+ mag.)	1	1	*	3	2	*	2	1	-	*	-	1	-
Leucoxene(+wh.ct.)	41	19	25	18	2	1	34	7	27	21	21	1	14
Limonite (+br.ct.)	*	1	1	2	2	3	1	1	1	*	6	2	3
Compound (+pt.ct.)	37	20	30	28	32	22	39	13	24	24	17	2	13
Pyrite	-	-	-	-	*	5	-	-	-	-	-	-	-
Garnet	1	4	7	9	17	16	3	19	4	5	6	5	8
Apatite	-	-	-	-	-	-	-	-	-	-	-	-	-
Lepidolite	*	3	1	2	11	10	3	17	5	3	3	36	4
Chlorite	-	-	-	-	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	-	-	-	-	-	-	-	-	-
Tourmaline	1.8	2.0	0.7	0.7	1.5	1.5	4.0	3.0	11.2	12.8	4.6	3.2	2.0
Anthophyllite	-	-	-	-	-	-	-	-	-	-	-	-	-
Tremolite	*	1	*	*	2	1	*	1	-	-	*	2	*
Actinolite	-	-	-	-	-	-	*	-	-	-	-	*	-
Hornblende	*	*	-	*	*	-	1	-	-	-	-	*	*
Glaucophane	-	-	-	-	-	-	-	-	-	-	-	-	-
Enstatite	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypersthene	-	-	-	-	-	-	-	-	-	-	-	-	-
Epidote	2	1	*	1	1	2	-	-	-	-	*	1	*
Monazite	-	-	-	-	-	-	-	*	-	*	-	-	-
Titanite	-	-	-	-	-	-	-	-	-	-	-	-	-
Zircon	8.6	3.3	2.7	16.3	13.5	19.3	3.8	13.9	14.6	24.0	15.7	5.6	12.8
Anatase	4	44	30	20	12	16	6	19	12	7	18	38	38
Spinel	*	*	*	-	*	-	-	*	-	-	-	1	*
Rutile	2	1	*	1	2	1	3	4	2	2	8	1	2
Unidentified	0.6	0.2	0.7	0.4	0.6	0.7	0.3	0.6	0.3	0.4	0.3	0.8	1.2
GRAINS COUNTED (AVERAGE - 378)	500	700	300	270	333	270	400	330	330	250	350	500	250

Note that the number frequency of zircon is greater than that of tourmaline in all cases except that of # 44.

TABLE 17.

MINERAL NUMBER FREQUENCY PERCENTAGES - Grade size -0.062 mm.

SAMPLE NUMBER	03	19	21	27	29	31	44	51	13	15	34	35	42
Ilmenite (+ mag.)	1	1	1	3	2	2	1	1	1	-	-	2	-
Leucoxene(+wh.ct.)	35	26	22	9	3	2	18	5	19	8	6	4	3
Limonite (+br.ct.)	2	1	2	1	3	1	1	2	1	1	2	1	3
Compound (+pt.ct.)	32	23	21	22	12	23	22	11	24	11	9	3	11
Pyrite	-	-	*	-	-	1	-	-	-	-	-	-	-
Garnet	3	3	30	7	32	35	23	38	8	10	9	29	36
Apatite	-	-	-	-	-	-	-	-	-	-	-	-	-
Lepidolite	1	*	2	3	11	3	14	6	8	19	10	25	5
Chlorite	-	-	-	-	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	-	-	-	-	-	-	-	-	-
Tourmaline	0.9	5.4	2.0	0.7	2.0	0.6	0.6	0.6	6.4	4.3	2.9	0.8	0.7
Anthophyllite	-	-	-	-	-	-	-	-	-	-	-	-	-
Tremolite	*	*	-	1	1	1	-	1	1	*	-	1	-
Actinolite	-	-	-	-	-	-	-	-	-	-	-	-	-
Hornblende	*	-	1	-	1	-	-	-	-	-	-	1	-
Glaucophane	-	-	-	-	-	-	-	-	-	-	-	-	-
Enstatite	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypersthene	-	-	-	-	-	-	-	-	-	-	-	-	-
Epidote	1	*	-	2	2	*	-	-	*	-	-	1	1
Monazite	-	-	-	-	-	-	-	-	-	-	-	-	-
Titanite	-	-	-	-	-	-	-	-	-	-	-	-	-
Zircon	20.3	35.4	10.8	46.7	23.0	26.7	16.0	24.6	27.6	38.3	54.3	11.8	23.2
Anatase	3	3	6	2	5	5	2	5	2	5	3	17	16
Spinel	-	-	-	-	-	-	-	-	-	-	-	1	-
Rutile	1	1	1	2	2	*	1	6	1	2	4	3	3
Unidentified	0.5	0.6	0.8	-	1.0	0.6	0.9	-	0.8	-	-	1.6	-
GRAINS COUNTED (AVERAGE - 377)	650	700	250	300	360	333	350	350	250	300	280	500	280

Note that in all cases the number frequency of zircon is greater than that shown by varieties of tourmaline.

When insufficient grains were seen a second parallel band was examined, but even this, in addition, did not always display the required number in the case of the coarser grades. With the finer sizes more than 400 grains per slide were observed, and sometimes it was only necessary to examine a single field in order to obtain counts of 700 grains.

The opaque minerals most commonly recorded, as might be expected, were the various iron oxides and compound coated grains. These included black opaque magnetite and ilmenite, probably mostly the latter; white opaque leucoxene, and white coated grains; brown opaque limonite, sometimes with cubical forms after pyrite; and quartz or other minerals having iron oxide inclusions or partial coatings. More rarely pyrite was observed, this mineral being particularly well displayed in mounts from sample number 31, showing crystal faces with striations (very good examples in the +115 mesh size).

The only isotropic mineral seen was garnet. This appeared in several forms, colourless, pale greenish-yellow to apricot-yellow, rarely pinkish (as in sample 35). In the coarser sizes some of the garnet was observed in association with lepidolite and appears to have been derived by contamination from other sources during the process of crushing.

Apatite was very rarely seen and, in fact, could hardly be expected after the double acid treatment to which all the samples were subjected: a colourless and well-rounded grain was, however, observed in sample 15 (+115). Lepidolite plates, colourless to mauve-pink, frequently with inclusions, and often with hexagonal ray striations, were observed in the coarser sizes of several samples: their presence would appear to be due to contamination from Pala material previously passed through the crusher. Plates of brown biotite mica were occasionally seen. Chlorite was also recorded, but only rarely.

Tourmaline was seen to occur in a variety of colour shades and displayed different degrees of rounding. Colourless to pale yellowish and pinkish shades are comparatively rare, while strongly pleochroic straw-yellow to yellow-brown, and brownish-yellow to greenish-brown varieties, are common, usually sub-rounded to rounded forms in samples numbered 44, 51, 13, 15, 34, 35, 42; angular in samples numbered 03, 19, 21, 27, 29, 31: these yellow-brown types often show gas-inclusion cavities, but are more commonly without. Sub-rounded varieties, coloured brownish-green to black, and greenish--blue to mauve, are frequent in samples of the first group (44 to 42): these are particularly well displayed in slide 15 (+80), in addition, to the good elongated or egg-shaped yellow-brown types very well shown in slide 35 (+115), but are relatively rare in samples of the second group (03 to 31).

Amongst the amphiboles observed most commonly were colourless tremolite with $Z \wedge c = 20^{\circ}$, lineated inclusions, and index of refraction very near to that of the Arochlor mounting medium. Pale greenish actinolite was seen, with similar properties, but was not common, as also rare colourless anthophyllite displaying parallel extinction. Hornblende, usually bluish-green to yellowish-green, was quite often recorded, but only in small numbers. Glaucophane, distinctively lavender-blue to royal-blue, was extremely rare and only observed in two slides, 51, (+115), and 35 (+115).

TABLE 18.

OBSERVED NUMBER FREQUENCY PERCENTAGES - Grade size +0.250 mm.

SAMPLE NUMBER		03	19	21	27	29	31	44	51	13	15	34	35	42
TOURMALINE -	Total	1.28	0.93	-	0.39	0.28	0.34	0.99	0.89	9.15	6.95	5.22	0.65	-
colourless to pink-yellow	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	0.21	-	-	-	-	-	-	-	-	-	-	-	-
	sub-rounded	-	-	-	-	-	-	-	-	-	-	-	-	-
	rounded	-	-	-	-	-	-	-	-	-	-	-	-	-
straw-yellow to yellow-brown	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	0.44	0.24	0.29	-	-
	sub-rounded	-	-	-	-	-	-	-	-	0.87	0.24	0.58	-	-
	rounded	-	-	-	-	-	-	-	-	1.09	0.24	0.58	-	-
brown-yellow to green-brown	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	0.64	0.62	-	0.39	0.28	-	-	-	1.53	1.44	0.58	0.33	-
	sub-rounded	0.43	0.31	-	-	-	0.34	-	-	1.74	1.68	0.87	-	-
	rounded	-	-	-	-	-	-	-	-	1.31	1.68	0.87	-	-
brown-green to black	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-rounded	-	-	-	-	-	-	-	-	0.44	0.24	0.29	-	-
	rounded	-	-	-	-	-	-	0.99	0.89	0.65	0.48	0.58	0.33	-
green-blue to mauve	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	0.22	0.24	-	-	-
	sub-rounded	-	-	-	-	-	-	-	-	0.65	0.24	-	-	-
	rounded	-	-	-	-	-	-	-	-	0.22	0.24	0.58	-	-
ZIRCON -	Total	4.27	2.79	2.81	1.16	1.11	1.02	-	-	5.66	4.32	1.45	0.33	-
colourless or dusky	angular	1.28	0.62	0.80	-	-	-	-	-	0.65	0.96	0.29	-	-
	sub-angular	1.28	0.93	0.80	0.39	-	0.34	-	-	0.65	0.72	0.29	-	-
	sub-rounded	0.43	0.31	-	-	0.28	-	-	-	0.87	0.72	-	-	-
	rounded	-	-	-	-	-	-	-	-	0.44	0.24	-	-	-
pinkish	angular	0.21	0.31	0.40	-	0.28	0.34	-	-	0.22	0.24	0.29	-	-
	sub-angular	0.21	0.31	-	0.39	0.28	0.34	-	-	0.87	0.48	0.29	-	-
	sub-rounded	0.43	0.31	0.40	-	-	-	-	-	1.53	0.72	0.29	0.33	-
	rounded	0.21	-	-	-	-	-	-	-	0.44	0.24	-	-	-
mauve-pink to purplish	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-rounded	-	-	-	-	0.28	-	-	-	-	-	-	-	-
	rounded	0.21	-	0.40	0.39	-	-	-	-	-	-	-	-	-
T/Z VOLUME FREQUENCY RATIO		0.30	0.33	<0.14	0.33	0.25	0.33	>1.00	>1.00	1.61	1.61	3.60	2.00	-

TABLE 19.

OBSERVED NUMBER FREQUENCY PERCENTAGES - Grade size +0.175 mm.

SAMPLE NUMBER		03	19	21	27	29	31	44	51	13	15	34	35	42
TOURMALINE -	Total	0.90	0.66	0.19	0.24	0.42	0.30	0.94	1.54	10.29	7.46	4.38	3.08	0.83
colourless to pink-yellow	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-rounded	-	-	-	-	-	-	-	-	-	-	-	-	-
	rounded	-	-	-	-	-	-	-	-	-	-	-	-	-
straw-yellow to yellow-brown	angular	-	-	-	-	-	-	-	-	-	0.30	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	0.98	0.30	0.24	0.28	-
	sub-rounded	-	-	-	-	-	-	0.31	-	0.49	0.60	0.72	-	-
	rounded	-	-	-	-	-	-	-	0.51	-	0.30	0.72	0.56	0.28
brown-yellow to green-brown	angular	-	0.33	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	0.54	-	0.19	0.24	0.42	-	-	0.51	0.49	2.09	0.96	-	-
	sub-rounded	0.36	0.33	-	-	-	0.30	-	0.51	1.47	1.19	0.72	0.28	0.28
	rounded	-	-	-	-	-	-	-	-	0.98	1.19	0.72	0.56	-
brown-green to black	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	0.49	0.30	-	-	-
	sub-rounded	-	-	-	-	-	-	0.31	-	1.96	0.30	-	-	0.28
	rounded	-	-	-	-	-	-	0.31	-	2.45	0.30	0.24	0.84	-
green-blue to mauve	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	0.49	-	-	-	-
	sub-rounded	-	-	-	-	-	-	-	-	-	0.60	-	-	-
	rounded	-	-	-	-	-	-	-	-	0.49	-	0.24	0.56	-
ZIRCON -	Total	1.46	0.98	0.56	0.48	1.68	0.60	0.31	-	2.94	6.27	0.96	0.28	0.28
colourless	angular	0.54	0.33	0.19	-	-	0.30	-	-	0.49	0.90	-	-	-
	sub-angular	0.36	0.66	0.19	0.24	-	-	-	-	0.49	1.79	0.48	0.28	-
	sub-rounded	0.36	-	-	-	-	-	0.31	-	0.49	1.19	0.24	-	-
	rounded	-	-	-	-	-	-	-	-	0.49	-	-	-	-
pinkish	angular	-	-	-	-	0.42	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	0.24	0.42	-	-	-	0.49	0.90	0.24	-	-
	sub-rounded	0.18	-	0.19	-	0.42	0.30	-	-	0.49	1.49	-	-	-
	rounded	-	-	-	-	-	-	-	-	-	-	-	-	0.28
mauve-pink to purplish	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-rounded	-	-	-	-	0.42	-	-	-	-	-	-	-	-
	rounded	-	-	-	-	-	-	-	-	-	-	-	-	-
T/Z VOLUME FREQUENCY RATIO		0.63	0.67	0.33	0.50	0.25	0.50	3.00	>3.00	3.50	1.19	4.75	11.00	3.00

TABLE 20.

OBSERVED NUMBER FREQUENCY PERCENTAGES - Grade size +0.125 mm.

SAMPLE NUMBER		03	19	21	27	29	31	44	51	13	15	34	35	42
TOURMALINE -	Total	1.31	0.50	0.35	0.25	1.50	0.66	2.08	5.63	12.30	11.98	7.46	16.14	2.28
colourless to pink-yellow	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-rounded	-	-	-	-	-	-	-	-	-	-	-	-	-
	rounded	-	-	-	-	-	-	-	0.23	-	-	-	-	-
straw-yellow to yellow-brown	angular	-	-	-	-	-	-	-	-	0.26	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	0.23	0.26	0.56	-	0.32	-
	sub-rounded	0.19	-	-	-	-	-	0.26	0.47	0.52	0.56	0.28	0.95	-
	rounded	-	-	-	-	-	-	0.26	0.47	0.79	0.84	0.28	1.27	0.25
brown-yellow to green-brown	angular	0.19	-	0.18	-	0.25	-	-	0.47	1.05	0.56	-	-	-
	sub-angular	0.37	0.25	-	0.25	0.50	0.22	-	0.70	1.57	1.95	0.28	1.58	0.51
	sub-rounded	0.37	0.25	0.18	-	0.75	0.44	0.26	0.70	2.09	1.95	1.10	2.53	0.76
	rounded	0.19	-	-	-	-	-	0.26	0.94	1.57	2.23	1.10	2.85	0.25
brown-green to black	angular	-	-	-	-	-	-	-	-	0.26	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	0.23	0.79	0.56	0.55	0.95	-
	sub-rounded	-	-	-	-	-	-	-	0.23	1.31	0.84	1.38	2.22	0.25
	rounded	-	-	-	-	-	-	0.26	0.47	1.05	1.39	1.66	2.85	0.25
green-blue to mauve	angular	-	-	-	-	-	-	-	0.23	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	0.26	-	0.26	-	0.28	-	-
	sub-rounded	-	-	-	-	-	-	0.26	0.23	0.26	0.28	0.28	0.32	-
	rounded	-	-	-	-	-	-	0.26	-	0.26	0.28	0.28	0.32	-
ZIRCON -	Total	3.36	4.24	1.23	4.25	2.50	3.11	1.04	1.64	2.88	3.90	3.31	1.27	2.03
colourless	angular	1.12	0.75	0.53	0.50	0.50	1.33	-	-	0.52	0.84	-	0.32	-
	sub-angular	1.12	1.50	0.18	0.75	0.50	0.44	0.26	0.47	0.79	0.56	0.55	-	0.25
	sub-rounded	0.37	1.00	0.18	0.50	0.25	0.22	0.26	0.47	0.26	0.56	0.55	0.32	0.25
	rounded	-	0.25	-	-	-	-	0.26	0.23	0.26	0.28	0.55	-	-
pinkish	angular	0.19	0.25	-	0.75	0.25	0.44	-	-	-	0.56	0.28	-	-
	sub-angular	0.19	0.25	-	0.25	0.25	0.22	-	0.23	0.26	0.28	0.55	0.32	0.51
	sub-rounded	0.37	0.25	0.18	0.75	0.50	0.22	0.26	0.23	0.52	0.28	0.55	-	0.25
	rounded	-	-	-	0.25	0.25	-	-	-	-	-	-	-	0.25
mauve-pink to purplish	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	0.25	-	-	-	-	-	-	0.28	-	-
	sub-rounded	-	-	-	0.25	-	-	-	-	0.26	0.28	-	-	0.25
	rounded	-	-	0.18	-	-	0.22	-	-	-	0.28	-	0.32	0.25
T/Z VOLUME FREQUENCY RATIO		0.39	0.12	0.29	0.06	0.60	0.21	2.00	3.43	4.27	3.07	2.25	12.75	1.13

TABLE 21.

OBSERVED NUMBER FREQUENCY PERCENTAGES - Grade size +0.088 mm.

SAMPLE NUMBER		03	19	21	27	29	31	44	51	13	15	34	35	42
TOURMALINE -	Total	1.33	1.11	0.60	0.40	0.80	0.89	3.89	3.77	6.20	16.29	11.71	10.38	2.33
colourless to pink-yellow	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-rounded	-	-	-	-	-	0.22	-	-	-	-	0.29	-	-
	rounded	-	-	-	-	0.20	-	-	0.22	-	-	-	0.19	-
straw-yellow to yellow-brown	angular	-	-	-	-	-	-	-	-	0.20	0.29	-	-	-
	sub-angular	-	-	-	-	-	0.22	-	-	0.40	0.86	0.57	0.19	-
	sub-rounded	-	-	-	-	0.20	0.22	0.19	0.22	0.60	0.57	0.86	0.58	0.33
	rounded	-	-	-	-	-	-	-	0.22	0.40	0.29	1.14	0.77	-
brown-yellow to green-brown	angular	0.53	0.22	0.20	-	-	-	0.19	-	0.40	0.57	0.57	0.58	-
	sub-angular	0.53	0.22	-	0.20	0.20	-	0.56	0.22	0.60	1.71	1.43	0.96	0.33
	sub-rounded	0.13	0.22	0.20	0.20	0.20	0.22	0.37	0.67	1.00	2.29	1.43	1.54	0.33
	rounded	0.13	0.22	0.20	-	-	-	0.37	0.67	0.80	2.29	1.43	1.73	0.33
brown-green to black	angular	-	-	-	-	-	-	0.19	-	0.20	-	0.57	0.19	-
	sub-angular	-	-	-	-	-	-	0.56	0.22	0.20	0.86	0.57	0.38	-
	sub-rounded	-	-	-	-	-	-	0.37	0.22	0.40	2.00	0.57	0.96	-
	rounded	-	-	-	-	-	-	0.56	0.44	0.40	2.29	0.86	1.16	0.33
green-blue to mauve	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	0.22	-	-	-	-	0.19	-	0.20	0.29	0.29	0.38	0.33
	sub-rounded	-	-	-	-	-	-	0.19	0.22	0.20	0.86	0.57	0.38	0.33
	rounded	-	-	-	-	-	-	0.19	0.44	0.20	1.14	0.57	0.38	-
ZIRCON -	Total	3.47	2.22	1.60	11.80	8.80	6.44	2.22	5.33	3.20	7.43	7.43	5.58	3.67
colourless	angular	0.80	0.89	0.20	1.00	1.40	0.44	0.19	-	-	0.29	0.29	-	0.33
	sub-angular	1.07	0.67	0.60	1.20	1.00	1.11	0.37	0.44	0.40	1.14	1.43	0.77	0.33
	sub-rounded	0.40	0.22	0.20	1.40	0.80	0.67	0.37	1.56	0.80	0.86	1.43	1.16	0.33
	rounded	0.13	-	-	0.60	0.40	0.44	0.19	1.33	0.60	0.86	0.57	0.58	0.33
pinkish	angular	-	-	-	1.40	-	0.44	-	-	0.20	0.29	0.29	0.19	-
	sub-angular	0.53	0.22	-	2.00	1.20	0.67	0.19	0.67	0.40	1.14	0.86	0.77	0.67
	sub-rounded	0.27	-	-	1.60	1.80	0.89	0.56	0.67	0.40	1.43	1.14	0.96	1.00
	rounded	-	-	0.20	0.80	1.00	0.44	0.37	0.44	-	0.57	0.29	0.77	0.33
mauve-pink to purplish	angular	-	-	-	0.20	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	0.40	0.20	0.22	-	-	0.20	0.57	0.29	-	-
	sub-rounded	0.13	0.22	0.20	0.80	0.40	0.67	-	-	0.20	0.29	0.57	0.38	0.33
	rounded	0.13	-	0.20	0.40	0.60	0.44	-	0.22	-	-	0.29	-	-
T/Z VOLUME FREQUENCY RATIO		0.38	0.50	0.38	0.03	0.09	0.14	1.75	0.71	1.94	2.19	1.58	1.86	0.64

TABLE 22.

OBSERVED NUMBER FREQUENCY PERCENTAGES - Grade size +0.062 mm.

SAMPLE NUMBER		03	19	21	27	29	31	44	51	13	15	34	35	42
TOURMALINE -	Total	1.80	2.00	0.67	0.74	1.50	1.48	4.00	3.03	11.21	12.80	4.57	3.20	2.00
colourless to pink-yellow	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	0.30	-	-	-	-
	sub-rounded	-	-	-	-	-	-	-	-	-	-	-	-	-
	rounded	-	-	-	-	-	-	-	-	-	-	-	-	-
straw-yellow to yellow-brown	angular	-	-	-	-	-	-	-	-	0.30	0.40	-	0.20	-
	sub-angular	0.20	-	-	-	0.30	0.37	-	-	0.61	0.40	0.29	-	-
	sub-rounded	-	0.14	-	-	-	-	-	0.30	0.61	0.80	0.29	0.20	-
	rounded	-	-	-	-	-	-	-	-	0.30	0.40	0.57	0.20	0.40
brown-yellow to green-brown	angular	0.40	0.57	0.33	-	0.30	-	0.25	0.30	0.61	1.20	-	-	0.40
	sub-angular	0.40	0.71	0.33	-	0.60	-	0.50	0.61	1.21	2.00	0.57	0.40	0.40
	sub-rounded	0.20	0.43	-	0.37	0.30	0.37	0.50	0.30	2.42	2.00	0.57	0.60	0.40
	rounded	0.20	-	-	-	-	0.37	0.25	0.30	0.91	1.20	0.86	0.60	-
brown-green to black	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	1.21	0.80	0.29	-	0.40
	sub-rounded	-	-	-	-	-	0.37	0.50	0.30	0.30	0.80	0.29	0.20	-
	rounded	-	-	-	-	-	-	0.50	-	0.30	0.40	-	0.40	-
green-blue to mauve	angular	-	-	-	-	-	-	0.25	-	0.30	-	-	-	-
	sub-angular	0.20	-	-	0.37	-	-	0.25	0.30	0.61	0.40	0.29	-	-
	sub-rounded	0.20	0.14	-	-	-	-	0.50	0.30	0.91	1.60	0.29	0.20	-
	rounded	-	-	-	-	-	-	0.50	0.30	0.30	0.40	0.29	0.20	-
ZIRCON -	Total	8.60	3.29	2.67	16.30	13.50	19.26	3.75	13.94	14.55	24.00	15.71	5.60	12.80
colourless	angular	2.00	0.71	1.00	2.22	2.40	2.22	0.25	0.30	1.21	2.00	0.57	0.40	1.60
	sub-angular	1.80	1.00	0.33	2.96	2.10	3.33	0.75	2.12	2.42	4.00	3.14	0.80	2.00
	sub-rounded	1.00	0.57	0.67	2.96	1.50	2.59	0.75	3.94	2.73	4.00	3.71	1.00	2.40
	rounded	0.20	0.14	-	1.11	0.90	1.11	0.25	2.73	2.42	2.40	1.43	0.80	1.20
pinkish	angular	1.40	0.14	0.33	0.74	0.30	1.48	-	-	0.61	0.80	0.57	0.20	0.80
	sub-angular	1.00	0.29	-	1.85	1.50	2.96	0.50	1.21	1.52	2.80	1.71	0.60	1.20
	sub-rounded	0.60	0.29	0.33	2.22	2.10	3.33	0.50	2.12	2.12	4.00	2.86	1.00	2.00
	rounded	0.20	-	-	1.11	1.50	1.11	0.75	1.52	1.21	3.20	1.14	0.60	0.80
mauve-pink to purplish	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	0.20	-	-	0.37	0.30	-	-	-	-	-	-	-	0.40
	sub-rounded	0.20	0.14	-	0.74	0.60	0.74	-	-	0.30	0.40	0.29	-	0.40
	rounded	-	-	-	-	0.30	0.37	-	-	-	0.40	0.29	0.20	-
T/Z VOLUME FREQUENCY RATIO		0.21	0.61	0.25	0.05	0.11	0.08	1.07	0.22	0.77	0.53	0.29	0.57	0.16

TABLE 23.

OBSERVED NUMBER FREQUENCY PERCENTAGES - Grade size -0.062 mm.

SAMPLE NUMBER		03	19	21	27	29	31	44	51	13	15	34	35	42
TOURMALINE -	Total	0.92	5.43	2.00	0.67	2.00	0.60	0.57	0.57	6.40	4.33	2.86	0.80	0.71
colourless to pink-yellow	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-rounded	-	-	-	-	-	-	-	-	-	-	-	-	-
	rounded	-	-	-	-	-	-	-	-	-	-	-	-	-
straw-yellow to yellow-brown	angular	-	-	-	-	-	-	-	-	0.40	-	-	-	-
	sub-angular	-	0.29	-	-	-	0.30	-	-	0.40	0.33	0.71	-	-
	sub-rounded	-	-	-	-	1.00	-	-	-	0.40	0.33	-	-	-
	rounded	-	-	-	-	-	-	-	-	0.40	0.33	-	0.20	-
brown-yellow to green-brown	angular	0.46	1.43	0.80	0.33	-	0.30	-	-	0.40	0.33	-	-	-
	sub-angular	0.31	1.71	0.80	0.33	1.00	-	0.29	-	1.60	0.33	0.71	-	0.36
	sub-rounded	0.15	1.14	-	-	-	-	-	-	0.80	0.67	0.71	0.20	0.36
	rounded	-	-	-	-	-	-	-	-	-	0.33	-	-	-
brown-green to black	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	-	-	-	-	-	-	0.33	-	0.20	-
	sub-rounded	-	0.29	-	-	-	-	-	0.57	0.40	0.33	-	-	-
	rounded	-	-	-	-	-	-	0.29	-	-	0.33	-	0.20	-
green-blue to mauve	angular	-	0.29	-	-	-	-	-	-	0.40	-	-	-	-
	sub-angular	-	-	0.40	-	-	-	-	-	0.40	0.33	-	-	-
	sub-rounded	-	0.29	-	-	-	-	-	-	0.40	0.33	0.71	-	-
	rounded	-	-	-	-	-	-	-	-	0.40	-	-	-	-
ZIRCON -	Total	20.31	35.43	10.80	46.67	23.00	26.70	16.00	24.57	27.60	38.33	54.29	11.80	23.21
colourless	angular	4.62	9.14	2.80	10.00	3.00	3.60	1.14	1.14	1.60	3.33	2.86	0.60	1.79
	sub-angular	5.23	11.43	4.40	13.33	4.00	6.90	2.86	7.43	4.00	8.33	12.86	2.80	5.00
	sub-rounded	2.77	7.14	1.60	5.33	4.00	6.00	4.00	8.57	6.80	7.67	17.14	3.20	5.36
	rounded	0.92	2.57	0.80	1.33	2.00	1.50	2.29	4.00	2.80	4.00	5.71	2.20	2.14
pinkish	angular	1.85	0.57	0.40	0.67	1.00	2.40	0.57	-	1.60	2.00	1.43	0.20	0.36
	sub-angular	2.15	1.43	0.40	4.67	2.00	2.70	1.71	1.14	4.40	4.67	4.29	1.00	3.57
	sub-rounded	1.54	2.29	0.40	6.00	4.00	3.00	2.29	1.71	4.00	5.33	6.43	1.00	3.21
	rounded	0.62	0.86	-	2.67	2.00	0.60	1.14	0.57	1.60	3.00	2.86	0.60	1.07
mauve-pink to purplish	angular	-	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	-	-	-	0.67	-	-	-	-	0.40	-	-	-	0.36
	sub-rounded	0.31	-	-	1.33	1.00	-	-	-	0.40	-	0.71	-	-
	rounded	0.31	-	-	0.67	-	-	-	-	-	-	-	0.20	0.36
T/Z VOLUME FREQUENCY RATIO		0.05	0.15	0.19	0.01	0.09	0.02	0.04	0.02	0.23	0.11	0.05	0.07	0.03

Enstatite and hypersthene occur, but only rarely, and display their characteristic pale-greenish to pinkish pleochroism. Good splintery fragments of yellow-green to straw-yellow epidote are frequent in the coarser grades of all samples, and cleavage plates often give good optic-axis figures. Axial pleochroic changes determined were Z = pistachio green, Y = smoky and strongly absorbed, X = yellowish; absorption Y>Z>X. Monazite was recorded most noticeably in slide 19 (+80) as a few sub-rounded grains, roughly egg-shaped in general outline and greenish-yellow in colour, but with reddish--brown spotty stains: unspotted sub-angular greenish-yellow grains were also observed in 03 (+80). Doubtful titanite was recorded in a few samples.

Zircon, which was most commonly seen in all the finer grades, was classified into three main varieties, colourless, often prismatic euhedra with inclusions; smoky or pinkish, frequently euhedral with inclusions, and sometimes with striations or zoning marks; and mauvish-pink, rarely with inclusions, and usually sub-rounded to rounded in form. Good euhedral pinkish types with inclusions are well displayed in slides 31 (+60), 29 (+80), 27 (+115), and 29 (+115); lop-sided squat smoky euhedral forms in 21 (+115), and 31 (+115); elongated yellow-pinkish prismatic forms in 34 (+115); and colourless types, usually with inclusions, in 15 (+80), 31 (+80), 19 (+170), and 21 (+250).

Anatase is very commonly present in the medium sizes in the form of deep indigo-blue plates, occasionally also bluish-green: these are particularly well shown in slides 19, 21, 35, 44, (+115 mesh), and in 19, 44, (+170 mesh), while in the latter also occurs a nearly colourless to pale yellow variety.

A rich red-brown variety of rutile is noticeably more frequent in the finer grade sizes, particularly well displayed in sample 44 (various sizes), in 42 (+115) (good striations), and in 51 (various).

A N A L Y T I C A L   R E V I E W

STATISTICAL DATA.

In making the observed mineral counts for each of the slides, an average of 354 grains were recorded for each of 7 grade sizes of 13 samples; an overall total of more than 32,000 grains. The results obtained, computed as mineral number frequency percentages for each grade size of each sample, are recorded in tables 11-17; they are shown in greater detail, according to variations of colour and roundness distribution for tourmaline and zircon, in tables 18-23.

The quotations to two decimal places in the latter series of tables does not imply that sufficient grains were counted to justify this degree of accuracy, but only serves to better indicate relative variation frequencies. According to A.L.Dryden (1931), Krumbein and Pettijohn (1938, p.470), the probable error (P.E.) for counts (n) dealing with mineral frequencies (p) would be P.E. (no. of grains) $= 0.6745\sqrt{npq} = 0.6745\sqrt{np(1-p)}$. On this basis the maximum probable error for counts of 354 would not exceed plus or minus $1\frac{1}{4}$ grains in $3\frac{1}{2}$ ($\pm$ 35 percent) for mineral frequencies of 1 in 100, and plus or minus $3\frac{3}{4}$ grains in 35 ($\pm$ 11 percent) for mineral frequencies of 10 in 100.

TABLE 24.

CALCULATED OVERALL NOMINAL WEIGHT FREQUENCY PERCENTAGES - Size limits 0.351 mm. to 0.062 mm.

SAMPLE	NUMBER	03	19	21	27	29	31	44	51	13	15	34 35	42
TOURMALINE -	Total	1.35	0.99	0.35	0.33	0.86	0.58	2.85	3.57	9.89	11.45	6.45	1.47
colourless to pink-yellow	angular	-	-	-	-	-	-	-	-	-	-	-	-
	sub-angular	0.05	-	-	-	-	-	-	-	0.09	-	-	-
	sub-rounded	-	-	-	-	-	0.02	-	-	-	-	0.02	-
	rounded	-	-	-	-	0.03	-	-	0.11	-	-	0.02	-
straw-yellow to yellow-brown	angular	-	-	-	-	-	-	-	-	0.15	0.20	0.02	-
	sub-angular	0.03	-	-	-	0.05	0.06	-	0.09	0.49	0.48	0.21	-
	sub-rounded	0.06	0.02	-	-	0.03	0.02	0.16	0.27	0.61	0.57	0.42	0.05
	rounded	-	-	-	-	-	-	0.07	0.26	0.52	0.42	0.58	0.19
brown-yellow to green-brown	angular	0.24	0.21	0.14	-	0.10	-	0.12	0.25	0.52	0.55	0.10	0.05
	sub-angular	0.49	0.32	0.07	0.28	0.46	0.06	0.28	0.48	1.13	1.83	0.66	0.25
	sub-rounded	0.30	0.29	0.09	0.03	0.25	0.35	0.30	0.46	1.82	1.88	0.93	0.39
	rounded	0.12	0.06	0.05	-	-	0.04	0.23	0.50	1.10	1.72	1.04	0.12
brown-green to black	angular	-	-	-	-	-	-	0.05	-	0.11	-	0.06	-
	sub-angular	-	-	-	-	-	-	0.15	0.11	0.63	0.54	0.27	0.05
	sub-rounded	-	-	-	-	-	0.04	0.27	0.17	0.74	0.87	0.58	0.15
	rounded	-	-	-	-	-	-	0.46	0.41	0.76	0.98	0.93	0.12
green-blue to mauve	angular	-	-	-	-	-	-	0.07	0.09	0.09	-	-	-
	sub-angular	0.03	0.06	-	0.02	-	-	0.19	0.06	0.36	0.21	0.12	0.05
	sub-rounded	0.03	0.02	-	-	-	-	0.25	0.17	0.46	0.78	0.19	0.05
	rounded	-	-	-	-	-	-	0.25	0.10	0.27	0.44	0.34	-
ZIRCON -	Total	4.26	2.82	1.80	2.98	4.65	3.80	1.91	3.98	6.69	10.37	3.56	2.72
colourless	angular	1.18	0.70	0.53	0.27	0.70	0.67	0.12	0.06	0.61	1.07	0.16	0.24
	sub-angular	1.19	0.98	0.45	0.59	0.59	0.66	0.37	0.66	1.11	1.79	0.66	0.36
	sub-rounded	0.49	0.47	0.19	0.33	0.48	0.38	0.41	1.13	1.20	1.65	0.70	0.40
	rounded	0.06	0.09	-	0.08	0.20	0.16	0.19	0.77	1.01	0.92	0.34	0.19
pinkish	angular	0.32	0.13	0.14	0.29	0.27	0.40	-	-	0.14	0.43	0.17	0.09
	sub-angular	0.38	0.21	-	0.47	0.63	0.52	0.18	0.40	0.76	1.25	0.47	0.39
	sub-rounded	0.38	0.15	0.21	0.37	0.81	0.55	0.35	0.58	1.09	1.75	0.67	0.46
	rounded	0.08	-	0.05	0.16	0.44	0.16	0.30	0.35	0.41	1.02	0.22	0.29
mauve-pink to purplish	angular	-	-	-	0.01	-	-	-	-	-	-	-	-
	sub-angular	0.03	-	-	0.10	0.08	0.02	-	-	0.05	0.11	0.06	0.05
	sub-rounded	0.06	0.08	0.05	0.14	0.32	0.14	-	-	0.20	0.22	0.10	0.17
	rounded	0.08	-	0.19	0.03	0.14	0.14	-	0.02	-	0.16	0.09	0.07
T/Z NOMINAL WEIGHT RATIO		0.32	0.35	0.19	0.11	0.19	0.15	1.49	0.90	1.48	1.10	1.81	0.54

TABLE 25.

CALCULATED OVERALL NOMINAL WEIGHT FREQUENCY PERCENTAGES - Size limits 0.351 mm. to 0.062 mm.

FORMATION	AVERAGE	03-19-21	27-29-31	44-51-13	34 15-35-42
TOURMALINE -	Total	0.90	0.59	5.44	6.46
colourless to pink-yellow	angular	-	-	-	-
	sub-angular	0.02	-	0.03	-
	sub-rounded	-	0.01	-	0.01
	rounded	-	0.01	0.04	0.01
straw-yellow to yellow-brown	angular	-	-	0.05	0.07
	sub-angular	0.01	0.04	0.19	0.23
	sub-rounded	0.03	0.02	0.35	0.35
	rounded	-	-	0.28	0.40
brown-yellow to green-brown	angular	0.20	0.03	0.30	0.23
	sub-angular	0.29	0.27	0.63	0.91
	sub-rounded	0.23	0.21	0.86	1.07
	rounded	0.08	0.01	0.61	0.96
brown-green to black	angular	-	-	0.05	0.02
	sub-angular	-	-	0.30	0.29
	sub-rounded	-	0.01	0.39	0.53
	rounded	-	-	0.54	0.68
green-blue to mauve	angular	-	-	0.08	-
	sub-angular	0.03	0.01	0.20	0.13
	sub-rounded	0.02	-	0.29	0.34
	rounded	-	-	0.21	0.26
ZIRCON -	Total	2.96	3.81	4.19	5.55
colourless	angular	0.80	0.55	0.26	0.49
	sub-angular	0.87	0.61	0.71	0.94
	sub-rounded	0.38	0.40	0.91	0.92
	rounded	0.05	0.15	0.66	0.48
pinkish	angular	0.20	0.32	0.05	0.23
	sub-angular	0.20	0.54	0.45	0.70
	sub-rounded	0.25	0.58	0.67	0.96
	rounded	0.04	0.25	0.35	0.51
mauve-pink to purplish	angular	-	-	-	-
	sub-angular	0.01	0.07	0.02	0.07
	sub-rounded	0.06	0.20	0.07	0.16
	rounded	0.09	0.10	0.01	0.11
T/Z NOMINAL WEIGHT RATIO		0.29	0.15	1.29	1.15

TABLE 26.

OBSERVED TOURMALINE NUMBER FREQUENCY PERCENTAGES

SAMPLE NUMBER		GRADE SIZE + 0.351 mm.	+ 0.250 mm.	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	− 0.062 mm.	RANGE 0.351 to 0.062 mm. ARITH: MEAN SAMPLE	ARITH: MEAN FORMATION	NOMINAL COEFFT: SAMPLE	NOMINAL COEFFT: FORMATION
* TRIASSIC * (LIPIS) *	# 03	-	1.28	0.90	1.31	1.33	1.80	0.92	1.32		1.35	
	# 19	-	0.93	0.66	0.50	1.11	2.00	5.43	1.04		0.99	
	# 21	-	-	0.19	0.35	0.60	0.67	2.00	0.36		0.35	
	Average	-	0.74	0.58	0.72	1.01	1.49	2.78		0.91		0.90
* "UPPER" * (BENTONG) *	# 27	-	0.39	0.24	0.25	0.40	0.74	0.67	0.40		0.33	
	# 29	-	0.28	0.42	1.50	0.80	1.50	2.00	0.90		0.86	
	# 31	-	0.34	0.30	0.66	0.89	1.48	0.60	0.73		0.58	
	Average	-	0.34	0.32	0.80	0.70	1.24	1.09		0.68		0.59
* "LOWER" * (RAUB) *	# 44	-	0.99	0.94	2.08	3.89	4.00	0.57	2.38		2.85	
	# 51	-	0.89	1.54	5.63	3.77	3.03	0.57	2.97		3.57	
	# 13	-	9.15	10.29	12.30	6.20	11.21	6.40	9.83		9.89	
	Average	-	3.68	4.26	6.67	4.62	6.08	2.51		5.06		5.44
* "LOWER" * (BENTONG) *	# 15	-	6.95	7.46	11.98	16.29	12.80	4.33	11.10		11.45	
	# 34-35	-	2.94	3.73	11.80	11.05	3.89	1.83	6.68		6.45	
	# 42	-	-	0.83	2.28	2.33	2.00	0.71	1.49		1.47	
	Average	-	3.30	4.01	8.69	9.89	6.23	2.29		6.42		6.46

TABLE 27.

OBSERVED ZIRCON NUMBER FREQUENCY PERCENTAGES

SAMPLE NUMBER		GRADE SIZE + 0.351 mm.	+ 0.250 mm.	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	− 0.062 mm.	RANGE 0.351 to 0.062 mm. ARITH: MEAN SAMPLE	ARITH: MEAN FORMATION	NOMINAL COEFFT: SAMPLE	NOMINAL COEFFT: FORMATION
* TRIASSIC * (LIPIS) *	# 03	-	4.27	1.46	3.36	3.47	8.60	20.31	4.23		4.26	
	# 19	-	2.79	0.98	4.24	2.22	3.29	35.43	2.70		2.82	
	# 21	-	2.81	0.56	1.23	1.60	2.67	10.80	1.77		1.80	
	Average	-	3.29	1.00	2.94	2.43	4.85	22.18		2.90		2.96
* "UPPER" * (BENTONG) *	# 27	-	1.16	0.48	4.25	11.80	16.30	46.67	6.80		2.98	
	# 29	-	1.11	1.68	2.50	8.80	13.50	23.00	5.52		4.65	
	# 31	-	1.02	0.60	3.11	6.44	19.26	26.70	6.03		3.80	
	Average	-	1.10	0.92	3.29	9.01	16.35	32.12		6.12		3.81
* "LOWER" * (RAUB) *	# 44	-	-	0.31	1.04	2.22	3.75	16.00	1.46		1.91	
	# 51	-	-	-	1.64	5.33	13.94	24.57	4.18		3.98	
	# 13	-	5.66	2.94	2.88	3.20	14.55	27.60	5.85		6.69	
	Average	-	1.89	1.08	1.85	3.58	10.75	22.72		3.83		4.19
* "LOWER" * (BENTONG) *	# 15	-	4.32	6.27	3.90	7.43	24.00	38.33	9.18		10.37	
	# 34-35	-	0.89	0.62	2.29	6.51	10.66	33.05	4.19		3.56	
	# 42	-	-	0.28	2.03	3.67	12.80	23.21	3.76		2.72	
	Average	-	1.74	2.39	2.74	5.87	15.82	31.53		5.71		5.55

TABLE 28.

OBSERVED RUTILE NUMBER FREQUENCY PERCENTAGES

SAMPLE NUMBER		GRADE SIZE							RANGE 0.351 to 0.062 mm.			
		+ 0.351 mm.	+ 0.250 mm.	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	- 0.062 mm.	ARITH: MEAN		NOMINAL COEFFT:	
									SAMPLE	FORMATION	SAMPLE	FORMATION
TRIASSIC (LIPIS)	# 03	-	0.21	0.18	0.56	0.80	1.60	0.46	0.67		0.66	
	# 19	-	0.31	-	-	0.22	0.71	1.14	0.25		0.21	
	# 21	-	-	-	-	0.40	0.33	0.80	0.15		0.14	
	Average	-	0.17	0.06	0.19	0.47	0.88	0.80		0.36		0.34
"UPPER" (BENTONG)	# 27	-	0.39	-	0.50	1.00	0.74	2.00	0.53		0.35	
	# 29	-	0.28	0.84	0.75	1.80	2.10	2.00	1.15		1.03	
	# 31	-	0.34	-	0.66	0.67	1.11	0.30	0.56		0.45	
	Average	-	0.34	0.28	0.64	1.16	1.32	1.43		0.75		0.61
"LOWER" (RAUB)	# 44	-	-	0.31	1.30	2.22	2.75	1.14	1.32		1.71	
	# 51	-	0.89	0.51	0.70	4.44	4.24	6.29	2.16		1.80	
	# 13	-	0.65	0.49	0.79	1.40	1.52	1.20	0.97		1.10	
	Average	-	0.51	0.44	0.93	2.69	2.84	2.88		1.48		1.54
"LOWER" (BENTONG)	# 15	-	0.48	0.30	0.28	2.29	1.60	2.33	0.99		1.08	
	# 34-35	-	0.31	0.24	0.46	1.25	4.50	3.45	1.35		1.11	
	# 42	-	0.55	-	0.51	3.00	2.40	2.86	1.29		0.97	
	Average	-	0.45	0.18	0.42	2.18	2.83	2.88		1.21		1.05

TABLE 29.

CALCULATED RELATIVE PROPORTIONS OF TOURMALINE - RUTILE - ZIRCON

SAMPLE		NUMBER FREQUENCY PERCENTAGES				RELATIVE PROPORTIONS			
FORMATION	NUMBER	TOURM:	RUTILE	ZIRCON	TOTAL:	TOURM:	RUTILE	ZIRCON	TOTAL
TRIASSIC (LIPIS)	# 03	1.35	0.66	4.26	6.27	21.5	10.5	68.0	100.0
	# 19	0.99	0.21	2.82	4.02	24.6	5.2	70.2	100.0
	# 21	0.35	0.14	1.80	2.29	15.3	6.1	78.6	100.0
	Av:	0.89	0.34	2.96	4.19	20.5	7.3	72.3	100.1
"UPPER" (BENTONG)	# 27	0.33	0.35	2.98	3.66	9.0	9.6	81.4	100.0
	# 29	0.86	1.03	4.65	6.54	13.2	15.7	71.1	100.0
	# 31	0.58	0.45	3.80	4.83	12.0	9.3	78.7	100.0
	Av:	0.59	0.61	3.81	5.01	11.4	11.5	77.1	100.0
"LOWER" (RAUB)	# 44	2.85	1.71	1.91	6.47	44.1	26.4	29.5	100.0
	# 51	3.57	1.80	3.98	9.35	38.2	19.2	42.6	100.0
	# 13	9.89	1.10	6.69	17.68	55.9	6.2	37.9	100.0
	Av:	5.44	1.54	4.19	11.17	46.1	17.3	36.7	100.1
"LOWER" (BENTONG)	# 15	11.45	1.08	10.37	22.90	50.0	4.7	45.3	100.0
	34-35	6.45	1.10	3.56	11.11	58.1	9.9	32.0	100.0
	# 42	1.47	0.97	2.72	5.16	28.5	18.8	52.7	100.0
	Av:	6.46	1.05	5.55	13.06	45.5	11.1	43.3	99.9

TABLE 30.

CALCULATED TOURMALINE/ZIRCON VOLUME FREQUENCY RATIOS

SAMPLE NUMBER		GRADE SIZE							RANGE 0.351 to 0.062 mm.			
		+ 0.351 mm.	+ 0.250 mm.	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	− 0.062 mm.	ARITH: MEAN		NOMINAL COEFFT:	
									SAMPLE	FORMATION	SAMPLE	FORMATION
* TRIASSIC * (LIPIS) *	# 03	-	0.30	0.63	0.39	0.38	0.21	0.05	0.38		0.36	
	# 19	-	0.33	0.67	0.12	0.50	0.61	0.15	0.45		0.42	
	# 21	-	<0.14	0.33	0.29	0.38	0.25	0.19	<0.28		<0.28	
	Average	-	<0.26	0.54	0.27	0.42	0.36	0.13		<0.37		<0.35
* "UPPER" * (BENTONG) *	# 27	-	0.33	0.50	0.06	0.03	0.05	0.01	0.20		0.29	
	# 29	-	0.25	0.25	0.60	0.09	0.11	0.09	0.26		0.28	
	# 31	-	0.33	0.50	0.21	0.14	0.08	0.02	0.25		0.30	
	Average	-	0.30	0.42	0.29	0.09	0.08	0.04		0.24		0.29
* "LOWER" * (RAUB) *	# 44	-	>1.00	3.00	2.00	1.75	1.07	0.04	>1.76		>1.75	
	# 51	-	>1.00	>3.00	3.43	0.71	0.22	0.02	>1.67		>1.99	
	# 13	-	1.61	3.50	4.27	1.94	0.77	0.23	2.42		2.26	
	Average	-	>1.20	>3.17	3.23	1.47	0.69	0.10		>1.95		>2.00
* "LOWER" * (BENTONG) *	# 15	-	1.61	1.19	3.07	2.19	0.53	0.11	1.72		1.67	
	# 34-35	-	2.80	7.88	7.50	1.72	0.43	0.06	4.07		4.32	
	# 42	-	-	3.00	1.13	0.64	0.16	0.03	0.99		1.24	
	Average	-	1.47	4.02	3.90	1.52	0.37	0.07		2.26		2.41

TABLE 31.

CALCULATED TOURMALINE/RUTILE VOLUME FREQUENCY RATIOS

SAMPLE	NUMBER	GRADE SIZE + 0.351 mm.	+ 0.250 mm.	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	− 0.062 mm.	RANGE 0.351 to 0.062 mm. ARITH: MEAN SAMPLE	ARITH: MEAN FORMATION	NOMINAL COEFFT: SAMPLE	NOMINAL COEFFT: FORMATION
* TRIASSIC * (LIPIS) *	# 03	-	6.00	5.00	2.33	1.67	1.13	2.00	3.23		3.08	
	# 19	-	3.00	>2.00	>2.00	5.00	2.80	4.75	>2.96		>3.08	
	# 21	-	-	>1.00	>2.00	1.50	2.00	2.50	>1.30		>1.26	
	Average	-	>3.00	>2.67	>2.11	2.72	1.98	3.08		>2.50		>2.47
* "UPPER" * (BENTONG) *	# 27	-	1.00	>1.00	0.50	0.40	1.00	0.33	>0.78		>0.85	
	# 29	-	1.00	0.50	2.00	0.44	0.71	1.00	0.93		0.98	
	# 31	-	1.00	>1.00	1.00	1.33	1.33	2.00	>1.13		>1.07	
	Average	-	1.00	>0.83	1.17	0.72	1.01	1.11		>0.95		>0.97
* "LOWER" * (RAUB) *	# 44	-	>1.00	3.00	1.60	1.75	1.45	0.50	>1.76		>1.75	
	# 51	-	1.00	3.00	8.00	0.85	0.71	0.18	2.73		3.93	
	# 13	-	14.00	21.00	15.67	4.43	7.40	5.33	12.50		10.90	
	Average	-	>5.33	9.00	8.42	2.34	3.19	2.00		>5.66		>5.53
* "LOWER" * (BENTONG) *	# 15	-	14.50	24.00	43.00	7.13	8.00	1.86	19.33		18.26	
	# 34-35	-	10.00	10.25	26.25	10.17	1.89	0.74	11.71		13.35	
	# 42	-	<1.00	>3.00	4.50	0.77	0.83	>0.25	>2.02		>2.50	
	Average	-	<8.50	12.42	24.58	6.02	3.57	>0.95		11.02		11.37

TABLE 32.

CALCULATED RUTILE/ZIRCON VOLUME FREQUENCY RATIOS

SAMPLE	NUMBER	GRADE SIZE + 0.351 mm.	+ 0.250 mm.	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	− 0.062 mm.	RANGE 0.351 to 0.062 mm. ARITH: MEAN SAMPLE	ARITH: MEAN FORMATION	NOMINAL COEFFT: SAMPLE	NOMINAL COEFFT: FORMATION
* TRIASSIC * (LIPIS) *	# 03	-	0.05	0.13	0.17	0.23	0.19	0.02	0.15		0.16	
	# 19	-	0.11	<0.33	<0.06	0.10	0.22	0.02	<0.16		<0.15	
	# 21	-	<0.14	<0.33	<0.14	0.25	0.13	0.07	<0.20		<0.19	
	Average	-	<0.10	<0.26	<0.12	0.19	0.18	0.04		<0.17		<0.17
* "UPPER" * (BENTONG) *	# 27	-	0.33	<0.50	0.12	0.09	0.05	0.04	<0.22		<0.31	
	# 29	-	0.25	0.50	0.30	0.20	0.16	0.09	0.28		0.30	
	# 31	-	0.33	<0.50	0.21	0.10	0.06	0.01	<0.24		<0.29	
	Average	-	0.30	<0.50	0.21	0.13	0.09	0.05		<0.25		<0.30
* "LOWER" * (RAUB) *	# 44	-	-	1.00	1.25	1.00	0.73	0.07	0.80		0.93	
	# 51	-	>1.00	>1.00	0.43	0.80	0.31	0.26	>0.71		>0.61	
	# 13	-	0.12	0.17	0.27	0.44	0.10	0.04	0.22		0.23	
	Average	-	>0.37	>0.72	0.65	0.75	0.38	0.12		>0.58		>0.59
* "LOWER" * (BENTONG) *	# 15	-	0.11	0.05	0.07	0.31	0.07	0.06	0.12		0.12	
	# 34-35	-	0.60	0.75	0.29	0.19	0.35	0.15	0.43		0.46	
	# 42	-	1.00	1.00	0.25	0.82	0.19	0.12	0.65		0.66	
	Average	-	0.57	0.60	0.20	0.44	0.20	0.11		0.40		0.41

These would be reduced to orders of ± $1\frac{1}{4}$ grains in 10 (± 23 percent) and ± $7\frac{1}{4}$ grains in 100 (± 7 percent) respectively for total counts of not less than 1000 in each case.

Calculated overall nominal weight frequency distribution according to colour and roundness variation for each individual sample as well as formational averages, computed from the corresponding observed number frequency distribution for grade sizes between 0.351 mm and 0.062 mm diameter, are shown in tables 24 and 25 respectively. These figures have been compiled by summing the respective products of corresponding number (= volume) frequency (tables 18-22) and grade weight percentage (table 6), and dividing the total so obtained for each sample by the corresponding total weight percentage within the chosen range of grade sizes.

Tables 26-28 show the total number frequency percentages of tourmaline, zircon, and rutile, as observed respectively for each grade size, together with a compilation of arithmetic means as well as nominal coefficients of number frequency for each sample and formation average over the total range of sizes between 0.351 mm and 0.062 mm. The arithmetic means have been computed by adding the observed figures for each of the grade sizes +0.250 mm, +0.175 mm, +0.125 mm, +0.088 mm, and +0.062 mm, and dividing each sum total by five. The nominal coefficients, in contrast, have been determined by summing the respective products of corresponding grade size number frequency and grade weight percentage (table 6), and dividing the total so obtained for each sample by the corresponding total weight percentage within the same range of grade sizes.

It will be noticed from tables 26-28 that, while no very marked distinction between different samples are displayed by the frequency figures for zircon, samples numbered 03, 19, 21, 27, 29, 31, usually have frequencies of less than $1\frac{1}{2}$ percent for tourmaline and less than 1 percent for rutile, while samples numbered 44, 51, 13, 15, 34-5, 42, usually have figures higher than these amounts. This noticeable feature quite naturally leads to comparisons between the various minerals, and further observations show that, while tourmaline is less common than zircon for samples 03, 19, 21, 27, 29, 31, tourmaline is more common than zircon in the case of samples 44, 51, 13, 15, 34-5, 42, in all except the finest grade sizes. The relative proportions of tourmaline-rutile-zircon shown in table 29 have been computed from the nominal frequency coefficients for each of these minerals within the range 0.351 mm to 0.062 mm. These undoubtedly serve to bring out the distinctions between the two series of samples even more markedly.

The next step leads, again quite naturally, to the compilation of calculated volume frequency ratios instead of number frequencies. The resulting figures are displayed in tables 30-32 for each grade size of each sample and formation average. As in the case of the observed number frequency percentages, overall arithmetic means and nominal coefficients of volume frequency ratio within the range of sizes between 0.351 mm and 0.062 mm were also determined from the corresponding grade size figures, and in a similar manner. The comparisons are quite striking in the case of the tourmaline/zircon ratio, especially if plotted on a logarithmic scale.

Having successfully found a formula for distinction on the basis of relative frequency, the idea of comparative ratio was developed and extended to the consideration of colour variations and degrees of

TABLE 33.

CALCULATED TOURMALINE COLOUR RATIOS

SAMPLE NUMBER		GRADE SIZE							RANGE 0.351 to 0.062 mm.			
		+ 0.351 mm.	+ 0.250 mm.	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	- 0.062 mm.	ARITH: MEAN SAMPLE	ARITH: MEAN FORMATION	NOMINAL COEFFT: SAMPLE	NOMINAL COEFFT: FORMATION
* TRIASSIC * (LIPIS) *	# 03	-	-	-	-	-	0.29	-	0.06		0.04	
	# 19	-	-	-	-	0.25	0.08	0.19	0.07		0.08	
	# 21	-	-	-	-	-	-	0.25	-		-	
	Average	-	-	-	-	0.08	0.12	0.15		0.04		0.04
* "UPPER" * (BENTONG) *	# 27	-	-	-	-	-	1.00	-	0.20		0.04	
	# 29	-	-	-	-	-	-	-	-		-	
	# 31	-	-	-	-	-	0.33	-	0.07		0.03	
	Average	-	-	-	-	-	0.44	-		0.09		0.02
* "LOWER" * (RAUB) *	# 44	-	>1.00	2.00	1.00	1.33	1.67	1.00	>1.40		>1.40	
	# 51	-	>1.00	-	0.33	0.70	0.67	>1.00	>0.54		>0.54	
	# 13	-	0.31	1.33	0.52	0.41	0.54	0.45	0.62		0.55	
	Average	-	>0.77	1.11	0.62	0.81	0.96	>0.82		>0.85		>0.83
* "LOWER" * (BENTONG) *	# 15	-	0.26	0.25	0.39	0.84	0.52	0.63	0.45		0.47	
	# 34-35	-	0.69	0.48	1.08	0.52	0.45	0.67	0.64		0.68	
	# 42	-	-	0.50	0.29	0.75	0.25	-	0.36		0.36	
	Average	-	0.32	0.41	0.59	0.70	0.41	0.43		0.48		0.50

TABLE 34.

CALCULATED ZIRCON COLOUR RATIOS

SAMPLE NUMBER		GRADE SIZE							RANGE 0.351 to 0.062 mm.			
		+ 0.351 mm.	+ 0.250 mm.	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	- 0.062 mm.	ARITH: MEAN SAMPLE	ARITH: MEAN FORMATION	NOMINAL COEFFT: SAMPLE	NOMINAL COEFFT: FORMATION
* TRIASSIC * (LIPIS) *	# 03	-	0.05	-	-	0.08	0.05	0.03	0.04		0.04	
	# 19	-	-	-	-	0.11	0.05	-	0.03		0.04	
	# 21	-	0.17	-	0.17	0.33	-	-	0.13		0.16	
	Average	-	0.07	-	0.06	0.17	0.03	0.01		0.07		0.08
* "UPPER" * (BENTONG) *	# 27	-	0.50	-	0.13	0.18	0.07	0.06	0.18		0.22	
	# 29	-	0.33	0.33	-	0.16	0.10	0.05	0.18		0.19	
	# 31	-	-	-	0.77	0.26	0.06	-	0.22		0.22	
	Average	-	0.28	0.11	0.30	0.20	0.08	0.04		0.19		0.21
* "LOWER" * (RAUB) *	# 44	-	-	-	-	-	-	-	-		-	
	# 51	-	-	-	-	0.04	-	-	0.01		0.01	
	# 13	-	-	-	0.10	0.14	0.02	0.03	0.09		0.06	
	Average	-	-	-	0.03	0.06	0.01	0.02		0.03		0.02
* "LOWER" * (BENTONG) *	# 15	-	-	-	0.17	0.13	0.03	-	0.07		0.07	
	# 34-35	-	-	-	0.21	0.13	0.04	0.02	0.08		0.07	
	# 42	-	-	-	0.33	0.10	0.07	0.03	0.10		0.12	
	Average	-	-	-	0.24	0.12	0.05	0.02		0.08		0.09

TABLE 35.

CALCULATED TOURMALINE ROUNDNESS RATIOS

SAMPLE NUMBER		GRADE SIZE							RANGE 0.351 to 0.062 mm.			
		+ 0.351 mm.	+ 0.250 mm.	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	− 0.062 mm.	ARITH: MEAN SAMPLE	ARITH: MEAN FORMATION	NOMINAL COEFFT: SAMPLE	NOMINAL COEFFT: FORMATION
* TRIASSIC * (LIPIS) *	# 03	–	0.50	0.67	1.25	0.25	0.50	0.13	0.63		0.69	
	# 19	–	0.50	0.50	1.00	0.75	0.38	0.32	0.63		0.69	
	# 21	–	–	<1.00	0.50	1.50	<0.33	<0.11	<0.67		<0.85	
	Average	–	0.33	<0.72	0.92	0.83	<0.40	<0.19		<0.64		<0.74
* "UPPER" * (BENTONG) *	# 27	–	<1.00	<1.00	<1.00	1.00	1.00	<0.33	<1.00		<1.00	
	# 29	–	<1.00	<1.00	0.75	4.00	0.20	1.00	<1.39		<1.28	
	# 31	–	>1.00	>1.00	2.00	3.00	4.00	<0.33	>2.20		>1.75	
	Average	–	<1.00	<1.00	<1.25	2.67	1.73	<0.55		<1.53		<1.34
* "LOWER" * (RAUB-N) *	# 44	–	>2.00	>4.00	11.00	1.64	2.29	2.00	>4.19		>4.65	
	# 51	–	>2.00	3.00	2.27	12.00	1.60	>1.00	>4.17		>3.13	
	# 13	–	4.70	4.80	1.91	1.93	1.24	0.75	2.92		2.40	
	Average	–	>2.90	>3.93	5.06	5.19	1.71	>1.25		>3.76		>3.39
* "LOWER" * (BENTONG) *	# 15	–	4.00	1.91	3.13	3.26	1.47	1.83	2.75		2.72	
	# 34-35	–	5.00	11.60	7.99	2.86	4.20	3.00	6.33		6.79	
	# 42	–	–	>4.00	5.00	3.50	0.75	1.00	>2.65		>3.13	
	Average	–	3.00	>5.84	5.37	3.21	2.14	1.94		>3.91		>4.21

TABLE 36.

CALCULATED ZIRCON ROUNDNESS RATIOS

SAMPLE NUMBER		GRADE SIZE							RANGE 0.351 to 0.062 mm.			
		+ 0.351 mm.	+ 0.250 mm.	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	− 0.062 mm.	ARITH: MEAN SAMPLE	ARITH: MEAN FORMATION	NOMINAL COEFFT: SAMPLE	NOMINAL COEFFT: FORMATION
* TRIASSIC * (LIPIS) *	# 03	–	0.38	0.38	0.19	0.42	0.27	0.41	0.33		0.31	
	# 19	–	0.20	<0.25	0.47	0.17	0.43	0.50	<0.30		<0.31	
	# 21	–	0.38	0.33	0.57	1.20	0.33	0.32	0.56		0.61	
	Average	–	0.32	<0.32	0.41	0.60	0.34	0.41		<0.40		<0.41
* "UPPER" * (BENTONG) *	# 27	–	1.00	<0.50	0.53	0.84	0.93	0.55	<0.76		<0.73	
	# 29	–	0.67	0.67	0.56	1.35	1.03	1.21	0.86		0.80	
	# 31	–	<0.25	0.50	0.21	1.29	0.86	0.61	<0.62		<0.47	
	Average	–	<0.64	<0.56	0.43	1.16	0.94	0.79		<0.75		<0.67
* "LOWER" * (RAUB) *	# 44	–	–	>1.00	4.00	2.20	1.86	1.64	>1.81		>2.28	
	# 51	–	–	–	1.67	5.60	3.69	1.79	2.19		1.97	
	# 13	–	1.27	1.00	0.75	1.86	1.64	1.32	1.30		1.37	
	Average	–	0.42	>0.67	2.14	3.22	2.40	1.58		>1.77		>1.87
* "LOWER" * (BENTONG) *	# 15	–	0.67	0.60	0.62	1.36	1.65	1.14	0.98		1.05	
	# 34-35	–	>0.59	<0.67	1.07	2.08	1.88	1.75	1.26		1.17	
	# 42	–	–	>2.00	2.33	1.80	1.05	1.19	>1.44		>1.60	
	Average	–	>0.42	1.09	1.34	1.75	1.53	1.36		>1.23		>1.27

TABLE 37.

CALCULATED TOURMALINE/ZIRCON COLOUR RATIOS

SAMPLE NUMBER		GRADE SIZE							RANGE 0.351 to 0.062 mm.			
		+ 0.351 mm.	+ 0.250 mm.	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	− 0.062 mm.	ARITH: MEAN		NOMINAL COEFFT:	
									SAMPLE	FORMATION	SAMPLE	FORMATION
* TRIASSIC * (LIPIS) *	# 03	-	-	-	-	-	5.86	-	1.17		0.90	
	# 19	-	-	-	-	2.25	1.69	46.50	0.79		0.90	
	# 21	-	-	-	-	-	-	>6.25	-		-	
	Average	-	-	-	-	0.75	2.52	17.58		0.65		0.60
* "UPPER" * (BENTONG) *	# 27	-	-	-	-	-	13.67	-	2.73		0.58	
	# 29	-	-	-	-	-	-	-	-		-	
	# 31	-	-	-	-	-	5.44	-	1.09		0.54	
	Average	-	-	-	-	-	6.37	-		1.27		0.37
* "LOWER" * (RAUB) *	# 44	-	>1.00	>2.00	>4.00	16.00	25.00	56.00	>9.60		12.33	
	# 51	-	>1.00	-	>2.33	16.10	30.67	43.00	10.02		>8.88	
	# 13	-	>8.13	>8.00	5.20	2.86	25.46	15.23	>9.93		11.12	
	Average	-	>3.38	>3.33	>3.84	11.65	27.04	38.08		>9.85		10.78
* "LOWER" * (BENTONG) *	# 15	-	>4.70	>5.25	2.32	6.43	15.19	71.88	>6.78		>7.44	
	# 34-35	-	>1.46	>0.65	9.05	5.40	12.16	41.50	>5.75		>5.54	
	# 42	-	-	>0.50	0.86	7.50	3.75	-	>2.52		>1.93	
	Average	-	>2.05	>2.13	4.08	6.44	10.37	37.79		>5.02		>4.97

TABLE 38.

CALCULATED TOURMALINE/ZIRCON ROUNDNESS RATIOS

SAMPLE NUMBERS		GRADE SIZE							RANGE 0.351 to 0.062 mm.			
		+ 0.351 mm.	+ 0.250 mm..	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	− 0.062 mm.	ARITH: MEAN		NOMINAL COEFFT:	
									SAMPLE	FORMATION	SAMPLE	FORMATION
* TRIASSIC * (LIPIS) *	# 03	-	1.31	1.78	6.56	0.60	1.88	0.31	2.43		2.89	
	# 19	-	2.50	>2.00	2.14	4.50	0.90	0.63	>2.41		>2.61	
	# 21	-	<2.67	<3.00	0.88	1.25	<1.00	<0.35	<1.76		<1.71	
	Average	-	<2.16	2.26	3.19	2.12	<1.26	<0.43		2.22		2.40
* "UPPER" * (BENTONG) *	# 27	-	<1.00	<2.00	<1.88	1.19	1.07	<0.61	<1.43		<1.52	
	# 29	-	<1.50	<1.50	1.35	2.97	0.19	0.82	<1.50		<1.49	
	# 31	-	>4.00	>2.00	9.50	2.32	4.63	<0.55	>4.49		>4.77	
	Average	-	<2.17	1.83	<4.24	2.16	1.96	<0.66		<2.47		<2.59
* "LOWER" * (RAUB) *	# 44	-	>2.00	>4.00	2.75	0.74	1.23	1.22	>2.14		>1.93	
	# 51	-	>2.00	>3.00	1.36	2.12	0.43	>0.56	>1.78		>1.54	
	# 13	-	3.71	4.80	2.55	1.04	0.75	0.57	2.57		2.06	
	Average	-	>2.57	>3.93	2.22	1.30	0.80	>0.78		>2.16		>1.84
* "LOWER" * (BENTONG) *	# 15	-	6.00	3.18	5.09	2.40	0.89	1.61	3.51		3.36	
	# 34-35	-	24.25	15.80	7.44	1.42	2.22	1.64	10.23		11.34	
	# 42	-	-	>2.00	2.14	1.94	0.72	0.84	>1.36		>1.53	
	Average	-	10.08	>6.99	4.89	1.92	1.28	1.36		>5.03		>5.41

roundness displayed by both tourmaline and zircon. For determining colour ratio, the total number frequency of predominantly blue to greenish varieties was compared with that for predominantly pink to yellow-brown and colourless types. In the case of tourmaline this is simply the ratio of the last two varieties to the first three listed in tables 18-23. In the case of zircon it is the ratio of the mauve-pink varieties to colourless and plain pinkish or dusky varieties. The respective colour ratios are compiled in tables 33-34 for each grade size of each sample and formation average. Arithmetic means and nominal coefficients have also been determined from these by a process similar to that employed in the case of the volume ratios.

During the optical examination of each slide, each grain of tourmaline and zircon counted was classified, not only according to colour tone, but also whether euhedral and angular, sub-angular, sub-rounded, or rounded. Roundness ratios, as shown in tables 35-36, were computed for each grade size of each sample by taking the appropriate number frequency of sub-rounded mineral added to twice the value for rounded mineral, and dividing the total by the sum of sub-angular frequency plus twice the value of angular frequency. The same principle was followed both in the case of tourmaline and of zircon. As with the previous tables overall arithmetic means and nominal coefficients within the range of sizes between 0.351 mm and 0.062 mm were also determined from the grade size figures, and by a similar process.

Other tables were compiled for tourmaline/zircon colour ratios and roundness ratios. The former are displayed in table 37 and are purely nominal: the latter, on the other hand, are given in table 38 and serve to indicate the relative degree of wearing of the two minerals in the different samples and formations.

It must be borne in mind that all the data obtained is for partially weathered, but still coherent, quartzites which have been crushed, not unconsolidated sands. In the coarser sizes, therefore, the results have tended to be slightly vitiated by the state of imperfect disaggregation inevitable with such material. Furthermore, in the finest sizes, the under 230-mesh fraction is manifestly composed of more than one grade size. Instead of being all between 0.062 and 0.044 mm in diameter, as it should be for proper statistical comparison, it also contains grains between 0.044 and 0.031 mm, and even less than 0.031 mm in size. These are the reasons for eliminating the over 0.351 mm and under 0.062 mm grade sizes from the calculations of overall arithmetic means and nominal coefficients in the present instance. The difficulty could be overcome in future work by using one extra sieve or better, probably, by utilizing an infrasizer.

Another factor tending to distort the ratios calculated so far is the effect of sorting during original deposition. An attempt to eliminate this effect has been made by estimating the hydraulic equivalent sizes of the minerals, and by calculating the hydraulic ratios for formation averages. Rittenhouse (1943, 1944) has defined the hydraulic ratio of a heavy mineral as:

$$\frac{\text{weight of heavy mineral in a given range of sizes}}{\text{weight of light minerals of hydraulic equivalent size}} \times 100$$

Now the weight of heavy mineral in any grade size is equal to the weight frequency in the grade concentrate, multiplied by the weight of concentrate expressed as a fraction of the original sample, multiplied by the weight of the sample. Unfortunately the true mineral weight frequency in each grade size is not known, only the corresponding number frequency, which is approximately equal to the volume frequency. The mineral weight frequency may be calculated, however, by multiplying the mineral volume frequency in the grade concentrate, and the ratio of the specific gravity of the mineral to the average specific gravity of the grade concentrate. On the other hand, the weight of light minerals of hydraulic equivalent size is approximately equal to the corresponding mechanical analysis weight fraction of the original sample (mainly quartz). We can therefore derive the formula for hydraulic ratio as approximately equal to:

$$\frac{\text{number frequency \% x mineral specific gravity}}{\text{100 x average specific gravity of grade concentrate}}$$

$$\times \frac{\text{weight of grade concentrate expressed as \% of original sample}}{100}$$

$$\times \text{ weight of original sample x 100}$$

$$\div \frac{\text{H.E.S. mechanical analysis weight \% of original sample}}{100}$$

$$\div \text{ weight of original sample}$$

This may be simplified as:

$$\text{hydraulic ratio} \simeq \frac{\text{mineral no. freq. \% x grade conc. wt. \%}}{\text{hydraulic equivalent size lights weight \%}} \times \frac{\text{mineral specific gravity}}{\text{av. sp. gr. of grade conc.}}$$

Now tourmaline has a specific gravity of the order of 3.1, rutile of 4.2, and zircon of 4.7, so that if we assume the average specific gravity of the grade concentrate to be about 3.65 we obtain specific gravity ratios as follows:

for tourmaline; $\frac{3.1}{3.65} \simeq \frac{85}{100} = (100 - 15)\ \%$

for rutile; $\frac{4.2}{3.65} \simeq \frac{115}{100} = (100 + 15)\ \%$

for zircon; $\frac{4.7}{3.65} \simeq \frac{130}{100} = (100 + 30)\ \%$

thus the respective hydraulic ratios are approximately:

for tourmaline; $\frac{\text{no. freq. \% T x grade conc. wt. \%}}{\text{hydraulic equiv. size lights wt. \%}}$ less 15 %

TABLE 39.

CALCULATED PRODUCTS OF TOURMALINE NUMBER FREQUENCY PERCENTAGE AND GRADE SIZE CONCENTRATE WEIGHT PERCENTAGE OF MAIN SAMPLE

(less 15% ≏ TOURMALINE weight frequency percentage x 100) (units = 1 x 10^{-3})

SAMPLE	NUMBER	GRADE SIZE + 0.351 mm.	+ 0.250 mm.	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	− 0.062 mm.	RANGE under 0.500 mm. TOTAL PRODUCT	APPRX % WT:FREQ	RATIO T/R WTS:
* TRIASSIC * (LIPIS) *	# 03	–	39.7	9.0	52.4	38.6	36.0	7.4	183.1	1.56	2.04
	# 19	–	1.9	2.0	2.5	5.6	6.0	21.7	39.7	0.34	4.73
	# 21	–	–	0.6	1.8	3.0	2.0	2.0	9.4	0.08	2.47
	Average	–	13.9	3.9	18.9	15.7	14.7	10.4	77.4	0.66	3.08
* "UPPER" * (BENTONG) *	# 27	–	13.3	7.0	5.5	2.4	3.0	0.7	31.9	0.27	0.90
	# 29	–	0.8	1.3	4.5	1.6	3.0	2.0	13.2	0.11	0.86
	# 31	–	2.0	1.5	3.3	1.8	3.0	0.6	12.2	0.10	1.34
	Average	–	5.4	3.3	4.4	1.9	3.0	1.1	19.1	0.16	1.03
* "LOWER" * (RAUB) *	# 44	–	0.5	0.9	4.2	7.8	8.0	0.6	22.0	0.19	1.58
	# 51	–	0.9	0.8	11.3	1.9	3.0	–	17.9	0.15	1.99
	# 13	–	27.5	20.6	61.5	31.0	67.3	12.8	220.7	1.88	8.66
	Average	–	9.6	7.4	25.7	13.6	26.1	4.5	86.9	0.74	4.08
* "LOWER" * (BENTONG) *	# 15	–	20.9	14.9	35.9	48.9	51.2	8.7	180.5	1.53	8.68
	# 34-35	–	17.6	18.7	82.6	44.2	15.6	2.7	181.4	1.54	5.26
	# 42	–	–	3.7	11.4	5.8	4.0	0.7	25.6	0.22	1.31
	Average	–	12.8	12.4	43.3	33.0	23.6	4.0	129.2	1.10	5.08

TABLE 40.

CALCULATED PRODUCTS OF RUTILE NUMBER FREQUENCY PERCENTAGE AND GRADE SIZE CONCENTRATE WEIGHT PERCENTAGE OF MAIN SAMPLE

(plus 15% ≏ RUTILE weight frequency percentage x 100) (units = 1 x 10^{-3})

SAMPLE	NUMBER	GRADE SIZE + 0.351 mm.	+ 0.250 mm.	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	− 0.062 mm.	RANGE under 0.500 mm. TOTAL PRODUCT	APPRX % WT:FREQ	RATIO R/Z WTS:
* TRIASSIC * (LIPIS) *	# 03	–	6.5	1.8	22.4	23.2	32.0	3.7	89.6	1.03	0.125
	# 19	–	0.6	–	–	1.1	2.1	4.6	8.4	0.10	0.044
	# 21	–	–	–	–	2.0	1.0	0.8	3.8	0.04	0.078
	Average	–	2.4	0.6	7.5	8.8	11.7	3.0	33.9	0.39	0.082
* "UPPER" * (BENTONG) *	# 27	–	13.3	–	11.0	6.0	3.0	2.0	35.3	0.40	0.107
	# 29	–	0.8	2.5	2.3	3.6	4.2	2.0	15.4	0.18	0.185
	# 31	–	2.0	–	3.3	1.3	2.2	0.3	9.1	0.08	0.089
	Average	–	5.4	0.8	5.5	3.6	3.1	1.4	19.9	0.23	0.127
* "LOWER" * (RAUB) *	# 44	–	–	0.3	2.6	4.4	5.5	1.1	13.9	0.16	0.459
	# 51	–	0.9	0.3	1.4	2.2	4.2	–	9.0	0.10	0.452
	# 13	–	2.0	1.0	4.0	7.0	9.1	2.4	25.5	0.29	0.154
	Average	–	1.0	0.5	2.7	4.5	6.3	1.2	16.1	0.19	0.355
* "LOWER" * (BENTONG) *	# 15	–	1.4	0.6	0.8	6.9	6.4	4.7	20.8	0.24	0.090
	# 34-35	–	1.9	1.2	3.2	5.0	18.0	5.2	34.5	0.40	0.242
	# 42	–	1.7	–	2.6	7.5	4.8	2.9	19.5	0.22	0.281
	Average	–	1.7	0.6	2.2	6.5	9.7	4.3	24.9	0.29	0.204

TABLE 41.

CALCULATED PRODUCTS OF ZIRCON NUMBER FREQUENCY PERCENTAGE AND GRADE SIZE CONCENTRATE WEIGHT PERCENTAGE OF MAIN SAMPLE

(plus 30% ≃ ZIRCON weight frequency percentage x 100) (units = 1 x 10^{-3})

SAMPLE	NUMBER	GRADE SIZE							RANGE under 0.500 mm.		
		+ 0.351 mm.	+ 0.250 mm.	+ 0.175 mm.	+ 0.125 mm.	+ 0.088 mm.	+ 0.062 mm.	− 0.062 mm.	TOTAL PRODUCT	APPRX % WT:FREQ	RATIO Z/T WTS:
* TRIASSIC * (LIPIS) *	# 03	–	132.4	14.6	134.4	100.6	172.0	162.5	716.5	9.31	3.91
	# 19	–	5.6	2.9	21.2	11.1	9.9	141.7	192.4	2.50	4.85
	# 21	–	14.1	1.7	6.2	8.0	8.0	10.8	48.8	0.63	5.19
	Average	–	50.7	6.4	53.9	39.9	63.3	105.0	319.2	4.15	4.65
* "UPPER" * (BENTONG) *	# 27	–	39.4	13.9	93.5	70.8	65.2	46.7	329.5	4.28	10.33
	# 29	–	3.3	5.0	7.5	17.6	27.0	23.0	83.4	1.08	6.32
	# 31	–	6.1	3.0	15.6	12.9	38.5	26.7	102.8	1.34	8.43
	Average	–	16.3	7.3	38.9	33.8	43.6	32.1	171.9	2.23	8.36
* "LOWER" * (RAUB) *	# 44	–	–	0.3	2.1	4.4	7.5	16.0	30.3	0.39	1.38
	# 51	–	–	–	3.3	2.7	13.9	–	19.9	0.26	1.11
	# 13	–	17.0	5.9	14.4	16.0	57.1	55.2	165.6	2.15	0.75
	Average	–	5.7	2.1	6.6	7.7	26.2	23.7	71.9	0.94	1.08
* "LOWER" * (BENTONG) *	# 15	–	13.0	12.5	11.7	22.3	96.0	76.7	232.2	3.02	1.29
	# 34-35	–	5.3	3.1	16.0	26.0	42.6	49.6	142.6	1.85	0.79
	# 42	–	–	1.3	10.2	9.2	25.6	23.2	69.5	0.90	2.72
	Average	–	6.1	5.6	12.6	19.2	54.7	49.8	148.1	1.93	1.60

TABLE 42.

ESTIMATED APPROXIMATE HYDRAULIC RATIOS - Based on two grade sizes.

(mineral weight frequency % x 100) ÷ (weight frequency % lights H.E.S.)

FORMATION AVERAGE	HYDRAULIC RATIOS			RELATIVE HYDRAULIC RATIOS					
	Tourm:	Rutile	Zircon	T/R	R/Z	T/Z	T/R	R/Z	T/Z
TRIASSIC QUARTZITES * (Lipis)	0.0012	0.0010	0.0074	1.2	0.13	0.17	1	0.1	0.2
"UPPER" QUARTZITES * (Bentong)	0.0003	0.0005	0.0060	0.7	0.08	0.06	1	0.1	0.1
"LOWER" QUARTZITES * (Raub)	0.0011	0.0004	0.0019	2.7	0.23	0.62	3	0.2	0.6
"LOWER" QUARTZITES * (Bentong)	0.0023	0.0007	0.0041	3.5	0.16	0.56	4	0.2	0.6

for rutile; $\dfrac{\text{no. freq. \% R x grade conc. wt. \%}}{\text{hydraulic equiv. size lights wt. \%}}$ plus 15 %

for zircon; $\dfrac{\text{no. freq. \% Z x grade conc. wt. \%}}{\text{hydraulic equiv. size lights wt. \%}}$ plus 30 %

The mineral number frequency ($\simeq$ volume frequency) percentages are shown in tables 26-28, the grade size concentrates expressed as weight percentages of original samples, in table 6; while figures for their product are compiled in tables 39, 40, and 41, respectively for tourmaline, rutile, and zircon. The weight percentages by mechanical analysis of original sample (mainly quartz) are given in table 2.

Approximate hydraulic equivalent sizes were first estimated, in the case of all samples from the "Lower" quartzites, by plotting the average of the proportional products of number frequency percentage, respectively for tourmaline, rutile, and zircon, and the grade size concentrate expressed as mechanical analysis weight percentage of total concentrate. These values are the ones shown in figure 22, where they are compared with the mechanical size analysis weight percentage of the original sample. Idealized curves have been drawn and these give an indication of hydraulic equivalent size determined as 0.25 Ø for tourmaline, 0.8 Ø for rutile, and 1.1 Ø in the case of zircon. For the purposes of subsequent rough calculation, therefore, the hydraulic equivalent size for tourmaline was taken as ½Ø (½ grade size), for rutile as ¾Ø (1½ grade sizes), and for zircon as Ø (2 grade sizes).

Rough hydraulic ratios were then estimated by comparing, for each formation average, the ratio of absolute mineral weight frequency for tourmaline of half a grade size less than the maximum grade size weight percentage of light minerals (+ 0.125 mm) indicated by mechanical analysis of the original sample. In the case of rutile, the absolute mineral weight frequency for 1½ grade sizes less than (+ 0.125 mm) was compared, and in the case of zircon, the corresponding frequency for two grade sizes less.

Actually, instead of computing the ratio of one grade size against one hydraulic equivalent grade size, the corresponding grade size plus half a grade size each side (i.e. two grade sizes) were taken in each case for a more accurate determination. Thus grade sizes ½(+ 0.175 mm), (+ 0.125 mm), ½(+ 0.088 mm), were taken for light minerals (quartz);
grade sizes (+ 0.125 mm), (+ 0.088 mm), for tourmaline;
grade sizes (+ 0.088 mm), (+ 0.062 mm), for rutile;
grade sizes ½(+ 0.088 mm), (+ 0.062 mm), ½(- 0.062 mm), for zircon.
The hydraulic ratios so obtained, together with relative hydraulic ratios for tourmaline/rutile, rutile/zircon, and tourmaline/zircon, have been compiled for each formation average in table 42.

GRAPHICAL REPRESENTATION.

When all the statistical data had been compiled another object of this paper was brought into effect by the incorporation of what are believed to be a few new ideas, as well as adaptations of old ideas, for the graphical representation of statistical data in connection with heavy mineral studies.

FIGURE 4 - CHARTS SHOWING OBSERVED NUMBER FREQUENCY COLOUR DISTRIBUTION

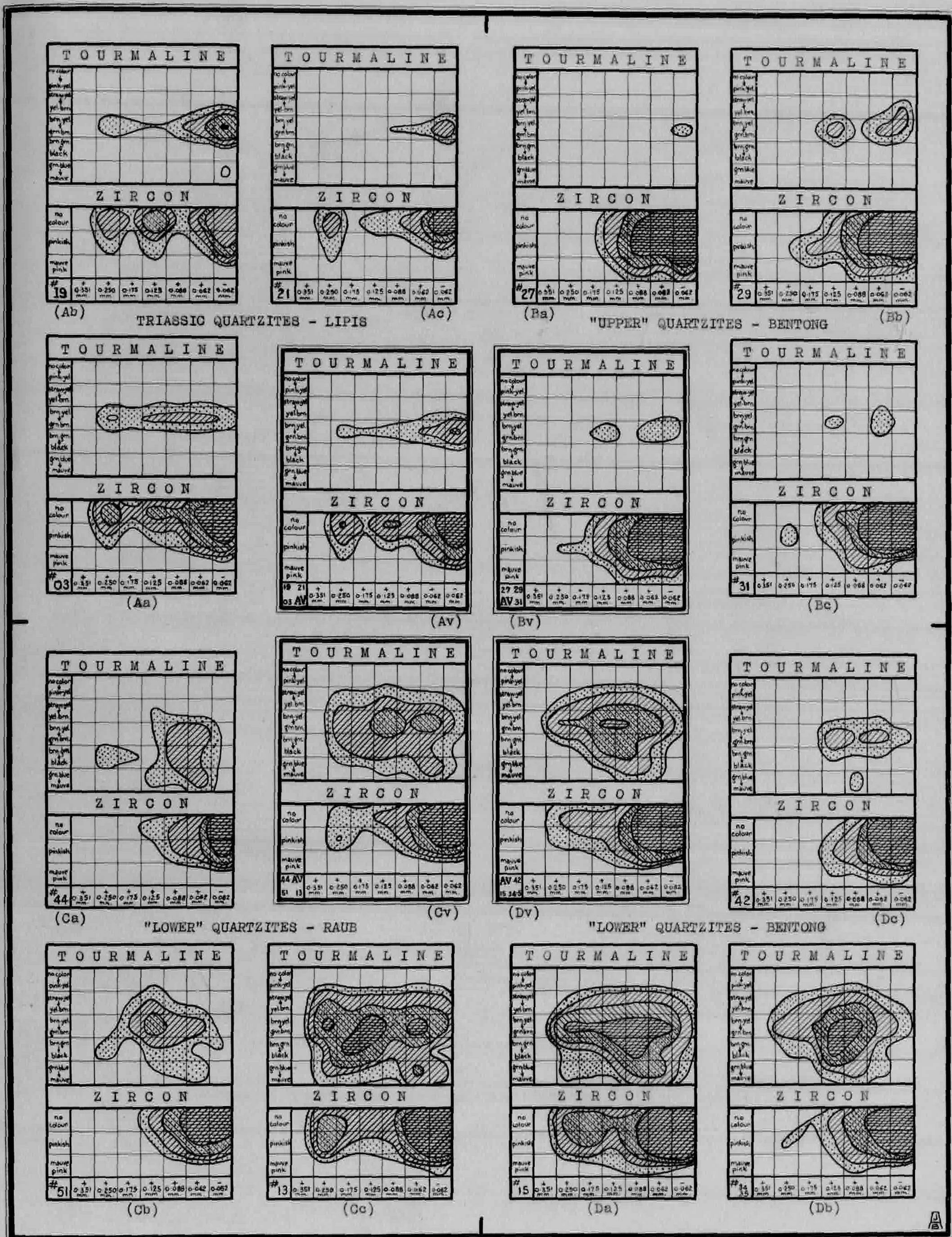
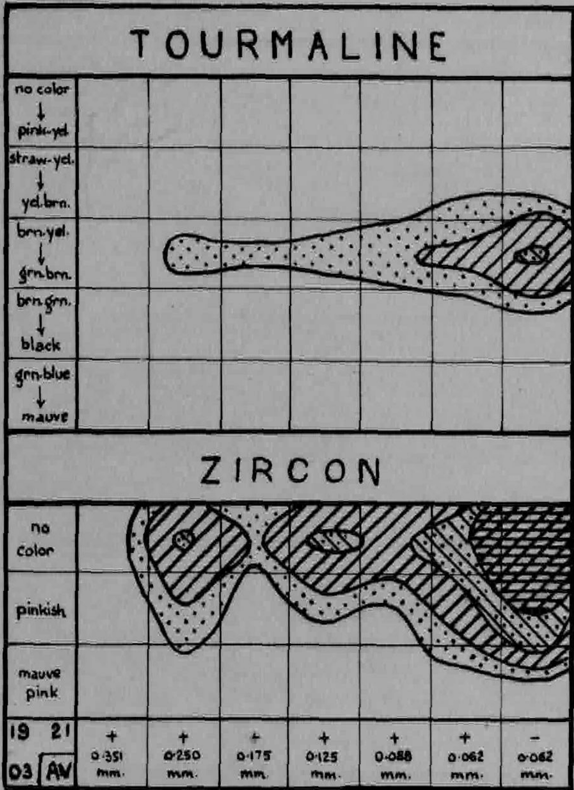


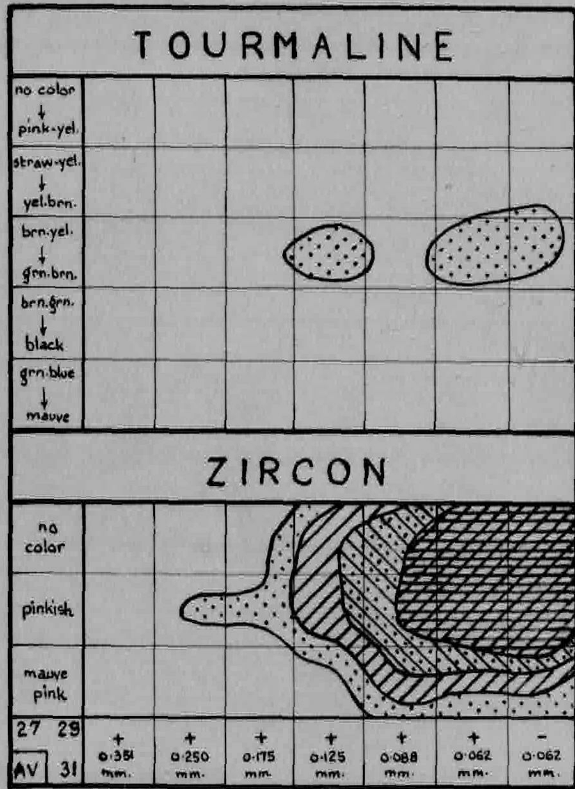
FIGURE 4(v) - CHARTS SHOWING NUMBER FREQUENCY COLOUR DISTRIBUTION

FORMATIONAL AVERAGES - based on grade sizes 0.351 mm to 0.062 mm.

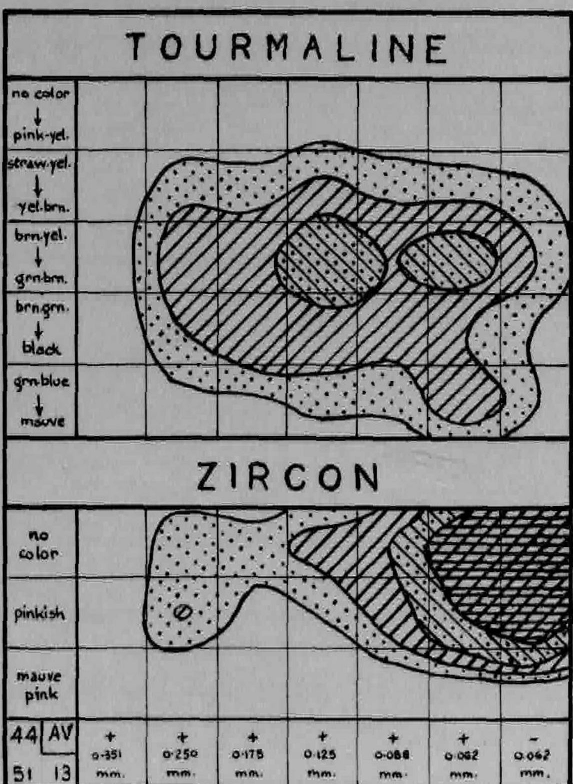
under 0.50 % | 0.50 - 0.99 % | 1.00 - 1.99 % | 2.00 - 3.99 % | over 4.00 %



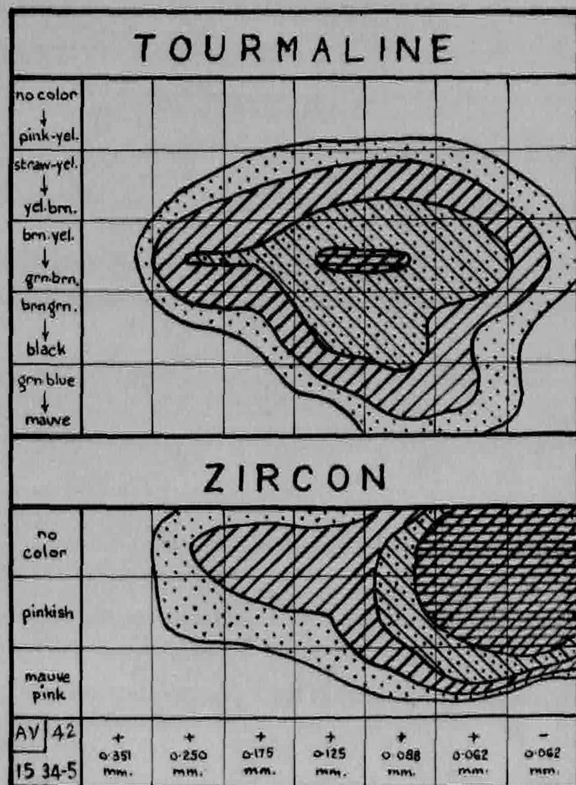
(Av)
TRIASSIC QUARTZITES - LIPIS



(Bv)
"UPPER" QUARTZITES - BENTONG



(Cv)
"LOWER" QUARTZITES - RAUB



(Dv)
"LOWER" QUARTZITES - BENTONG

FIGURE 5 - CHARTS SHOWING OBSERVED NUMBER FREQUENCY ROUNDNESS DISTRIBUTION

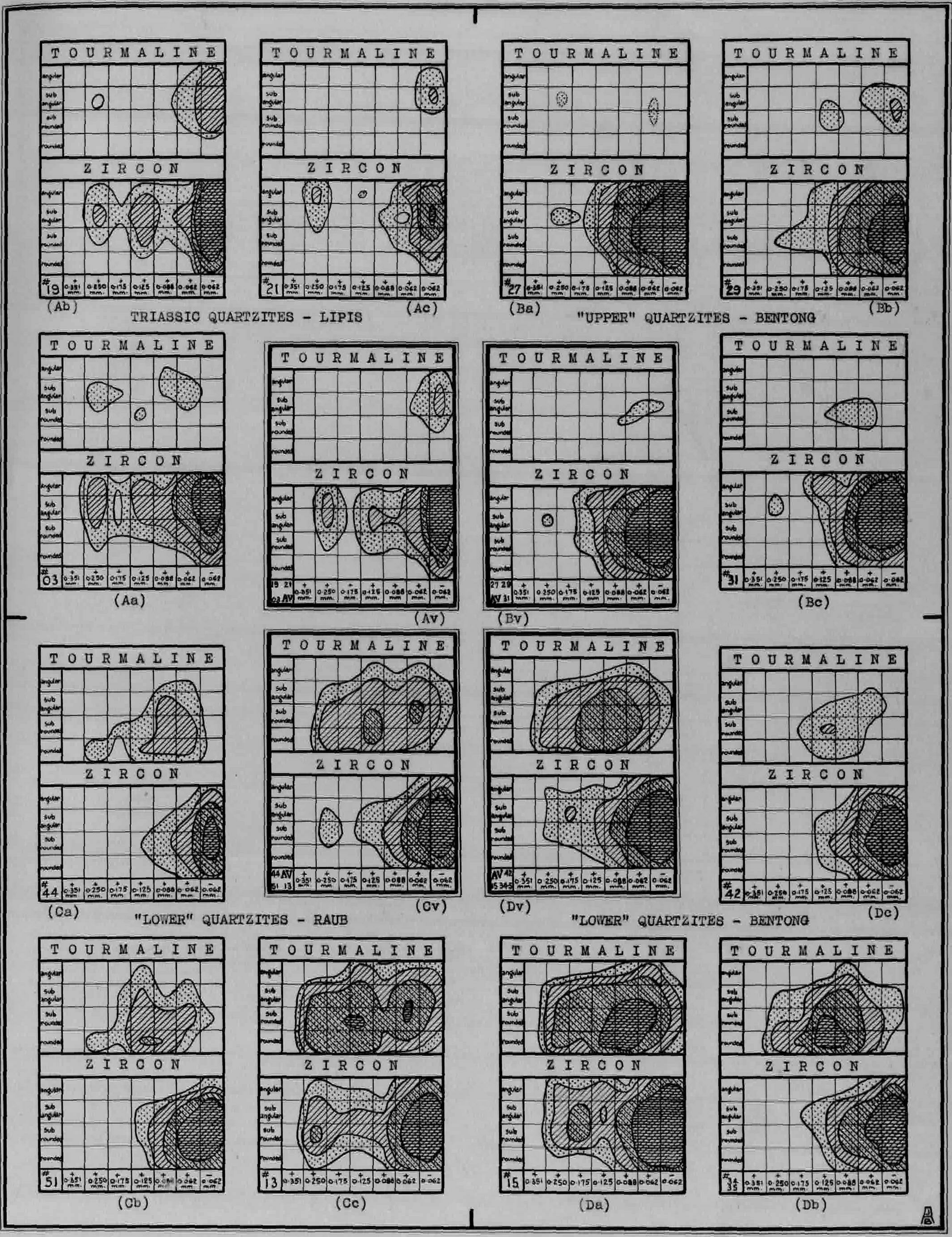


FIGURE 5(v) - CHARTS SHOWING NUMBER FREQUENCY ROUNDNESS DISTRIBUTION

FORMATIONAL AVERAGES - based on grade sizes 0.351 mm to 0.062 mm.

under 0.50 % | 0.50 - 0.99 % | 1.00 - 1.99 % | 2.00 - 3.99 % | over 4.00 %

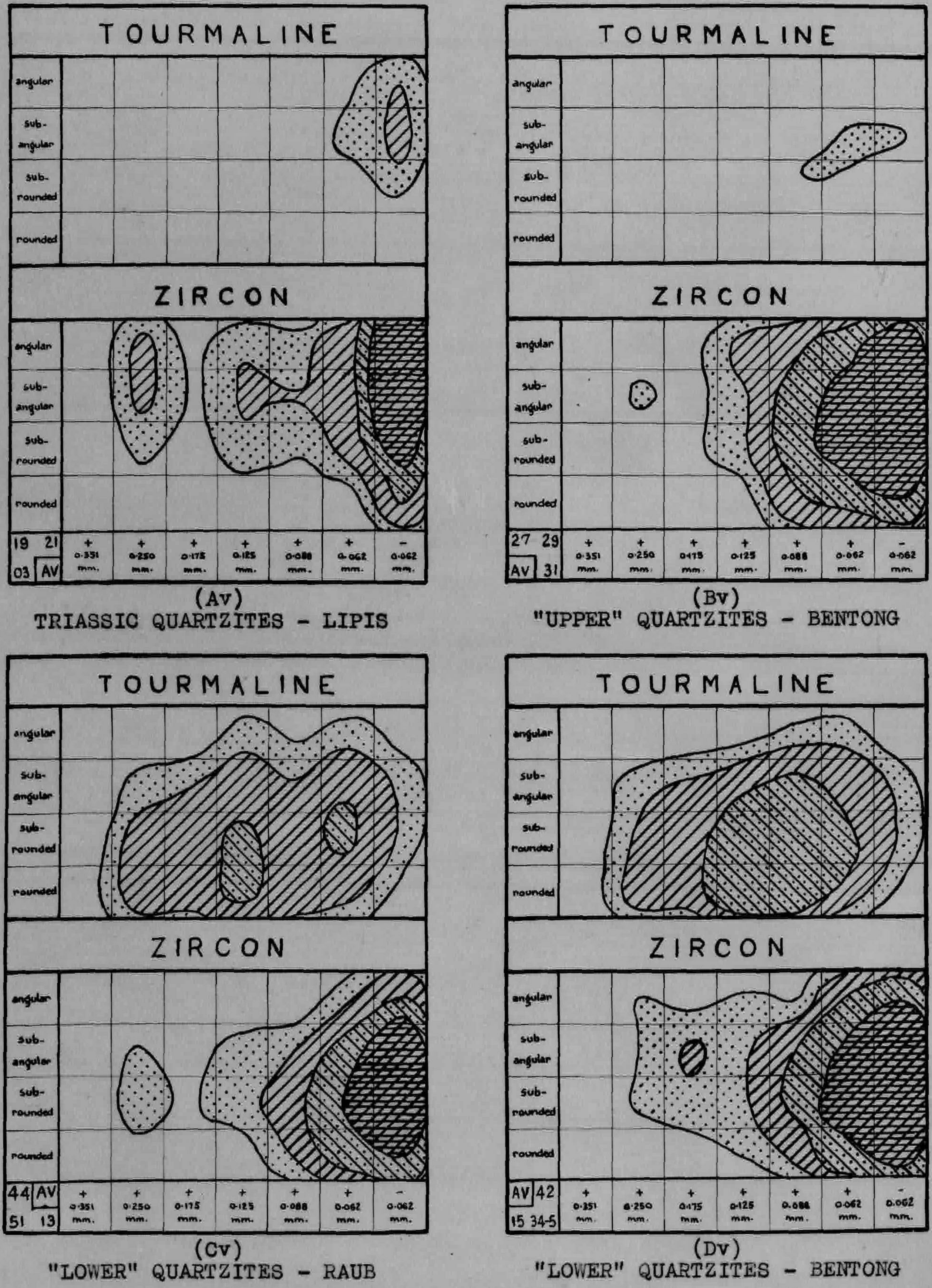


FIGURE 6.

COMPARATIVE CHART OF CALCULATED WEIGHT FREQUENCY DISTRIBUTION - Size limits 0.351-0.062 mm.

SAMPLE NUMBER		03	19	21	27	29	31	44	51	13	15	34 35	42
TOURMALINE -	Total	////	///	//	//	///	///	///+	///+	/+++	/+++	//++	////
colourless to pink-yellow	angular												
	sub-angular	*								*			
	sub-rounded						*					*	
	rounded					*			*			*	
straw-yellow to yellow-brown	angular									/	/	*	
	sub-angular	*				*	*		*	//	//	/	
	sub-rounded	*	*			*	*	/	//	///	///	//	*
	rounded							*	//	///	//	///	/
brown-yellow to green-brown	angular	/	/	/		*		/	//	///	///	*	*
	sub-angular	//	//	*	//	//	*	//	/	////	////	///	//
	sub-rounded	//	//	*	*	//	//	//	//	////	////	///	//
	rounded	/	*	*			*	/	///	////	////	////	/
brown-green to black	angular							*		*		*	
	sub-angular							/	*	///	///	//	*
	sub-rounded						*	//	/	///	///	///	/
	rounded							//	//	///	///	///	/
green-blue to mauve	angular							*	*	*			
	sub-angular	*	*		*			/	*	//	/	/	*
	sub-rounded	*	*					//	/	//	///	/	*
	rounded							//	*	//	//	//	
ZIRCON -	Total	//++	///+	////	///+	//++	///+	////	///+	//++	/+++	///+	///+
colourless	angular	////	///	///	//	///	///	/	*	///	////	/	/
	sub-angular	////	////	//	///	///	///	//	///	////	////	///	//
	sub-rounded	//	//	/	//	//	//	//	////	////	////	//	//
	rounded	*	*		*	/	/	/	///	////	///	//	/
pinkish	angular	//	/	/	//	//	//			/	//	/	*
	sub-angular	//	/		//	///	///	/	//	///	///	//	//
	sub-rounded	//	/	/	//	///	///	/	//	///	///	//	//
	rounded	*		*	/	//	/	//	//	//	////	/	//
mauve-pink to purplish	angular				*								
	sub-angular	*			*	*	*			*	*	*	*
	sub-rounded	*	*	*	/	//	/			/	/	*	/
	rounded	*		/	*	/	/		*		/	*	*
T/Z NOMINAL WEIGHT RATIO		//	//	/	*	/	/	////	///	////	////	////	///

* 0.01 - 0.11 % / 0.12 - 0.24 % // 0.25 - 0.49 % /// 0.50 - 0.99 %

//// 1.00 - 1.99 % ///+ 2.00 - 3.99 % //++ 4.00 - 7.99 % /+++ over 8.00 %

FIGURE 7.

COMPARATIVE CHART OF CALCULATED WEIGHT FREQUENCY DISTRIBUTION - Size limits 0.351-0.062 mm.

FORMATION	AVERAGE	03-19-21	27-29-31	44-51-13	15-35-42 (34)
TOURMALINE -	Total	///	///	//#	//#
colourless to pink-yellow	angular				
	sub-angular	*		*	
	sub-rounded		*		*
	rounded		*	*	*
straw-yellow to yellow-brown	angular			*	*
	sub-angular	*	*	/	/
	sub-rounded	*	*	//	//
	rounded			//	//
brown-yellow to green-brown	angular	/	*	//	/
	sub-angular	//	//	///	//
	sub-rounded	/	/	///	///
	rounded	*	*	///	///
brown-green to black	angular			*	*
	sub-angular			//	//
	sub-rounded		*	//	///
	rounded			///	///
green-blue to mauve	angular			*	
	sub-angular	*	*	/	/
	sub-rounded	*		//	//
	rounded			/	//
ZIRCON -	Total	///+	///+	//#	//#
colourless	angular	///	///	//	//
	sub-angular	///	///	///	///
	sub-rounded	//	//	///	///
	rounded	*	/	///	//
pinkish	angular	/	//	*	/
	sub-angular	/	///	//	//
	sub-rounded	//	///	//	///
	rounded	*	//	//	///
mauve-pink to purplish	angular				
	sub-angular	*	*	*	*
	sub-rounded	*	/	*	/
	rounded	*	*	*	*
T/Z NOMINAL WEIGHT RATIO		//	/	////	////

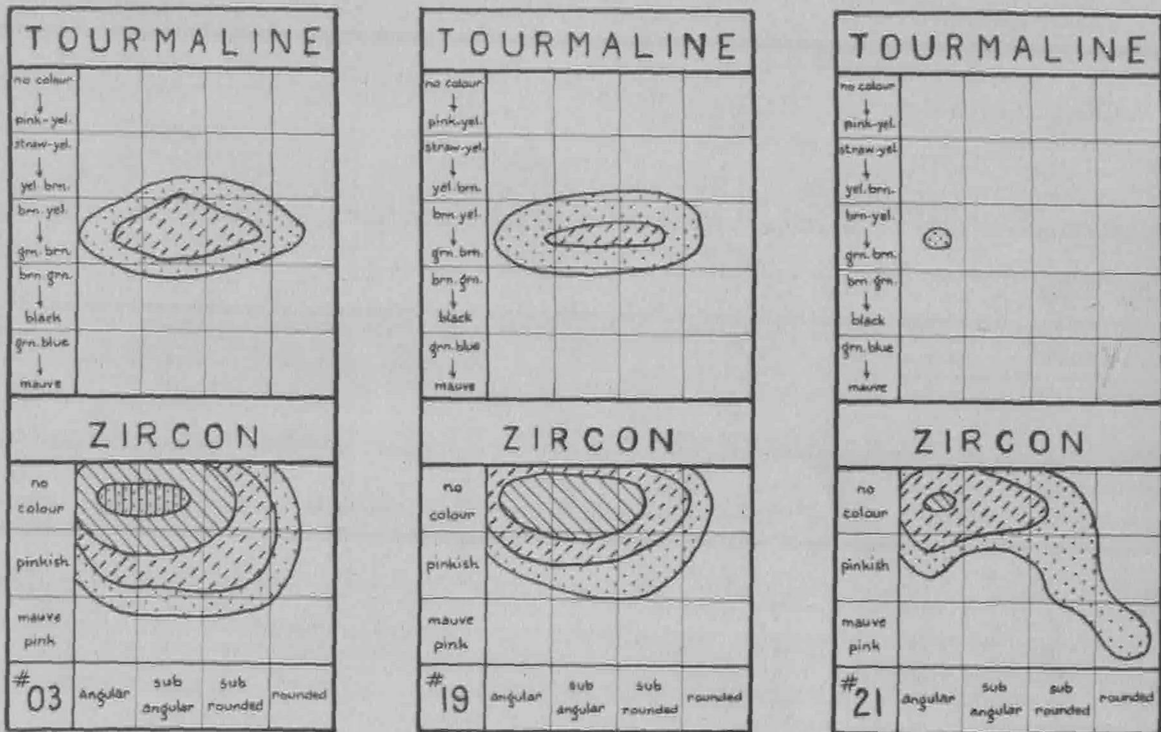
* 0.01 - 0.11 % / 0.12 - 0.24 % // 0.25 - 0.49 % /// 0.50 - 0.99 %

//// 1.00 - 1.99 % ///+ 2.00 - 3.99 % //# 4.00 - 7.99 % /## over 8.00 %

FIGURE 8 - WEIGHT FREQUENCY DISTRIBUTION CHARTS

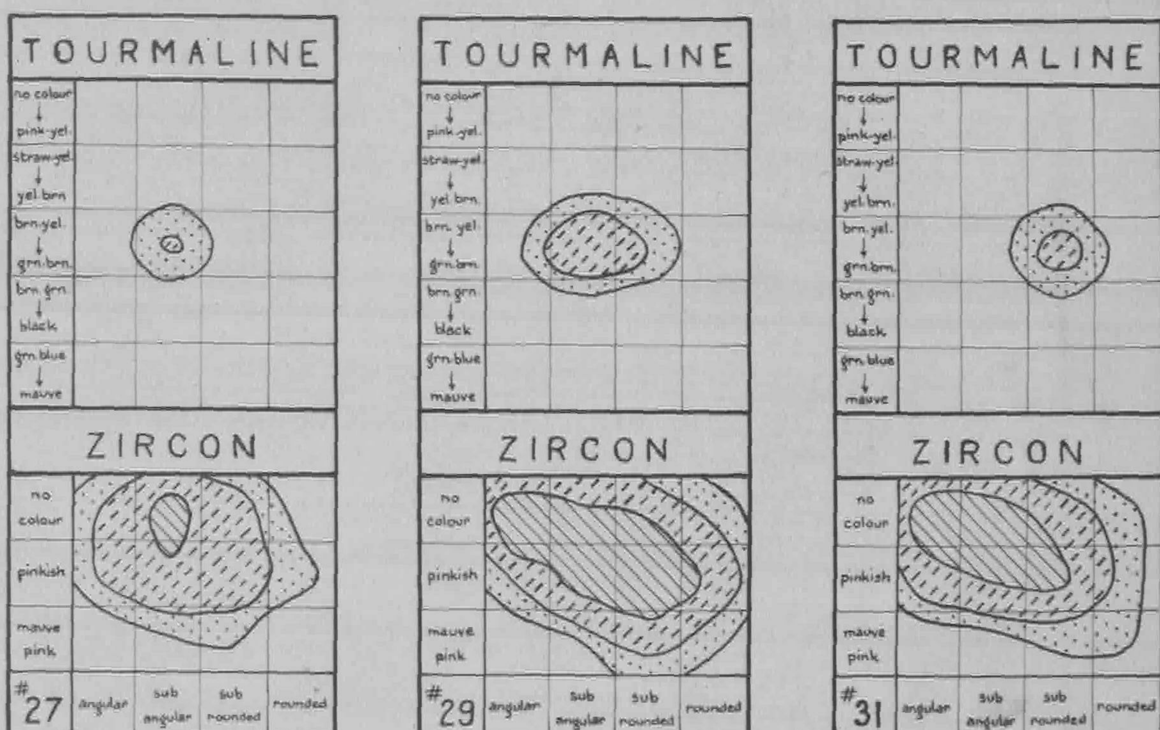
INDIVIDUAL SAMPLES - based on grade sizes 0.351 mm. to o.062 mm.

under 0.12 % | 0.12 - 0.24 % | 0.25 - 0.49 % | 0.50 - 0.99 % | 1.00 - 1.99 %



(a) (b) (c)

T R I A S S I C   Q U A R T Z I T E S - L I P I S   D I S T R I C T



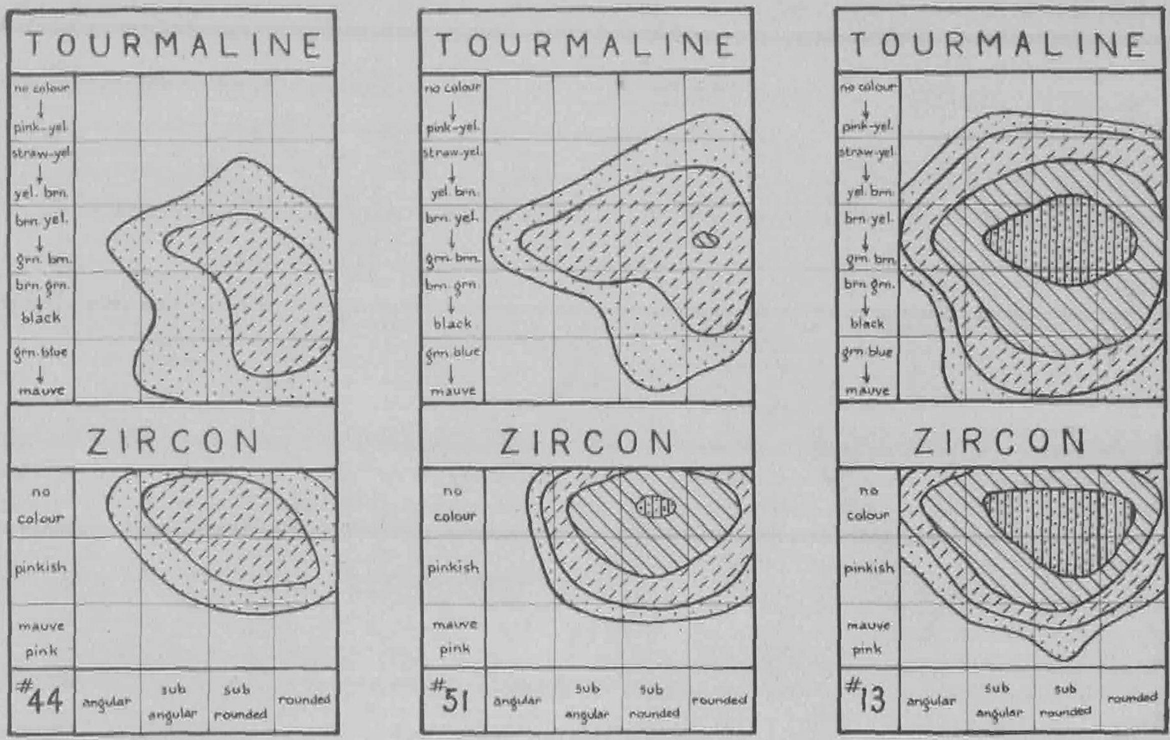
(d) (e) (f)

" U P P E R "   Q U A R T Z I T E S - B E N T O N G   D I S T R I C T

FIGURE 9 - WEIGHT FREQUENCY DISTRIBUTION CHARTS

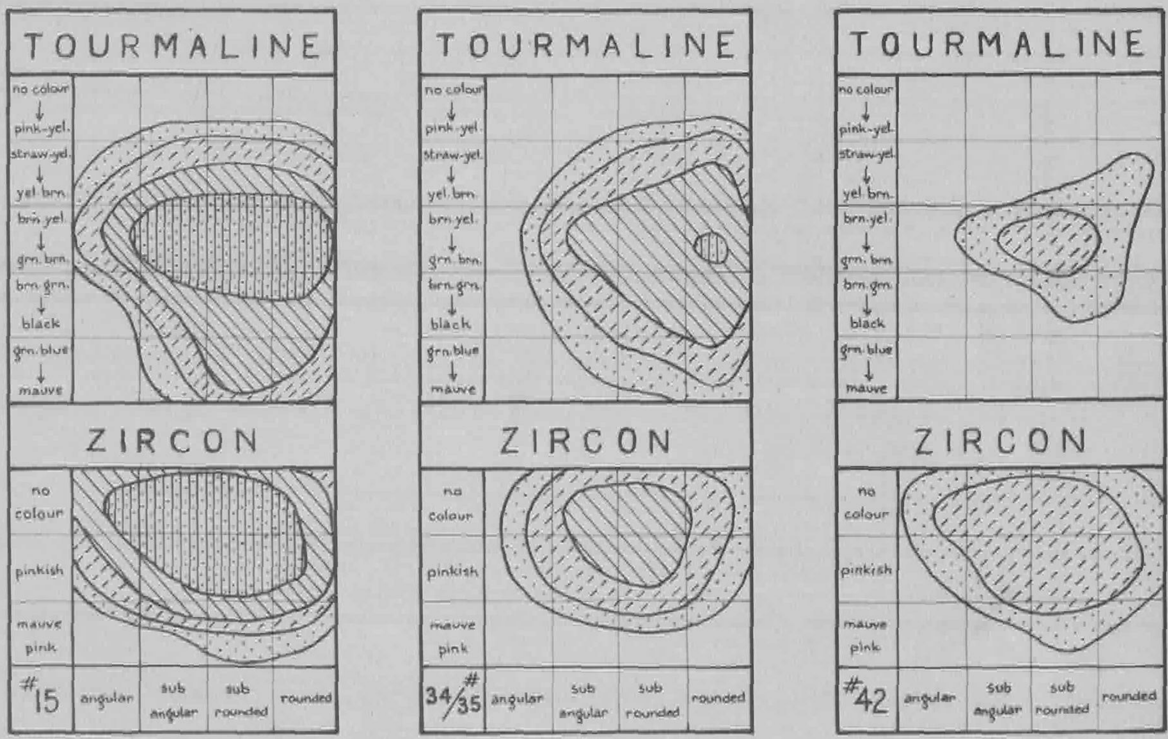
INDIVIDUAL SAMPLES - based On grade sizes 0.351 mm. to 0.062 mm.

under 0.12 % | 0.12 - 0.24 % | 0.25 - 0.49 % | 0.50 - 0.99 % | 1.00 - 1.99 %



(a) (b) (c)

"LOWER" QUARTZITES - RAUB DISTRICT



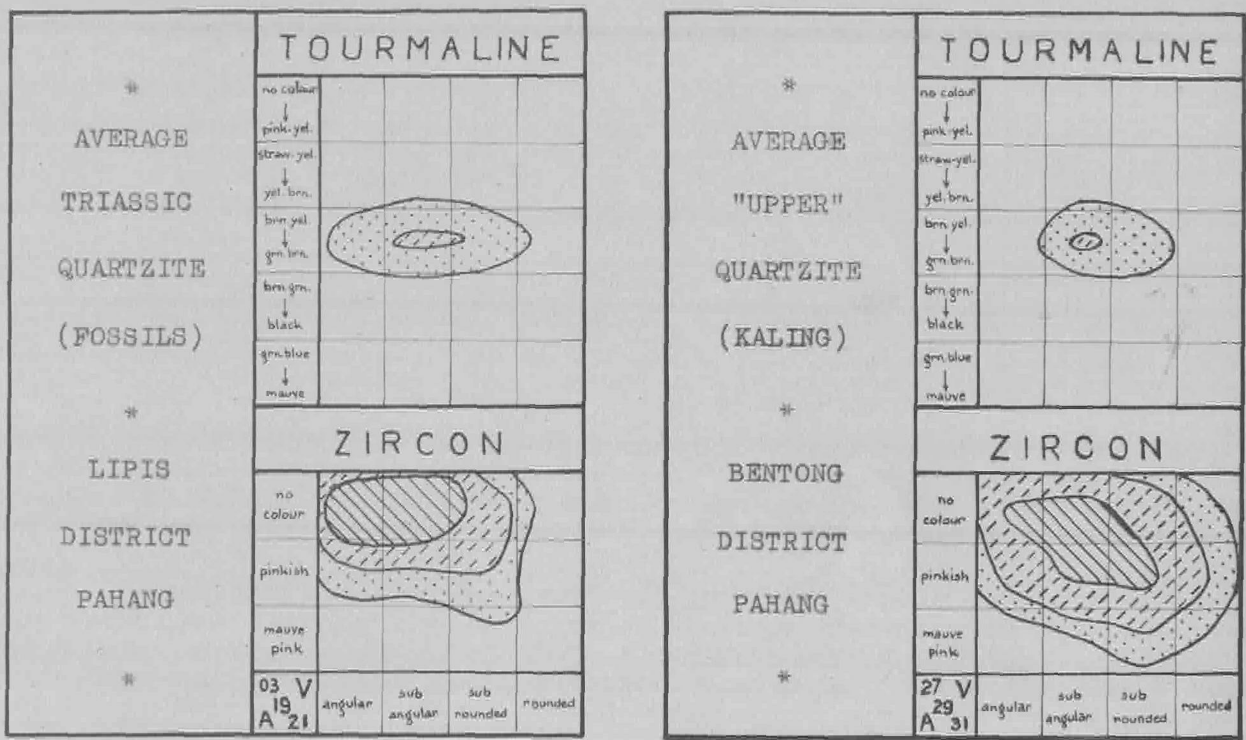
(d) (e) (f)

"LOWER" QUARTZITES - BENTONG DISTRICT

FIGURE 10 - WEIGHT FREQUENCY DISTRIBUTION CHARTS

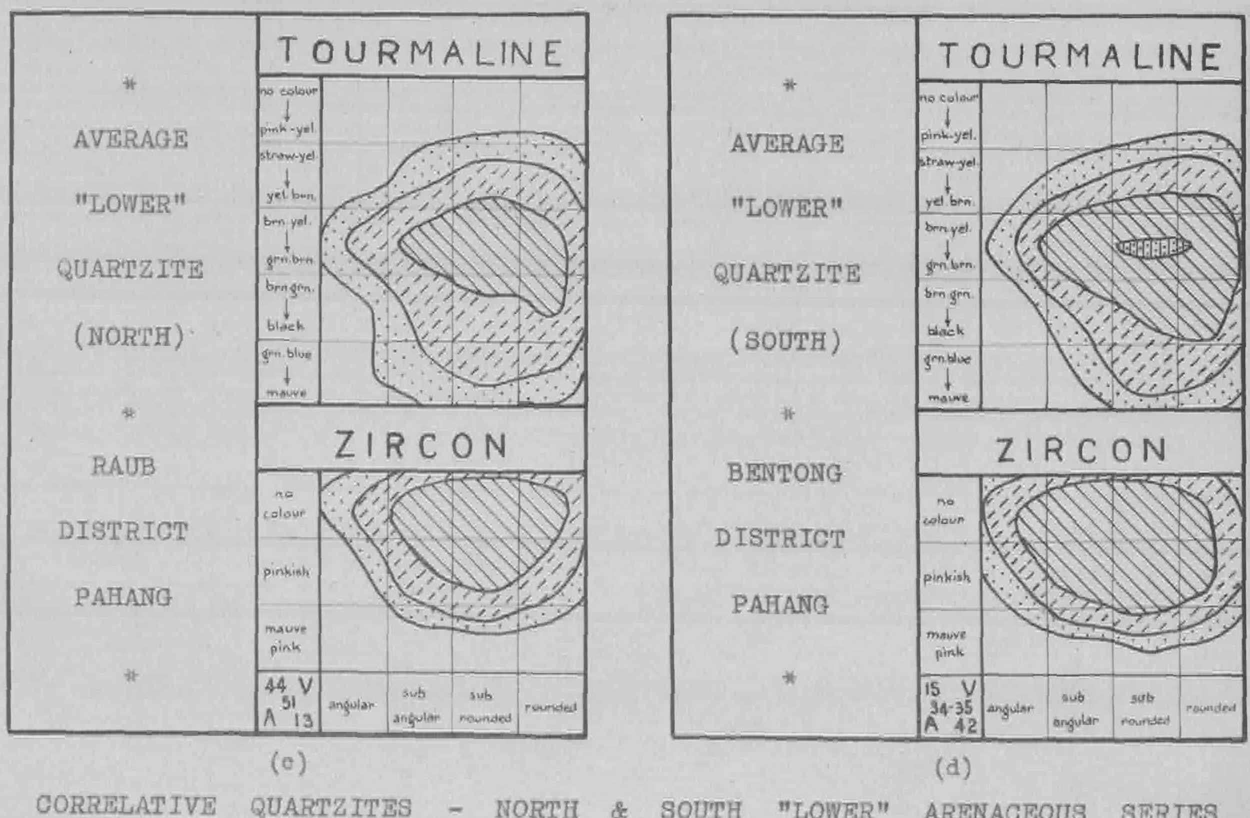
FORMATIONAL AVERAGES - based on grade sizes 0.351 mm. to 0.062 mm.

under 0.12 % | 0.12 - 0.24 % | 0.25 - 0.49 % | 0.50 - 0.99 % | 1.00 - 1.99 %



(a) (b)

CORRELATIVE QUARTZITES - TRIASSIC & "UPPER" ARENACEOUS SERIES

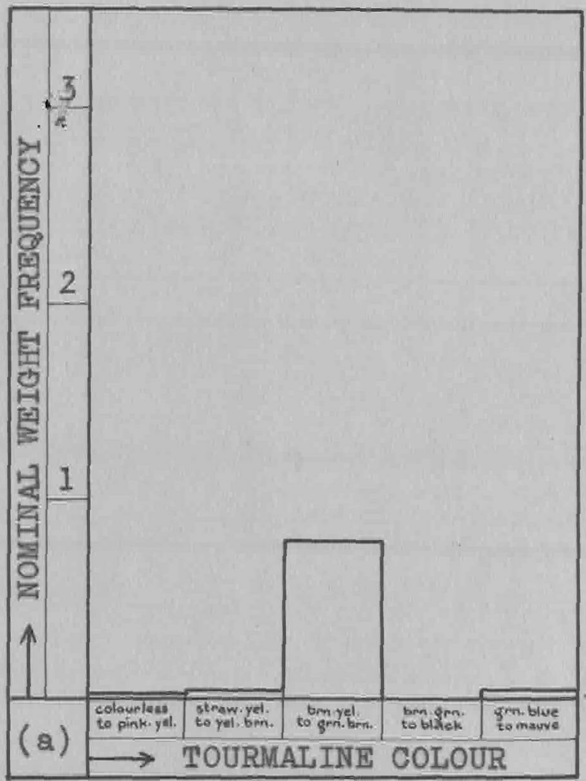


(c) (d)

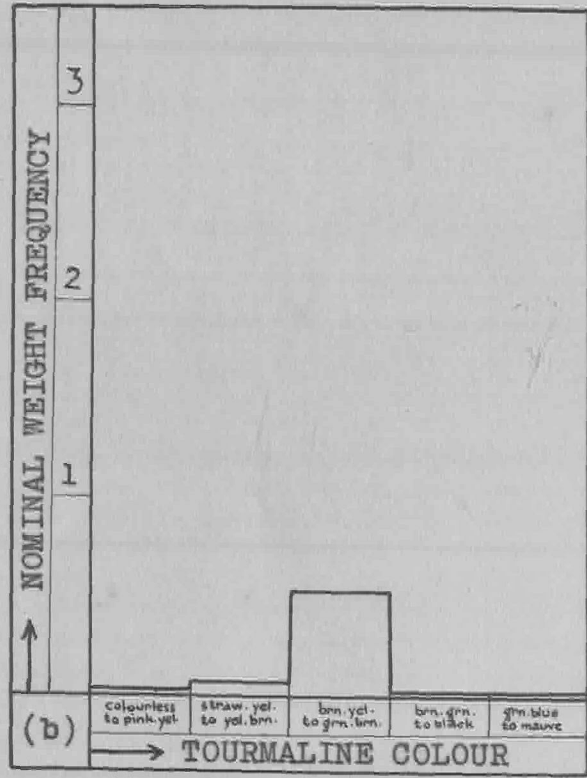
CORRELATIVE QUARTZITES - NORTH & SOUTH "LOWER" ARENACEOUS SERIES

FIGURE 11.

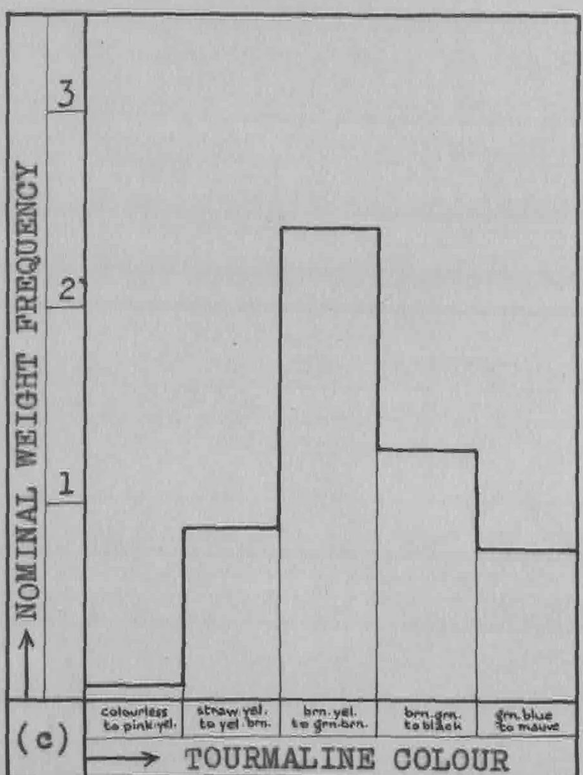
HISTOGRAMS SHOWING COMPARATIVE AVERAGE TOURMALINE COLOUR DISTRIBUTION



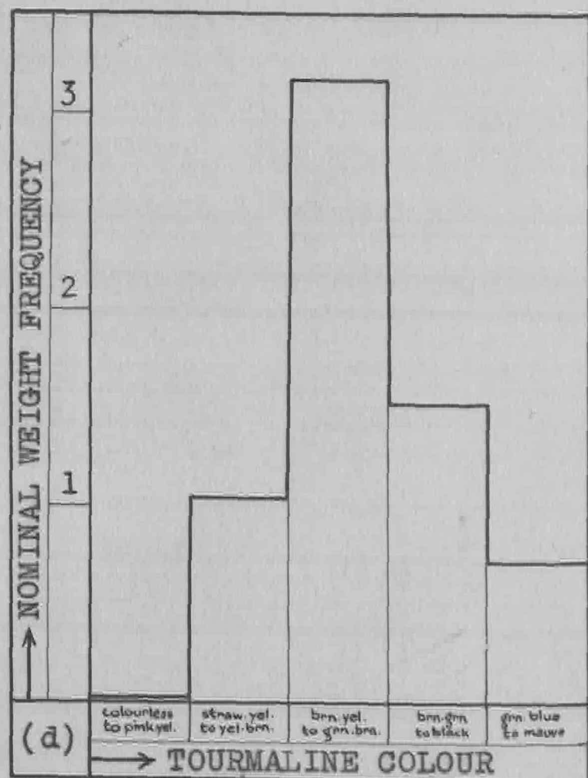
TRIASSIC QUARTZITES - LIPIS



"UPPER" QUARTZITES - BENTONG



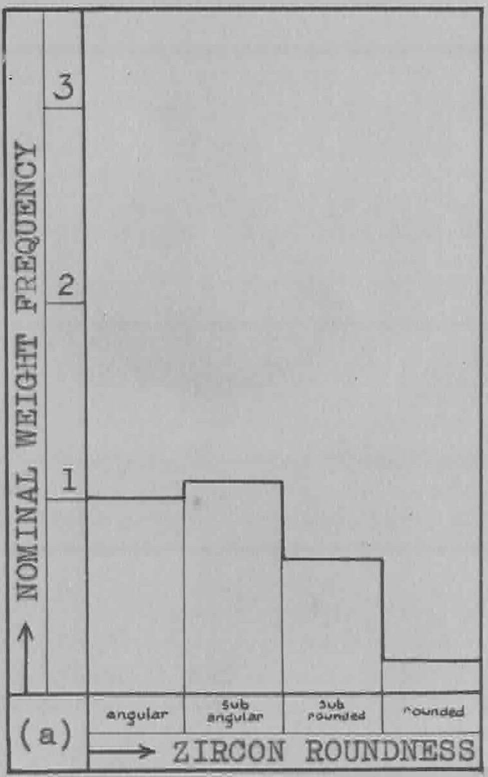
"LOWER" QUARTZITES - RAUB



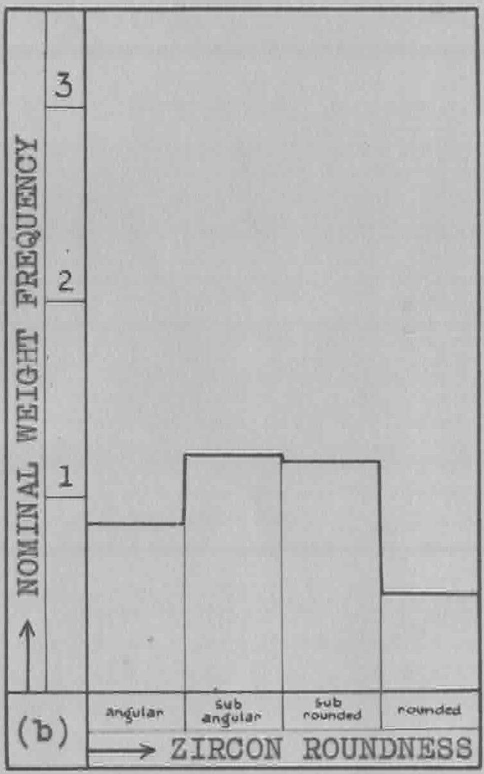
"LOWER" QUARTZITES - BENTONG

FIGURE 12.

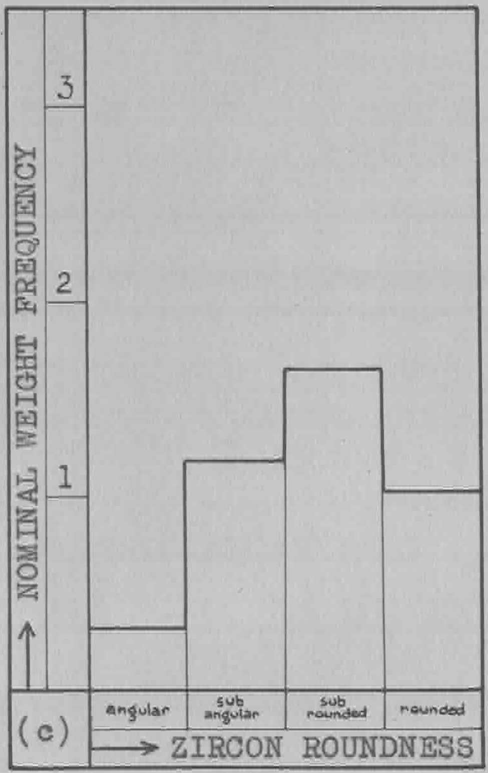
HISTOGRAMS SHOWING COMPARATIVE AVERAGE ZIRCON ROUNDNESS DISTRIBUTION



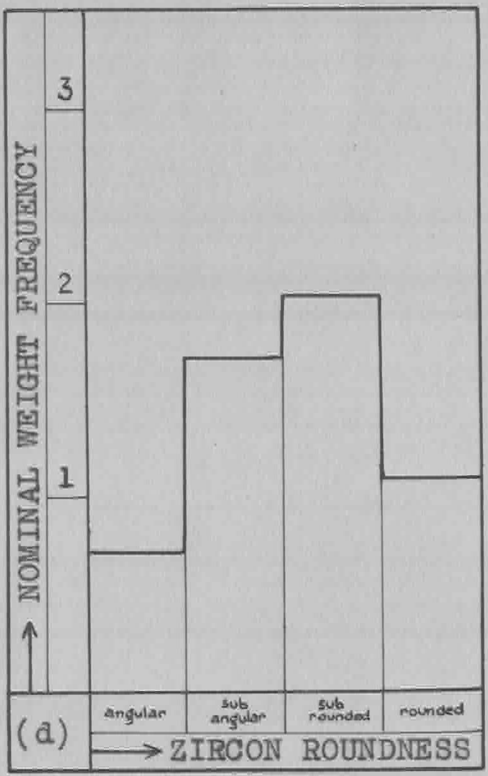
TRIASSIC QUARTZITES - LIPIS



"UPPER" QUARTZITES - BENTONG



"LOWER" QUARTZITES - RAUB



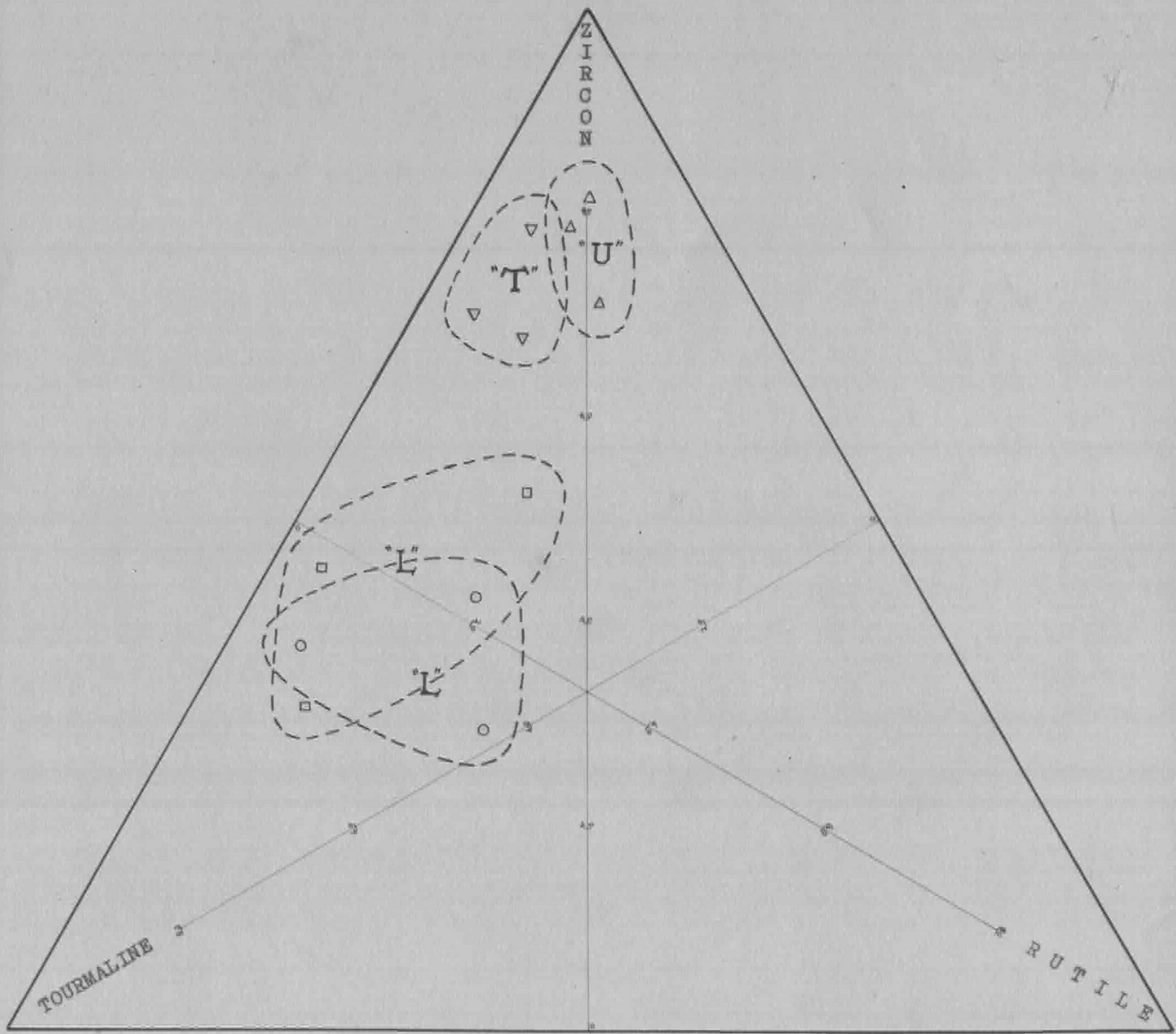
"LOWER" QUARTZITES - BENTONG

FIGURE 13.

TRILINEAR DIAGRAM

SHOWING COMPARATIVE VARIATIONS OF

RELATIVE PROPORTIONS OF TOURMALINE-RUTILE-ZIRCON.



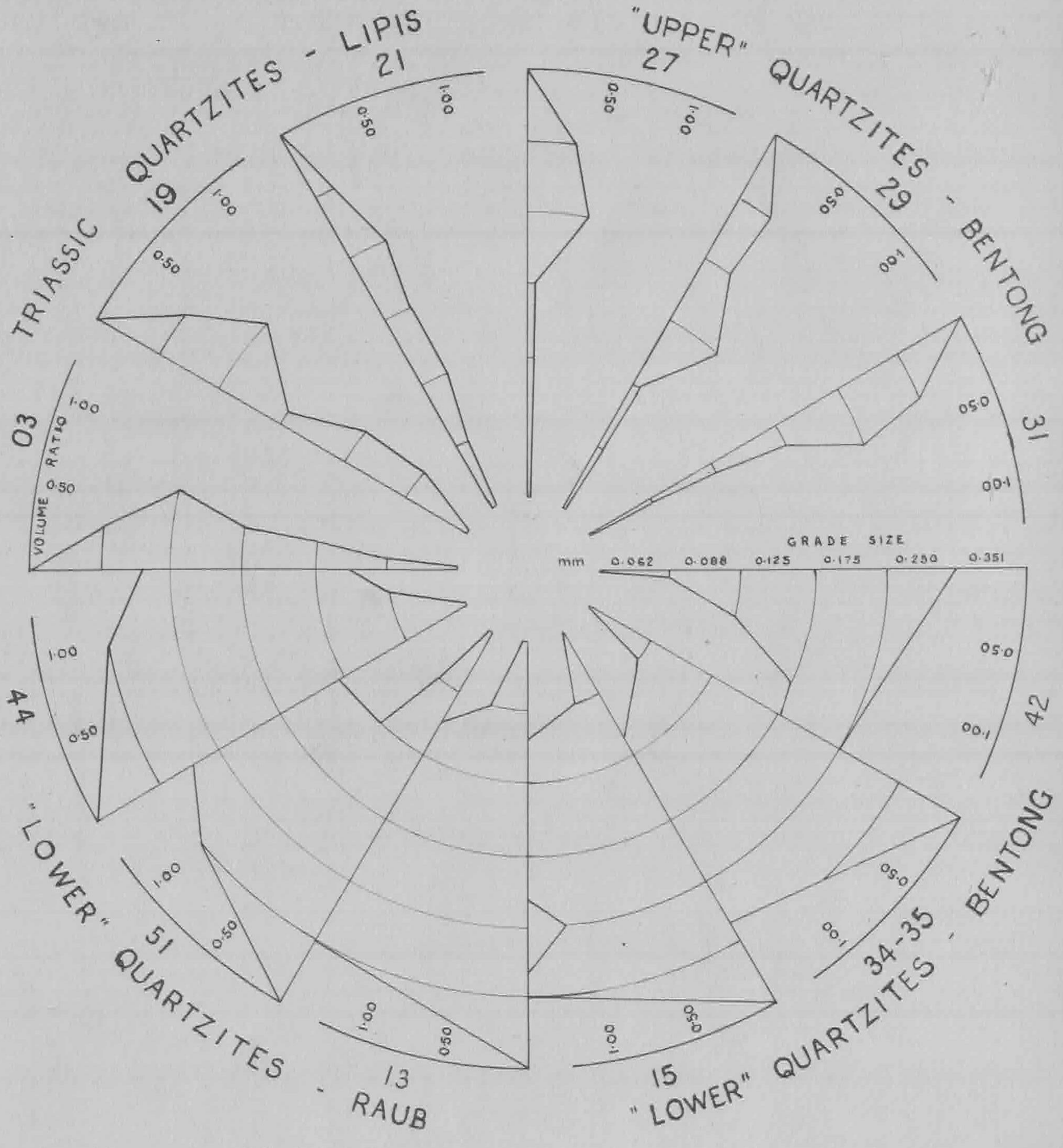
"T" - TRIASSIC QUARTZITES - "L" - "LOWER" QUARTZITES -

"U" - "UPPER" QUARTZITES - "L" - "LOWER" QUARTZITES -

FIGURE 14.

POLAR DIAGRAM

SHOWING COMPARATIVE INDIVIDUAL VARIATIONS OF TOURMALINE/ZIRCON VOLUME RATIO WITH GRADE SIZE.



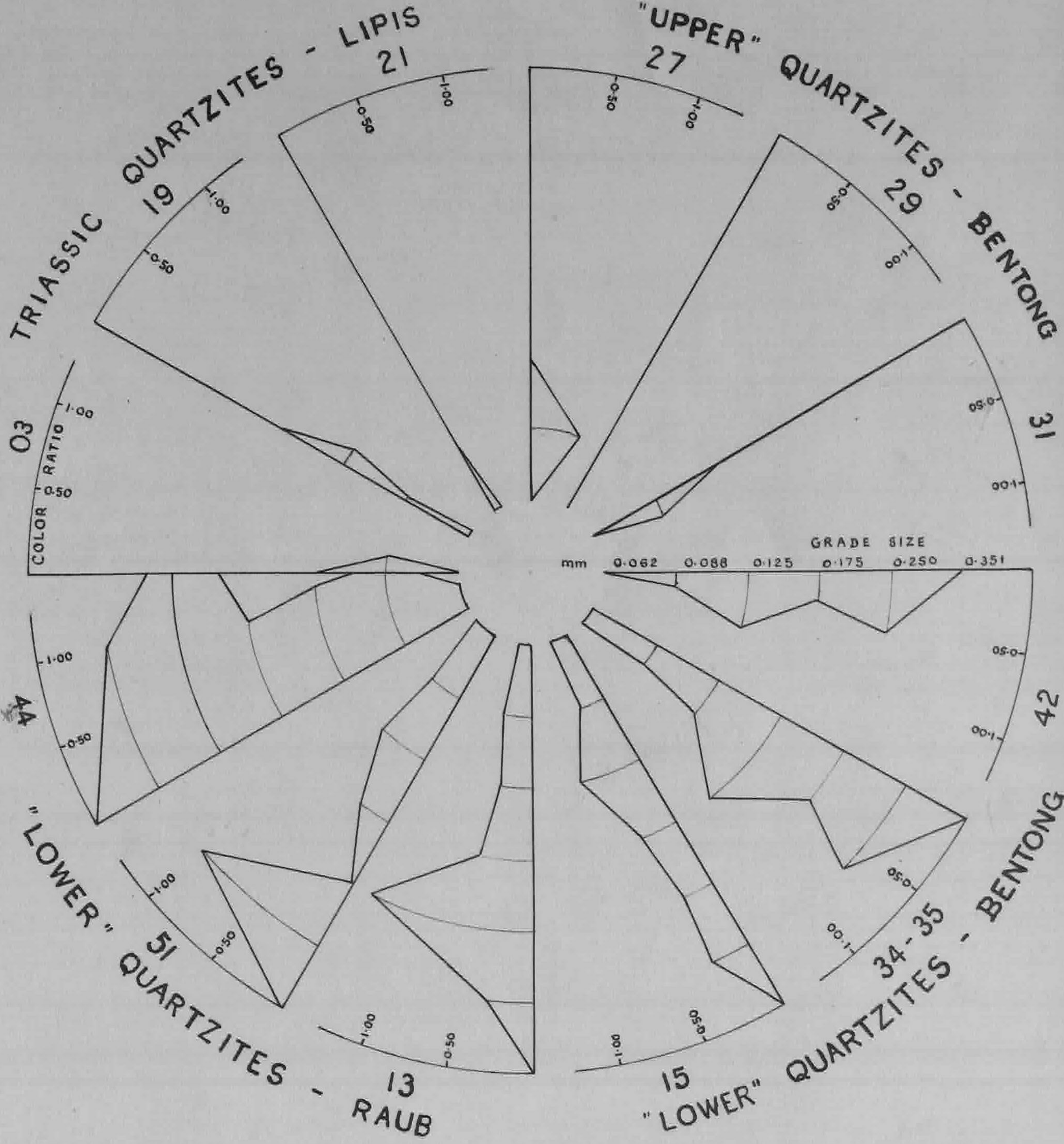


FIGURE 15.

POLAR DIAGRAM

SHOWING COMPARATIVE INDIVIDUAL VARIATIONS OF TOURMALINE COLOUR RATIO WITH GRADE SIZE.

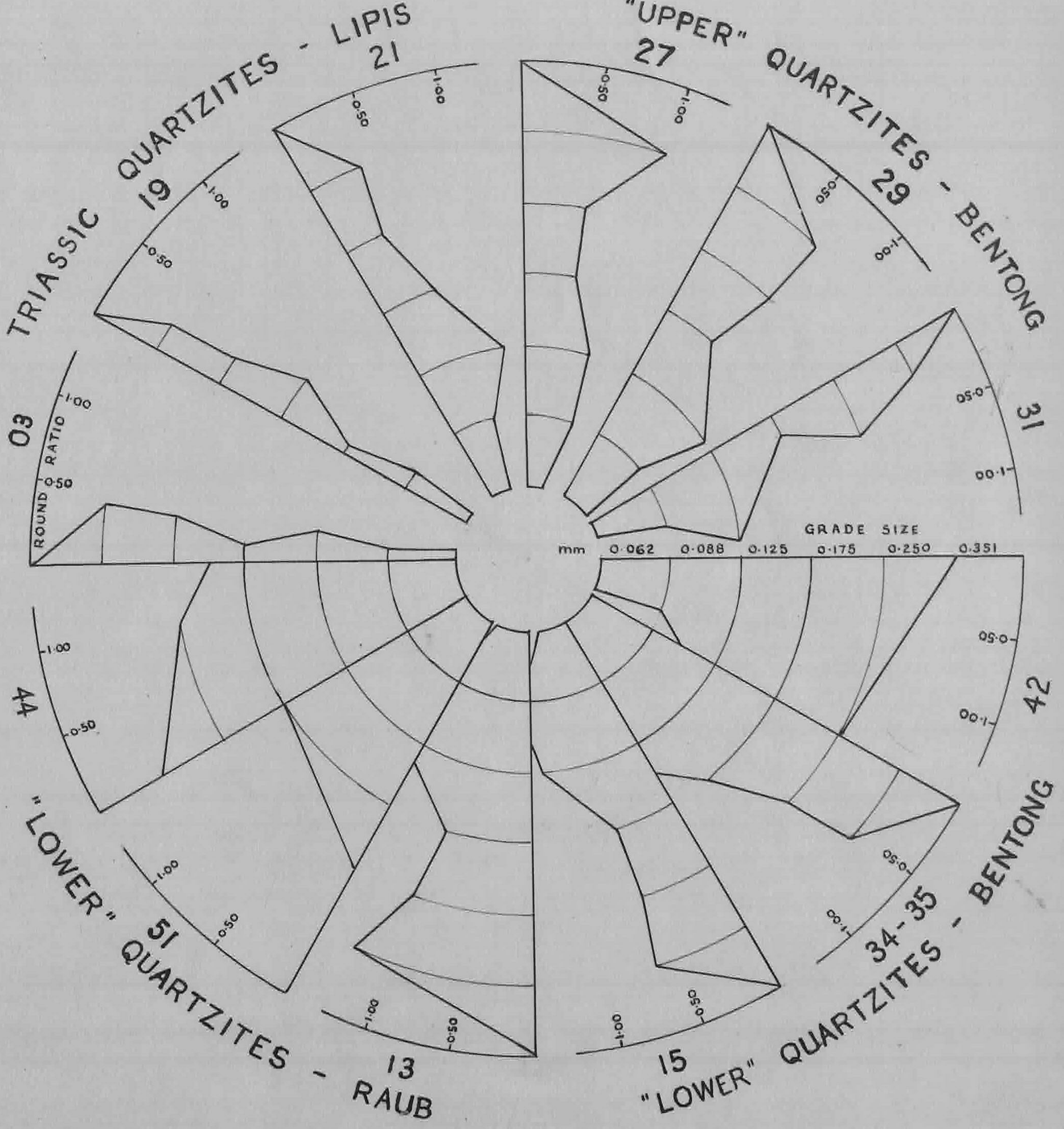


FIGURE 16.

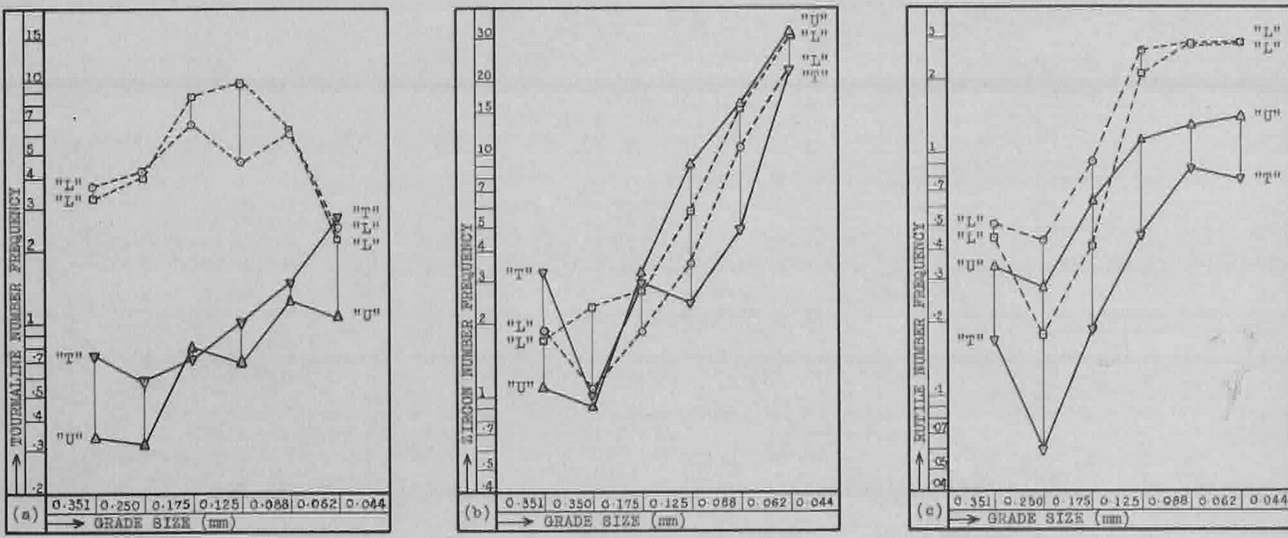
POLAR DIAGRAM

SHOWING COMPARATIVE INDIVIDUAL VARIATIONS OF ZIRCON ROUNDNESS RATIO WITH GRADE SIZE.

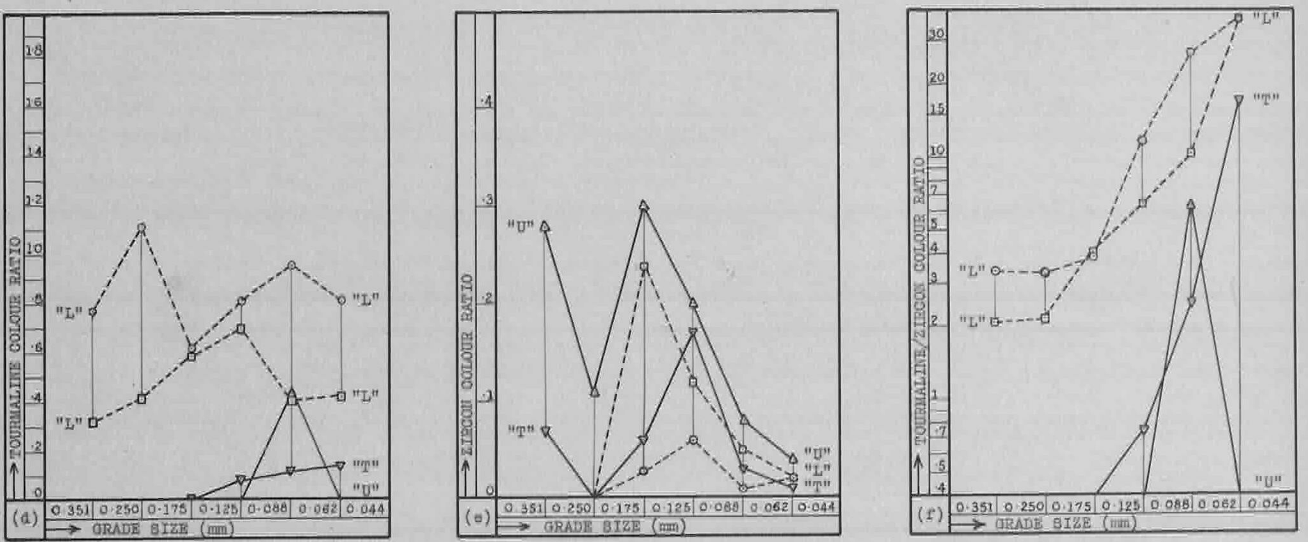
FIGURE 17.

DIAGRAMS SHOWING VARIATION CHARACTERISTICS WITH GRADE SIZE FOR FORMATIONAL AVERAGES.

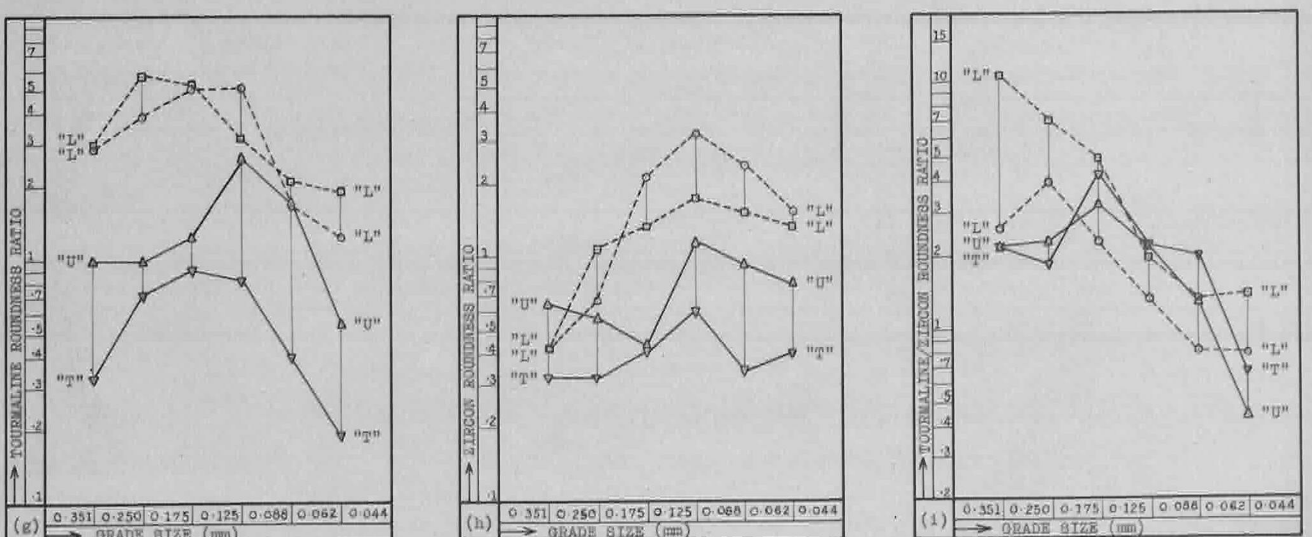
▽ TRIASSIC QUARTZITES - LIPIS   △ "UPPER" QUARTZITES - BENTONG   ○ "LOWER" QUARTZITES - RAUB   □ "LOWER" QUARTZITES - BENTONG



FORMATION AVERAGE NUMBER FREQUENCIES



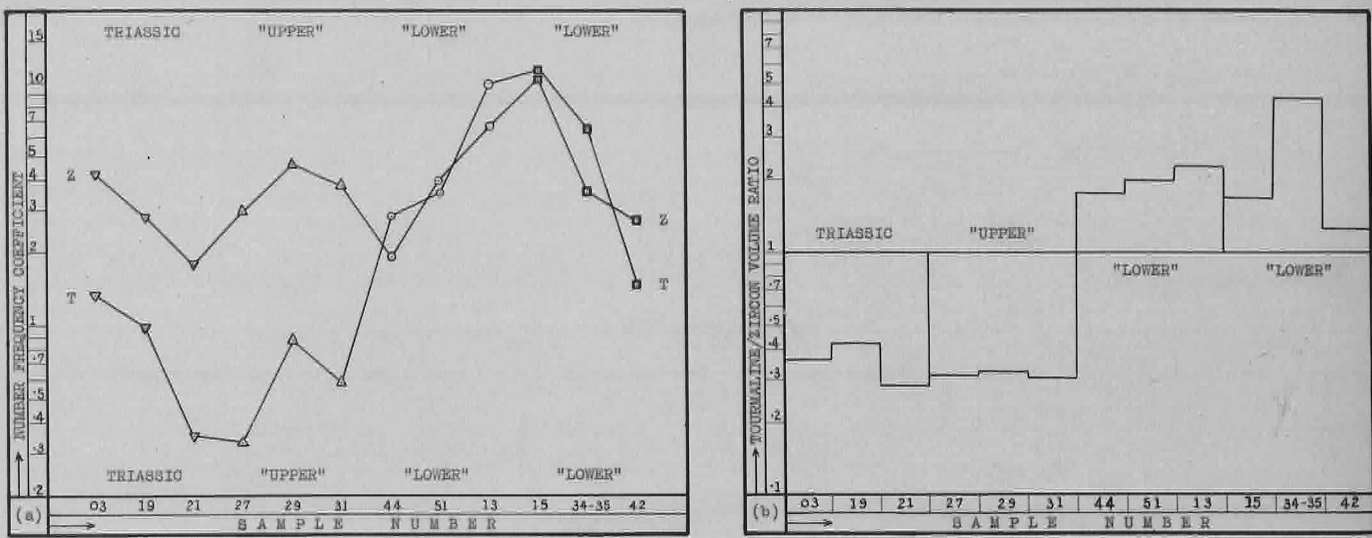
FORMATION AVERAGE COLOUR RATIOS



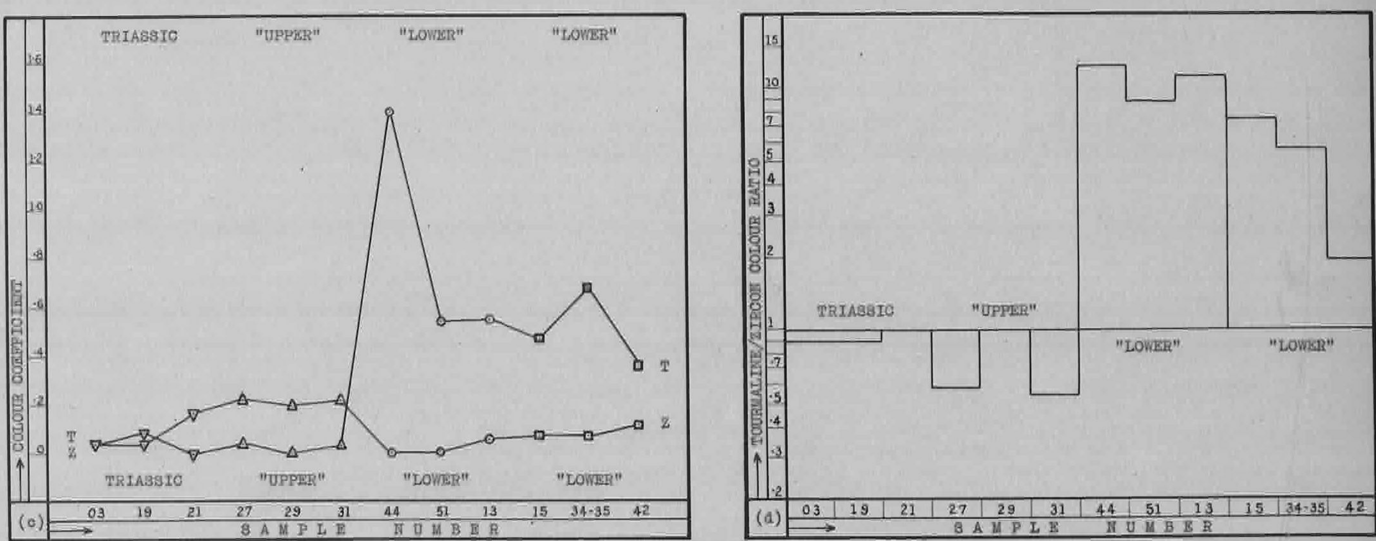
FORMATION AVERAGE ROUNDNESS RATIOS

FIGURE 18.

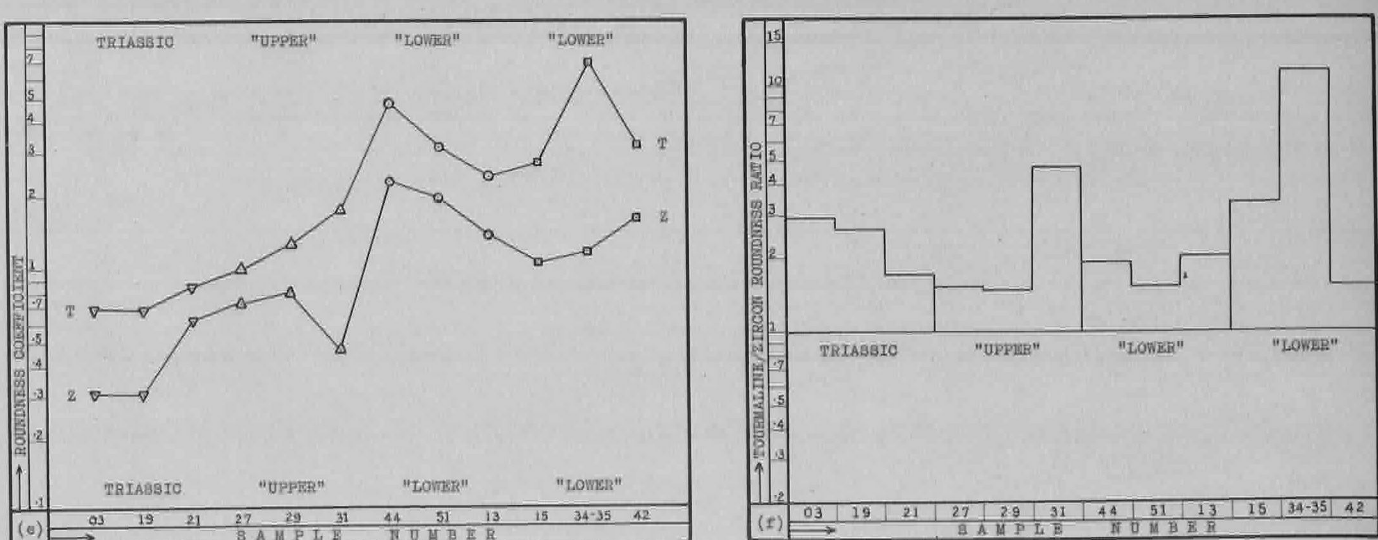
VARIATION DIAGRAMS SHOWING COMPARATIVE COEFFICIENTS FOR INDIVIDUAL SAMPLES.



COEFFICIENTS OF NUMBER FREQUENCY



COEFFICIENTS OF COLOUR RATIO

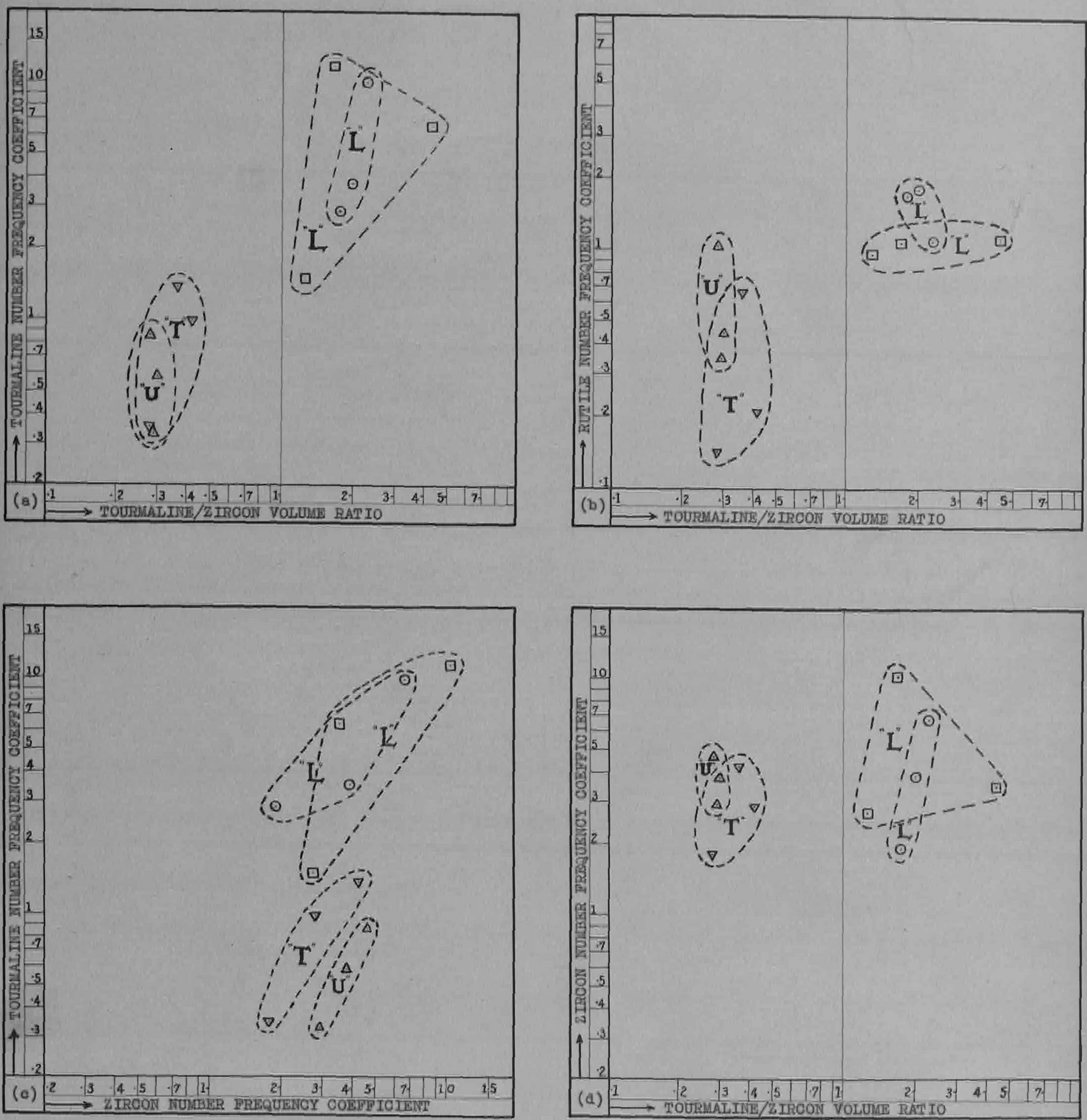


COEFFICIENTS OF ROUNDNESS RATIO

FIGURE 19.

SCATTER DIAGRAMS SHOWING COMPARATIVE COEFFICIENTS OF NUMBER FREQUENCY.

▽ TRIASSIC QUARTZITES △ "UPPER" QUARTZITES ⊙ "LOWER" QUARTZITES - RAUB ⊡ "LOWER" QUARTZITES - BENTONG

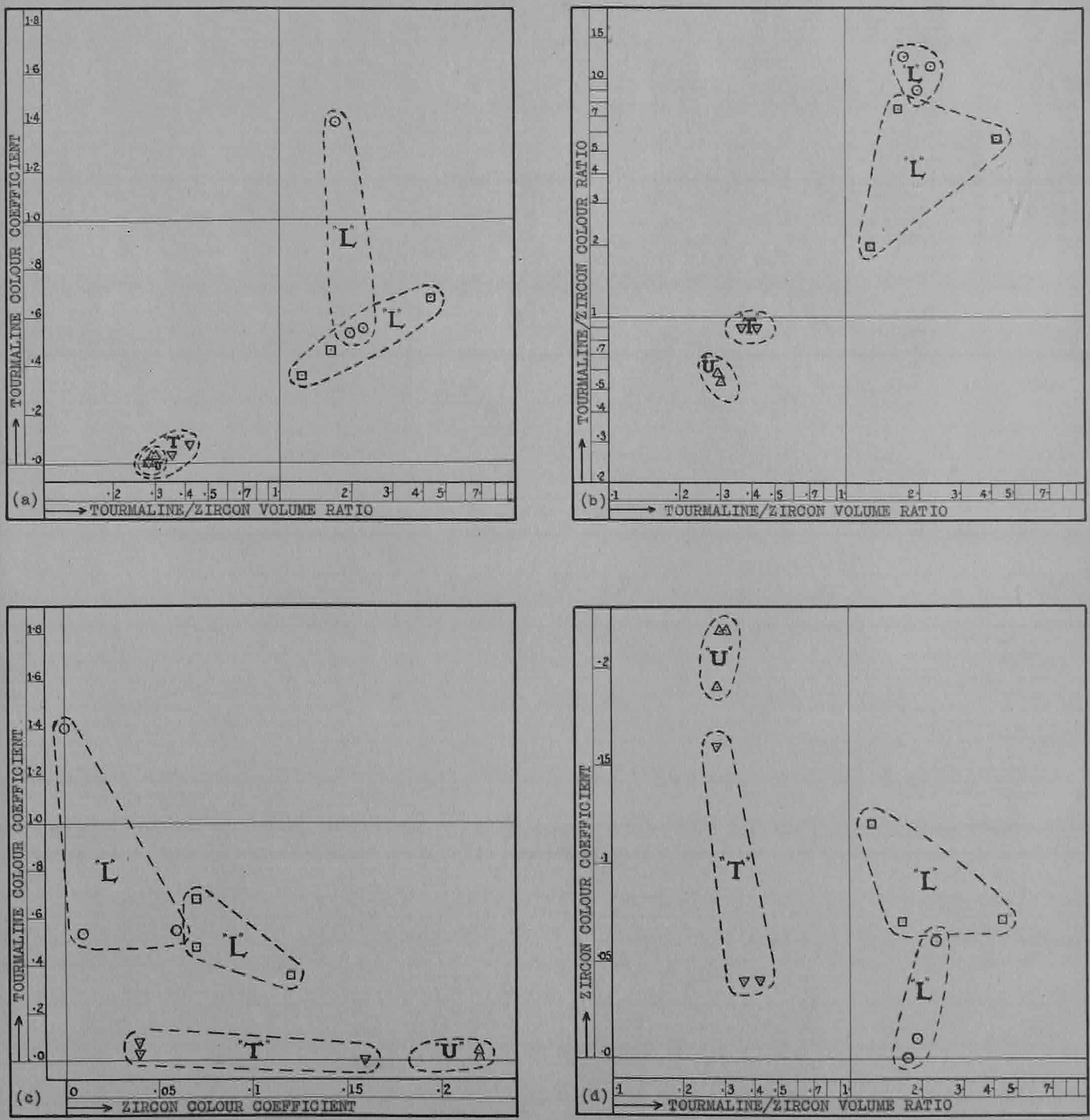


"T" - TRIASSIC QUARTZITES "U" - "UPPER" QUARTZITES "L" - "LOWER" QUARTZITES

FIGURE 20.

SCATTER DIAGRAMS SHOWING COMPARATIVE COEFFICIENTS OF COLOUR RATIO.

▽ TRIASSIC QUARTZITES   △ "UPPER" QUARTZITES   ⊙ "LOWER" QUARTZITES - RAUB   ▫ "LOWER" QUARTZITES - BENTONG

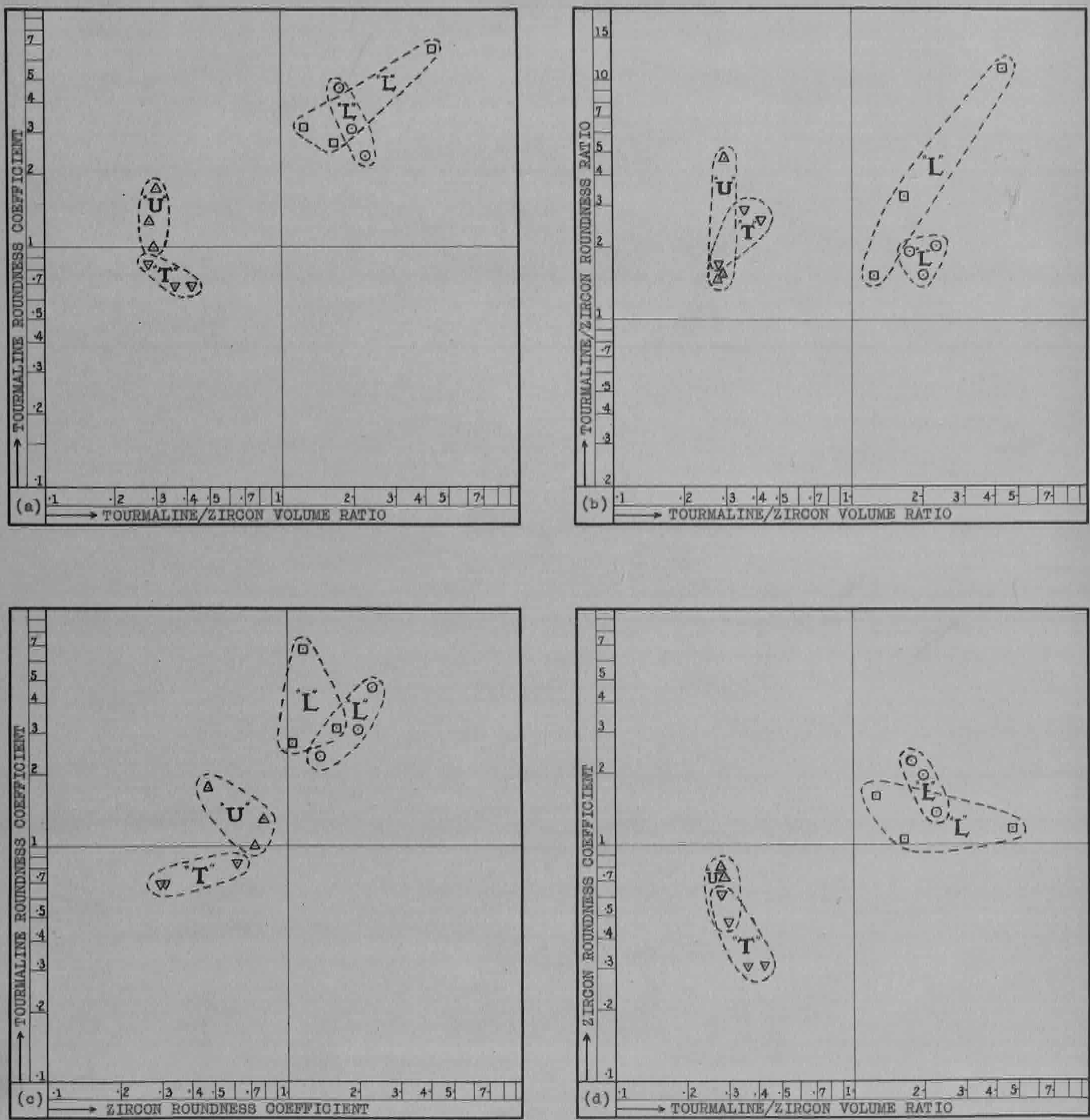


"T" - TRIASSIC QUARTZITES   "U" - "UPPER" QUARTZITES   "L" - "LOWER" QUARTZITES

FIGURE 21.

SCATTER DIAGRAMS SHOWING COMPARATIVE COEFFICIENTS OF ROUNDNESS RATIO.

▽ TRIASSIC QUARTZITES △ "UPPER" QUARTZITES ⊙ "LOWER" QUARTZITES - RAUB ⊡ "LOWER" QUARTZITES - BENTONG



"T" - TRIASSIC QUARTZITES "U" - "UPPER" QUARTZITES "L" - "LOWER" QUARTZITES

Figures 4 and 4(v) are charts showing the observed number frequency colour distribution according to grade size for individual samples and for formational averages: in effect they represent contour diagrams of number frequency density. Figures 5 and 5(v) likewise present a picture of observed number frequency distribution according to degree of roundness and grade size. Similarities and irregularities of distribution are at once apparent in all cases.

Figures 8 and 9 display the figures of calculated nominal weight frequency distribution according to colour and roundness, for the range 0.0351 mm to 0.062 mm, as compiled for individual samples in table 24 and displayed in roughly comparative chart form in figure 6. Figure 10 likewise shows similar figures calculated for formational averages, as compiled in table 25 and displayed in roughly comparative chart form in figure 7.

Figures 11 and 12 are histograms showing, respectively, comparative formational average tourmaline colour distribution, and zircon roundness distribution.

Figure 13 is a trilinear co-ordinate scatter diagram, displaying variations of the overall relative proportions of tourmaline, rutile, and zircon, for the range of grade sizes between 0.351 mm and 0.062 mm; as compiled in table 29 for individual samples.

Figures 14-16 are polar diagrams showing comparative individual variations with grade size of, respectively, tourmaline/zircon volume ratio, tourmaline colour ratio, and zircon roundness ratio. In each case the angular arc represents the amount of the characteristic being compared, and the polar radius the corresponding grade size. This device immediately makes evident similarities between individual samples of the Triassic and "Upper" quartzites, and corresponding dissimilarities from those of the "Lower" quartzites.

Figure 17 is a diagram showing the variation characteristics with grade size for formational averages. Most of these are plotted on a logarithmic scale, serving to emphasize the similarities between the Triassic and the "Upper" quartzites, and their distinction from the "Lower" quartzites. Insets (a), (b), and (c), represent the frequency variations; (d), (e), and (f), the colour variations; and (g), (h), and (i), the roundness variations. Figure 18 provides a series of variation diagrams showing the comparative calculated coefficients over the range 0.351 mm to 0.062 mm for individual samples:
(a) for mineral number frequencies as given in tables 26-27;
(b) for tourmaline/zircon volume ratios as given in table 30;
(c) for mineral colour ratios as given in tables 33-34;
(d) for tourmaline/zircon colour ratios as given in table 37;
(e) for mineral roundness ratios as given in tables 35-36;
(f) for tourmaline/zircon roundness ratios as given in table 38.

Figures 19-21 are scatter diagrams showing the relations between the various calculated coefficients for, respectively, number frequency, colour ratio, and roundness ratio. Again they are plotted mostly on a logarithm scale to indicate, even more strikingly, the linkage between the Triassic and "Upper" quartzites, and their corresponding distinction from "Lower" quartzites.

Figure 22 is a proportional mineral weight frequency diagram, based on mineral number frequency and weight of grade size concentrate expressed as a percentage of total concentrate. It shows an idealized

FIGURE 22 - DIAGRAM SHOWING IDEALIZED RELATION OF PROPORTIONAL MINERAL WEIGHT FREQUENCY TO GRADE SIZE.

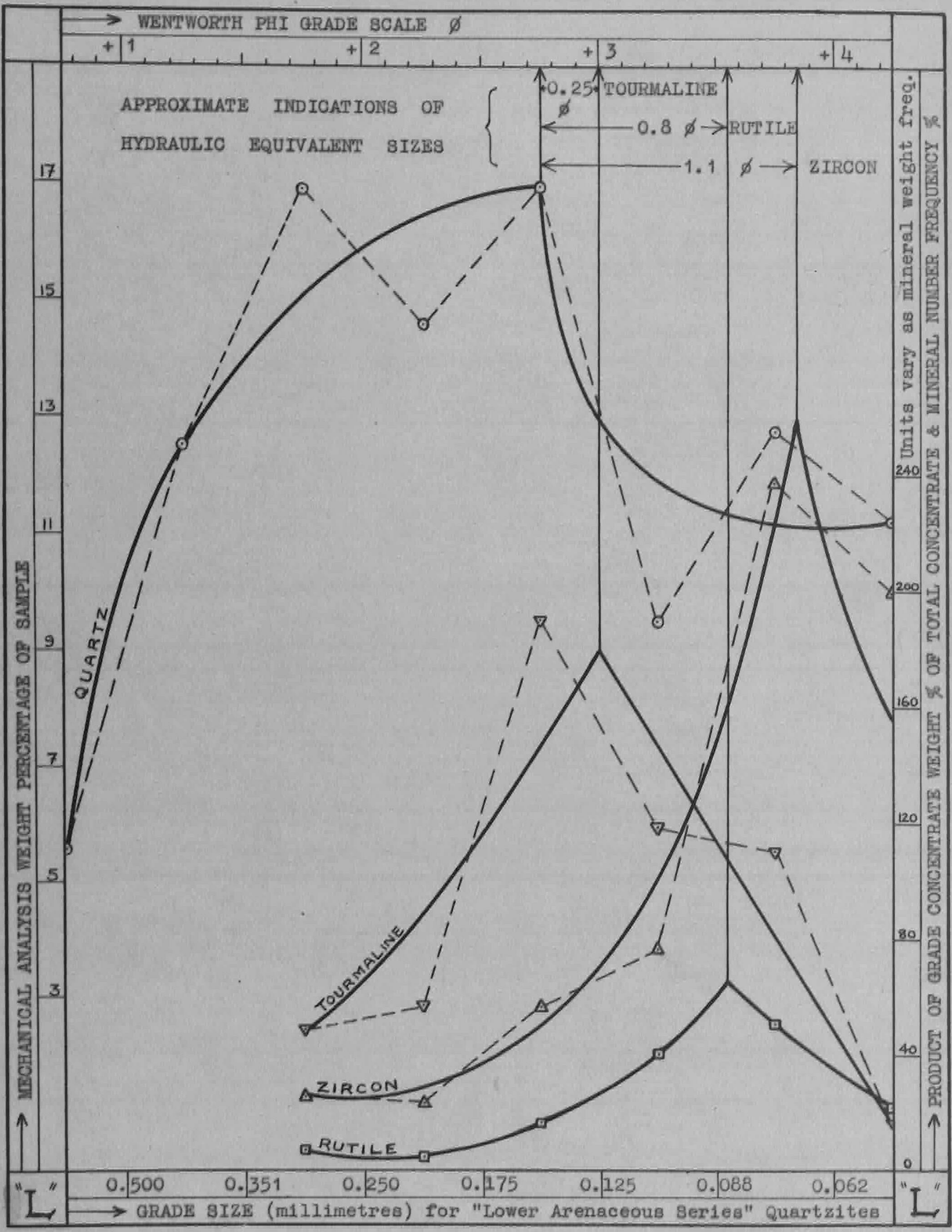
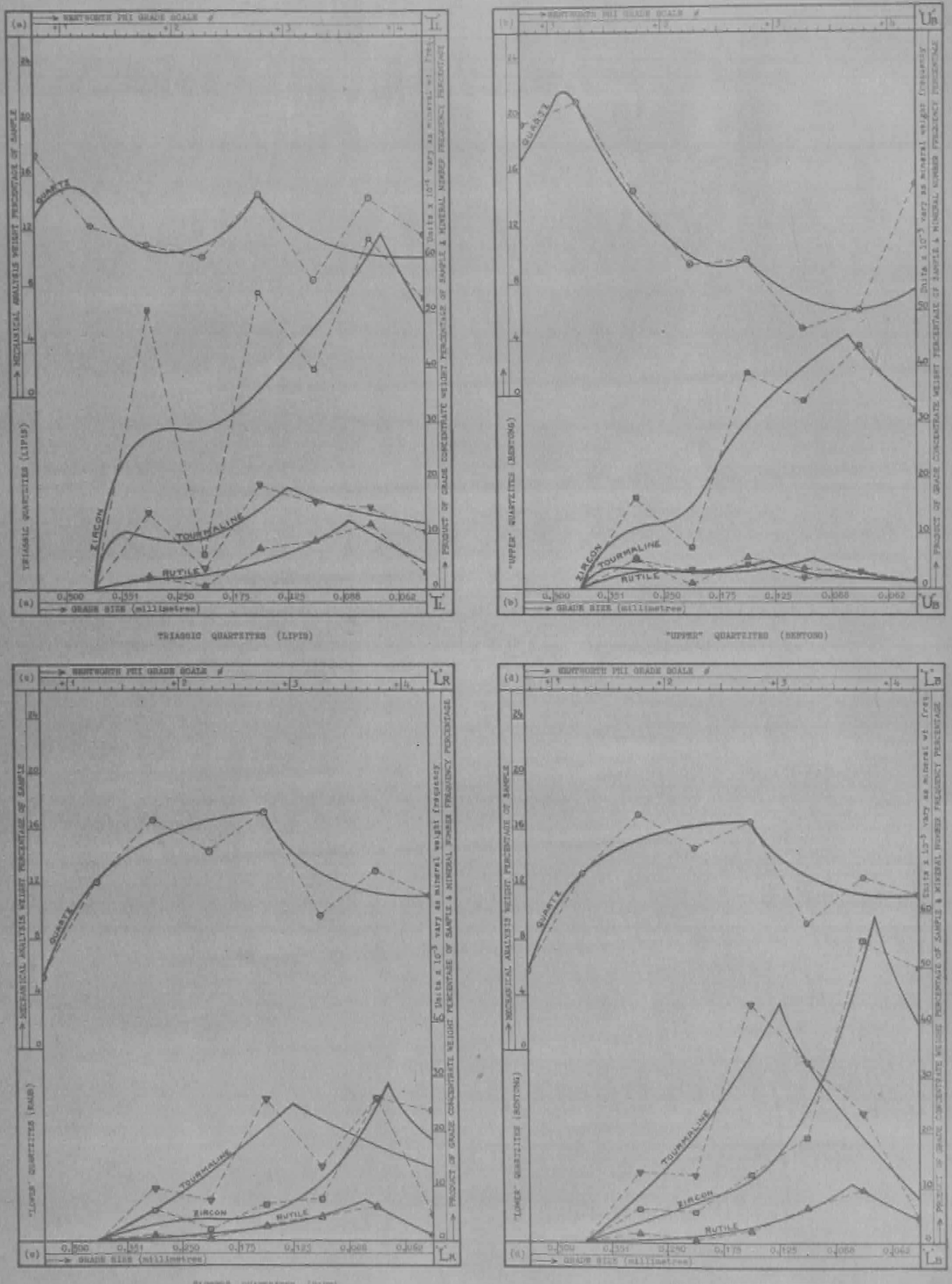


FIGURE 43 — DIAGRAMS SHOWING COMPARATIVE VARIATIONS OF PROPORTIONAL MINERAL WEIGHT FREQUENCY.



TRIASSIC QUARTZITES (LIPIS)

"UPPER" QUARTZITES (BENTONG)

"LOWER" QUARTZITES (RAUB)

"LOWER" QUARTZITES (BENTONG)

relation of mineral weight frequency to grade size for the average "Lower" quartzites, and serves to indicate the hydraulic equivalent sizes for tourmaline, rutile, and zircon. The values for these agree tolerably well with those determined by Rittenhouse (1944) for river sands. If anything, it would appear that the separation is rather more pronounced for the conditions under which the original sands now forming these quartzites were first laid down.

Figure 23 is a comparative series of proportional mineral weight frequency diagrams, based on mineral number frequency percentage and weight of grade size concentrate expressed as a percentage of original sample. It indicates the relation of mineral weight frequency to grade size for comparative formational averages, and confirms the results obtained more accurately for only one formation in figure 22.

CAUSES OF MINERAL VARIATION.

In reviewing all the possible causes for variation of mineral percentages in sedimentary deposits these may be summarized briefly as due, either to the absolute availability of the minerals, that is, their presence in or absence from the distributive province (the drainage area from which the deposits are derived), or to their relative availability, in cases where minerals may be present but not deposited, or only deposited in certain grades. Some discussion of new facts and theories in connection with this interesting subject of sedimentary variation and provenance have been given by Allen (1945) and other workers.

The absolute availability is determined by the source rock and the relative resistance to abrasion of its constituent minerals, as well as their relative resistance to alteration. While the source rock supply may comprise a single source area, either uniform for a considerable period, or with variations due to erosion (Brammell, 1928), or size (Krumbein and Tisdel, 1940), alternatively it may be multiple in nature, due either to mixing of tributary loads or contributions from several sources to the basin of deposition. As regards the relative resistance to abrasion (Thiel, 1940), whereas it was at one time believed that minerals such as felspars, pyroxenes, and amphiboles, could not survive long transport, it has been shown (Russell, 1939) that this is not so, and that little change occurs due to the process of transport itself. In the case of relative resistance to alteration, however, there are the effects to consider, not only of transport, but also those of the initial weathering of the source rock, and the alteration which may occur after deposition and burial, particularly if the formation is porous and permeable (Pettijohn, 1941).

Relative availability at the time of deposition is governed either by "local" sorting at one point, progressive sorting in the direction of transport, or a simultaneous combination of both processes. Whereas local sorting is dependent on the hydraulic condition prevailing at the point of deposition, with the shape of grains and settling time (Rubey, 1933b) as important factors, the more gradual process of progressive selective sorting may take a variety of forms depending on the mode of transport. Sorting of the latter type may occur by "out-running", the rolling of spherical grains in transport by traction and saltation; by "panning", the easier removal of lighter particles facilitated by carriage in suspension; or by "trading", involving a deposition on convex banks of water-courses and erosion on concave banks, and being a change by variation of meander and not of material transported. Both types of sorting are dependent on size of grain, whether relative or absolute (Rubey, 1933a; Russell, 1936; Allen, 1947), specific gravity of mineral, and shape of particle (Wadell, 1932, 1934). Other important factors involved are the velocity, degree of turbulence, viscosity, and specific gravity of the transporting agent. As far as practicable the best method of eliminating these sorting effects is by evaluating the corresponding hydraulic ratios (Rittenhouse, 1943, 1944).

In determining the hydraulic ratios as in table 42, portrayed diagrammatically in figures 22-23, the comparisons shown are reasonably free from sorting errors and therefore indicate absolute availability. Since the minerals tourmaline, rutile, and zircon, are the ones selected for determining the main comparative conclusions, and these are all ultra-stable, the question of relative resistance to alteration hardly enters. This leaves the factors of source rock and relative resistance to abrasion, as accounting for the differences observed between the correlative Triassic and "Upper" or "Younger" Arenaceous Series" quartzites, and the distinctive "Lower" or "Older Arenaceous Series" quartzites. The relative poorer resistance to abrasion of tourmaline is indicated by the higher degree of rounding displayed in comparison with zircon. This may also have resulted to some extent in the relative reduction of tourmaline frequency, but in the main the differences must be due to changes in the distributive province. It is hardly likely that a single source supplied all the material during the time taken to accumulate such thickness of formation as have been sampled. We are left, therefore, with the inevitable logical deduction that the differences observed are most probably due to changes of multiple source, a change of contribution from several sources to the same basin of deposition, such as might be expected to occur between Carboniferous and Triassic times, due to a change in the palaeogeography from the time when the landmass was first submerged beneath the seas of the Carboniferous-Permian era until it began to emerge again in the later Triassic period.

INTERPRETIVE CONCLUSIONS

Careful examination of the statistical data obtained, and the graphical representation thereof, indicates quite definitely the similarity between the results obtained for the Triassic quartzites of Lipis District, as represented by samples 03, 19, 21, and the "Upper" quartzites of Bentong District, as represented by samples 27, 29, 31. It is also evident that, as expected, there is a strong similarity between the "Lower" quartzites of Raub District, represented by samples 44, 51, 13, and the "Lower" quartzites of Bentong District, represented by samples 15, 34-35, 42. The "Lower" quartzites, however, show significant dissimilarities from the Triassic and "Upper" quartzites.

When assessing these similarities and dissimilarities, as implying correlation and differentiation between different formations, it is relevant to refer to and keep in mind certain discussions by Tickell (1924) and Dryden (1935). In the latter article Dryden explains the distinction between correlation as implying synchrony of geological formation determined by palaeontological data, and heavy mineral correlation, which he states is "an entirely different concept, although the process may lead to results quite analogous to those obtained by the use of fossils". While still not necessarily proof of age correlation or differentiation, therefore, there is still a strong probability that the results obtained may be due to this cause.

Of the schedule of information enumerated by Milner (1940) in his principles of correlation, the following were found to be most useful:

(a) relative frequency of minerals (tourmaline, rutile, and zircon);
(b) grade sizes of certain minerals (some relatively coarse zircon);
(c) average shape of minerals (particularly tourmaline and zircon);
(d) differences in colour preponderance (striking with tourmaline);
(e) reciprocal relations of the above characteristics.

To summarize the differences between the correlative Triassic and "Upper" or "Younger Arenaceous Series" quartzites, and the distinctive "Lower" or "Older Arenaceous Series" quartzites, it may be said that the latter possess a higher volume ratio of tourmaline to zircon, with a moderately high proportion of blue-green coloured varieties of tourmaline and a higher degree of rounding. The former group, on the other hand, possess a higher volume ratio of zircon to tourmaline, with virtually only yellow-brown tourmaline present and a higher degree of angularity. Even with the sorting effects, eliminated, or at least reduced and largely eliminated, these significant features of correlation and differentiation are still markedly in evidence.

That this is so is emphasized by the more careful examination of figure 23, showing proportional weight frequency percent for the various minerals in successive grade sizes. Whereas the "Lower" quartzites indicate only one size group of zircon, in the case of the Triassic and "Upper" quartzites there appears to be two groups. This effect may be due partly to the use of too large a size fraction for table treatment, but it is definitely more pronounced in the case of the Triassic and "Upper" quartzites. The coarser, more angular variety possibly represents an influx of material from a different source, whereas the other possibly represents a similar source to those occurring in the "Lower" quartzites, but with the difference that the proportion of tourmaline to this type of zircon is appreciably lower.

All these effects could be due either to changes in the original source rocks consequent on continued denudation over a long period of time, or to dilution on account of palaeogeographical changes in the distributive province. It appears probable, moreover, that the higher degree of rounding and greater number of colour varieties exhibited by the "Lower" quartzites may indicate that they are largely second-cycle sediments formed by the re-working of sedimentary strata, whereas the "Upper" and Triassic quartzites have been formed to a greater extent by the primary denudation of injected metamorphic terranes and plutonic igneous bedrock.

RECOMMENDATIONS FOR FURTHER INVESTIGATIONS

It is not claimed that more than a preliminary investigation of the subject has been effected, but that the gratifying results obtained are sufficiently striking to justify further detailed work. It is hoped, therefore, that within the next few years an opportunity may occur for the more thorough examination of quartzites occurring in other parts of Malaya, and that the conclusions determined so far will be found to hold valid over a wide area for a large number of samples. Only thus can it be established with a reasonable degree of conclusiveness whether or not the method is a consistently reliable guide, as an alternative to fossil evidence, to the ages of the various quartzites. With this end in view the following recommendations are compiled for the technique to be followed in any further investigations.

SAMPLING - Four discrete samples of 5 to 6 pounds weight should be obtained at four different points in any one locality, combined to make one composite "locality sample" of 20 to 25 pounds. A minimum of four such samples should be taken from four different localities when calculating "district averages". Four such district samples of the same formation should be selected for computing "formation averages".

DISAGGREGATION - The jaw-crusher setting at ¼ inch and Braun pulverizer at 1 to 0.5 millimetre, depending on grain size, proved very satisfactory and may be continued, although possibly a closer setting could be used for the pulverizer, especially when dealing with finer-grained material.

CONCENTRATION - The crushed product should be dry-sieved to sizes (+18 mesh), (+35 mesh), (+60 mesh), and the (-60 mesh) material wet-sieved to (+120 mesh), (+230 mesh), and (-230 mesh). The over 18-mesh size should be passed back to the pulverizer, and each of the other products in turn passed over concentrating tables. The finest size (-230 mesh) would only require one table retreatment, rejecting tails only, the (+230 mesh) and (+120 mesh) sizes each two retreatments, rejecting tails and half middlings, and the (+60 mesh) and (+35 mesh) sizes each probably three retreatments, finally rejecting tails and middlings. Each of the table sizes should be split to two grade sizes for treatment over the superpanner. Stained calcite should be used for visual control over tables, as well as when using the superpanner.

SEPARATION - After acid treatment and drying, each grade size of each sample should be subjected to a magnetic separation, in order to effectively remove all strongly magnetic material. The remaining concentrate should be cleaned by decantation using bromoform in open beakers. This method has been found perfectly satisfactory, more convenient, and much more rapid than using a separating funnel in the usual manner. Determination of average specific gravity should be carried out on each of the resulting heavy mineral residues, and sufficient material split off to yield slightly more than 1000 grains for mounting in Arochlor.

OPTICAL EXAMINATION - Count 1000 grains per slide so that, in effect, the count is virtually the whole of a split portion of the grade size concentrate sample. Place emphasis on examination of ultra-stable minerals, although making note of peculiarities of others. Amongst the characteristics noted should be included number frequency, colour variation, degree of roundness, and presence or absence of inclusions.

STATISTICAL COMPUTATION & GRAPHICAL REPRESENTATION - Absolute weight frequencies should be computed in each case by taking account of the average specific gravities of concentrate, and the corresponding hydraulic frequency ratios then determined. In addition colour variation ratios, roundness ratios, and inclusion ratios, may be computed for a suitable range of sizes, and plotted on scatter diagrams to a logarithmic scale as the best visual means for statistical comparison of different formations.

A C K N O W L E D G E M E N T S

The writer wishes to record his appreciation to Paul D. Krynine at the Pennsylvania State College for his excellent paper on "The Tourmaline Group in Sediments" (1946), which was undoubtedly the main initiating inspiration for the present investigation, while to Dr. F. T. Ingham, Director of the Geological Survey of Malaya, is due credit for approving this research project in sedimentology. The writer is also indebted for helpful suggestions by Dr. Ian Campbell of the California Institute of Technology, and by Dr. R. Dana Russell of the U.S. Navy Electronic Laboratory, San Diego. Amongst other individuals who contributed must be recorded Mr. Rudolf van Huene, technical assistant at Caltech, who gave welcome aid in working out the initial separation process. In conclusion, but by no means least, must also be mentioned the discussion, constructive criticism, and assistance rendered by my colleagues in Malaya, not only of the Geological Survey, but also in the Mines Department, and in the map reproduction section of the Survey Department.

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APPENDIX "A"

LIST OF TABLES

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APPENDIX "B"

L I S T   O F   I L L U S T R A T I O N S

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