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DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 72-30

"STANDARD SAMPLES" OF SILICATE ROCKS AND MINERALS— A REVIEW AND COMPILATION

Sydney Abbey

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(Report and 3 tables)

Sydney Abbey

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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ABSTRACT

A review is presented of the present state of international reference samples of silicate rocks and minerals. Usuable values of varying degrees of reliability are assigned where possible for major, minor and trace elements.

RÉSUMÉ

On présente une étude sommaire de l'état actuel d'échantillons de roches et minéraux silicatés proposés comme standards internationaux. On suggère des valeurs dont on peut se servir à divers niveaux de certitude pour les éléments majeurs et mineurs, ainsi que des oligoéléments.

"STANDARD SAMPLES" OF SILICATE ROCKS AND MINERALS - A REVIEW AND COMPILATION

INTRODUCTION

Ever since the first compilation of analytical data on the reference samples G-1 and W-1 (Fairbairn, 1951), many geological institutions throughout the world have prepared proposed standard samples and distributed them widely for collaborative analysis. The laboratories of the Geological Survey of Canada have been involved in collaborative analysis, not only of samples originating in this country, but also from the United States, Great Britain, France, Czechoslovakia, the Soviet Union, Tanzania, South Africa and Japan.

It will be noted that inverted commas are used in the title of this work, for the words "standard samples". There are two reasons for doing so:

(1) There has been little or no co-ordination between the "standard sample" programs in various countries, and frequently not even between different institutions in the same country.

(2) Very few "certified", "recommended", "proposed", "preferred", or otherwise usable compositional values are available.

With regard to the first reason, Flanagan (1970), has listed over 100 "geochemical standards" available from 23 sources in 11 different countries, and has rightly pointed out that "the possibility of confusion of identification symbols increases with the growing number of samples". Not only has there been a lack of consistency in identification symbols, but there has been a tendency for each group to use its own scheme of selection of what types of samples to prepare and how to prepare them. Thus we now have an overabundance of granite samples, characterized by relatively small differences in composition. On the other hand, most of the few available ultrabasic samples are also quite close together in composition. Awkward compositional gaps can result when one attempts to use such samples for calibration purposes. For example, the MgO contents of the six U.S. Geological Survey rocks (Flanagan, 1969; Abbey, 1970) are, in ascending order, approximately 0.8, 1.0, 1.5, 3.5, 43 and 50 per cent. As for bulk sample preparation techniques, it may be assumed that each group has endeavoured to achieve the best attainable degree of homogeneity, but a more uniform level of homogeneity would have been attained by the different preparations had there been some standardization of preparation techniques.

Concerning the second reason, although compilations of data derived from collaborative analysis of proposed standards have been published by most of the groups that have prepared samples, there has been little concensus on how to handle such data. One group (Roubault, de la Roche and Govindaraju, 1966) has calculated the mean of all values reported for a given component in a given sample (provided that a sufficient number of values were available), has rejected all values which differed from that mean by more than one standard deviation, has calculated a "preferred mean" from the remaining values and given that "preferred mean" as a "recommended value". As more data have become available, that group (Roubault, et al., 1968; de la Roche and Govindaraju, in press) has not hesitated to revise the recommended values, nor on occasion to introduce some subjective judgment in making such revisions. At the opposite extreme, Flanagan (1969) merely listed the reported values for six

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U.S. Geological Survey samples and calculated a grand average for each component of each sample. Some workers have mistakenly taken Flanagan's averages as "amount present" or "accepted value". A startling example of this is the quotation by one author of the fluorine value for sample GSP-1, taken from Table 5 in Flanagan's (1969) compilation. As it happens, that value was an "average" of only one determination, and as referral to Table 4 of the same work reveals, a highly inaccurate one. Abbey (1970) has described an empirical scheme for arriving at usable values for the major and minor elements in Flanagan's (1969) compilation. Other groups have treated their data by techniques intermediate between the positions taken by Roubault et al., and by Flanagan.

In view of the above, it is only with some hesitancy that one can accept most of the available "geochemical standards" as such. Compositional data from innumerable additional sources are widely scattered in the literature, not only in compilations, but in small clusters of values, generally where the samples had been used in testing proposed analytical methods.

This work was undertaken as an attempt at assessing the present status of the available samples and at assigning usable compositional values, where possible. It is hoped that subsequent revisions will be possible, as further data appear in the literature.

SAMPLES INCLUDED

Flanagan (1970) included not only rocks, but also "...mineral, ore, industrial product, counting and isotopic..." among his "geochemical standards". For this work, it was decided to include only silicate rocks and such compositionally similar minerals as feldspars and micas. The following additional restrictions were imposed:

a) Sufficient material must be available for use as standards.

b) Sufficient analytical data must be available from a variety of sources to permit assignment of usable values for at least all of the major elements.

c) The Geological Survey of Canada laboratories should have had some experience in using, or in providing data for, the samples.

The decisions taken, and reasons for them, are given below, using Flanagan's (1970) source list numbers.

1. The Msusulu Tonalite, MRT-T-1, is included as one of the better standards.

A compilation (Thomas and Kempe, 1963) is available. Although that reference is now rather old, a later note (Bowden and Luena, 1966) indicated that the sample was still available. The latter reference rightly warns against the all-too-frequent tendency of some workers to use as "accepted values" some that represent too few results. The results given in the compilation for major and minor elements, based on analyses done by 14 laboratories in seven different countries, are in very good agreement, the standard deviations being generally much lower than in compilations of data on other samples. No recommendation is made, in the compilation, for usable values. In assigning values in this present work, our own results were added to those in the previous compilation, crude means were calculated, the 15 per cent of the values farthest removed from the means were arbitrarily rejected (cf. Abbey, 1970), new means were calculated and assigned as usable values, with few reservations. Trace element data are less satisfactory, only eight elements having five or more results. It is hoped that additional compilations of data will be published in the future.

2. We have had no experience with the Bulgarian sample, granite GIB-G-B.

3. None of the British Chemical Standards samples listed by Flanagan (1970) are included in this work, as they do not come within the composition ranges of silicate rocks. However, two additional standards have subsequently become available from the same source, Soda Feldspar B.C.S. 375 and Potash Feldspar B.C.S. 376 (Ridsdale, 1970a, b). For both samples, the results from nine different laboratories, for eight major and minor components, are in excellent agreement, and there should be no hesitation in using their "average" values. For elements present at a higher level than 10 per cent, those averages are wisely given only to one decimal place, unlike the established, but questionable, practice in rock analysis.

One may well wonder why the data in these feldspars are more consistent than is usually the case with proposed standard rocks. Among possible explanations are:

a) The sample, being a mineral, is more homogeneous than a rock. Proposed standard rock samples have been subjected to homogeneity tests and have produced acceptable results from such tests. However, it is possible that artificially homogenized samples (such as a rock) can undergo density segregation in transit. Unless the sample is thoroughly mixed before analysis, the results obtained may be affected by inhomogeneity.

b) Analytical methods used are more uniform. This is generally true, but not universal, as is revealed by examining the Certificates of Analysis (Ridsdale, 1970a, b). In analyzing rocks, different analysts using essentially the same classical methods have been known to produce incompatible results.

c) The analysts are more expert in analyzing this type of material. In this case, all of the analysts are from the British ceramic industry, and have probably analyzed thousands of similar samples. Careful examination of compilations of rock analysis data (e.g. Flanagan, 1969) will reveal that the most consistent values were reported by those laboratories for whom analysis of rocks was an everyday experience. Less satisfactory results came from laboratories whose expertise lay in adjacent areas (e.g. ore analysis), who were more poorly equipped, whose personnel were less qualified or who unfortunately misapplied an unsuitable technique.

4. We have had no experience with the four samples from Queen Mary College, London - calcsilicate QMC-M-3, diabase QMC-I-3, granite QMC-I-1 and schist QMC-M-2. Flanagan's (1970) remarks for these samples read "Manuscript in preparation". At this writing, no such manuscript has appeared to our knowledge.

5. The address of this source should be amended to read: Centre de Recherches Pétrographiques et Géochimiques, case officielle no. 1, 54-Vandoeuvre-lès-Nancy, France. The original granite CRPG-GR, is not included in this work as it is no longer available. The two granites CRPG-GA, and CRPG-GH, and the basalt CRPG-BR are included, the assigned values being those "recommended" or "proposed" most recently by the originators (de la Roche and Govindaraju, in press). Somewhat less confidence is placed in three later samples from this source, biotite CRPG-Mica Fe, diorite ANRT-DR-N and serpentine ANRT-UB-N. Although the originators quote recommended values (Roubault, et al., 1968; de la Roche and Govindaraju, 1969), the standard deviations of the data are rather large, and the collaborating laboratories do not show world-wide representation as is the case with the older samples. The values for the later samples should therefore be used with caution. Data available on a still later sample, phlogopite CRPG-Mica Mg, are even more limited, the originators listing "proposed" rather than "recommended" values (de la Roche and Govindaraju, in press). Two additional samples, bauxite ANRT-BX-N and kyanite ANRT-DT-N, have been produced since Flanagan's (1970) listings, but their compositions are of

only marginal interest in silicate rock work, and relatively few results are available. Still another sample, synthetic glass ANRT-VS-N (Govindaraju, private comm., 1971), prepared specifically for trace element work, would be of greater interest, but the sample is in limited supply, and few results are available. Additional data will probably appear in the future.

6. We have had no experience with the six samples from the East German Zentrales Geologisches Institut, - anhydrite ZGI-AN, basalt ZGI-BM, clay shale ZGI-TB, granite ZGI-GM, limestone ZGI-KH and shale ZGI-TS.

7. The Khibiny - Generalnaya nepheline syenite from the Leningrad State University, identified at the Geological Survey of Canada as Len-NS-1, is included here as one of the better standards. The compilation (Kukharenko et al., 1968) reveals a consistency of results comparable to that shown for MRT-T-1 above, and assigned values in this work were calculated in the same manner for both samples. Len-NS-1 also resembles MRT-T-1 in the limited amount of trace element data available. It is not known whether Len-NS-1 is still available, but our laboratories were originally supplied with a generous quantity for contribution to the analytical data.

8. We have had no experience with the now exhausted sample Bern-Er-1, from the Mineralogisches-Petrographisches Institut, Bern University, Switzerland.

9. Gabbro SSC-MRG-1, produced by Ecole Polytechnique, Montreal, for the Spectroscopy Society of Canada, is included here, but only as a potentially useful sample. Our laboratories have contributed to the analysis of the sample, but the originators have produced no compilation. Syenite samples SSC-SY-2 and SSC-SY-3 are not included in this work because so few results are available. Those two samples, and also sulphide SSC-SU-1, are likely to be of more use as low-grade ore standards, and therefore of limited interest in rock work. The earlier syenite sample, SSC-SY-1, is no longer available.

10. The samples of dolomite, limestone, dolomite-limestone blends, hematite and magnetite, prepared by the G. Frederick Smith Chemical Company, have had some limited use in our laboratories, but are only of marginal interest in silicate rock analysis.

11. Of all the National Bureau of Standards samples listed by Flanagan (1970), only the potash feldspar NBS-70a and the soda feldspar NBS-99a qualify for use in the general analysis of silicate rocks for major and minor components. The Certificates of Analysis of those samples (Meinke, 1965a, b) list their compositions as "provisional", but the 1970 edition of NBS Miscellaneous Publication 260 gives the same figures without qualification. Many of the other National Bureau of Standards reference materials have been useful in work other than general rock analysis. Synthetic glass wafers, containing known amounts of added trace elements, have also been prepared, but very few results have been published.

12. The six samples from the United States Geological Survey, andesite USGS-AGV-1, basalt USGS-BCR-1, dunite USGS-DTS-1, granite USGS-G-2, granodiorite USGS-GSP-1, and peridotite USGS-PCC-1, have probably had more analytical work done on them than any other proposed standard, with the possible exception of the earlier diabase USGS-W-1. The values assigned in this work for major and minor elements in the six samples are based mainly on those derived in an earlier publication (Abbey, 1970). For the trace elements, Flanagan's (1969) values have been combined with many other values gleaned from the literature since them. Where at least ten values are available, the assigned value is the mean of the remaining values after the 20 per cent of the available data farthest removed from the crude mean have been arbitrarily rejected. Where between five and ten values are available, only an approximation is reported, being the mean of available values. Where fewer than five figures are available, no value or approximation is given. For USGS-W-1, all values and "magnitudes" listed are those given by Fleischer (1969). Flanagan (1970) lists a number of additional

samples in various stages of preparation. Similarly, several samples of synthetic glass have been prepared for use as spectrographic standards for trace elements, but at this writing, no further information is available.

12a. No further information is available on the United States Geological Survey's phosphate sample USGS-PBV-1, and it is not likely to be of general interest in silicate rock analysis.

13. Our laboratories have on hand some of the Pennsylvanian State University samples - two feldspars PSU-Or-1 and PSU-Ab-1, and a pyroxenite PSU-5-118 (which may be the same as Flanagan's (1970) PSU-Px-1); also a muscovite PSU-M-1 and a lepidolite PSU-60-1252. However, the quantities available are quite limited. More important, the only analytical data published for these samples come from a single laboratory. Although that laboratory is widely recognized as one of the best in the world, collaborative analysis by other laboratories would be desirable before such samples could be considered as standards.

14. The one basalt sample from the University of California, UCB-BCR-2, is intended for rare gas analysis and therefore of limited interest in this work.

15. The basalt GSJ-JB-1 and granodiorite GSJ-JG-1, from the Geological Survey of Japan, are two more of the better reference samples. A compilation is available (Ando, et al., 1971), from which values for major and minor elements are assigned in this work by the same procedure as outlined for MRT-T-1 and Len-NS-1 above. The standard deviations from the means of all values in the compilation are not quite as good as those for MRT-T-1 and Len-NS-1, as far as silica is concerned, but they are comparable for other components. A possible reservation regarding the validity of JB-1 involves the fact that the summation of the "grand averages" slightly exceeds 100 per cent, without including some trace elements believed to be present at significant levels (such as Ba, Cr, Ni, Sr, V and Zr). However, some of those trace elements were likely included with major elements in the conventional analysis. Again, trace element data are quite limited.

16. The six South African samples, dunite NIM-D, granite NIM-G, lujavrite NIM-L, norite NIM-N, pyroxenite NIM-P, and syenite NIM-S, have been analyzed in the Geological Survey of Canada laboratories and results reported to the originators, but at this writing, no compilation has appeared. NIM-L represents an uncommon rock type, but it should prove useful in bridging gaps in composition ranges for some elements.

17. We have no information on the Knox College shale, KnC-Shp-1.

18. All of the U.S. Atomic Energy Commission's NBL samples are of interest in studies involving uranium and thorium, but not for rock analysis in general.

19. Samples of the Swiss biotite Basel-1B and hornblende Basel-1H were received by our laboratories several years ago. Only about 5 g of each was supplied. No analytical work has been done because the quantities consumed in analysis would have left little for future use as a standard. No compilation is available to our knowledge.

20. The Swiss biotite, Bern-4B, and muscovite Bern-4M are of interest for geochronological measurements, but not for general silicate analysis.

21. We have no knowledge of "Engineered Materials" quartz GEM-430.

22. U.S. Geological Survey isotopic sample USGS-3633 is of no interest in general rock analysis.

23. We have no information on the Jordanian shale JOS-1.

Two additional sources of proposed standards have appeared since Flanagan's (1970) list.

24. Prof. Zdenek Valcha, Institute of Mineral Raw Materials, Kutná Hora, Hloušecká ul. 279, Czechoslovakia. The Geological Survey of Canada laboratories have contributed analytical data for the two samples, a glass sand and a magnesite. Compositions of both are outside the usual ranges for silicate rocks.

25. Prof. L.V. Tauson, Institute of Geochemistry, P.B. 701, Irkutsk 33, U.S.S.R. A supply of three samples was received in our laboratories early in 1972, but no analytical work has been done at this writing. The samples are trap IGI-2001, gabbro IGI-2003 and albitized granite IGI-2005. The originators are soliciting contributions to collaborative analysis.

ARRANGEMENT OF THE TABLES

In Table 1 are given assigned values for major and minor elements in 18 of the "best" samples, arranged in alphabetical order of the sample numbers. Initials of the issuing group are shown above the sample number. The order of listing of the components is based on that proposed by Maxwell (1968, p. 12), except that those components which would ordinarily be determined in a composite instrumental scheme (e.g. X-ray fluorescence, atomic absorption, direct reading emission spectrometer) are given first, followed by more "chemically" oriented components involving oxidation state, non-metals, etc. Although there are exceptions, the term "major element" is reserved for components present to the extent of one per cent or greater, "minor elements" from 1.00 to 0.01 per cent, and trace elements below 0.01 per cent. Following convention, most major and minor elements are listed as "per cent, oxide", trace elements as "parts per million, element".

Values listed without qualification are believed to be sufficiently well established that significant changes are not likely to result from future compilations. Values given with a question mark are less certain - e.g. the "valeurs proposées" of de la Roche and Govindaraju (in press), or Fleischer's (1969) "magnitudes". Where a question mark follows a blank space, the indication is that the component is probably present to a significant extent, but there are not sufficient data (e.g. fewer than five values) to justify showing a value. Other blank spaces merely indicate that insufficient data (or none at all) are available.

In Table 2, the samples are arranged in descending order of concentration for every major and minor element, an arrangement that should be useful in calibrating instrumental analytical methods. The samples are listed by their identifying letters or numbers only, initials of the originating groups being omitted to save space. In addition to all of the data from Table 1, Table 2 also includes values (shown with question marks) for some less well-established samples. Although the data for some components in such samples are still somewhat uncertain, values for some others are better. However, no distinction is made in Table 2 between the two categories. It is suggested that all are usable, but with caution. Blank spaces are shown in Table 2 for the same missing values as in Table 1, and also for those samples that have been analyzed in our laboratories, but for which no compilation has been published. The position of each sample in the descending concentration series is based on our own analysis. Values shown with question marks in Table 1 are similarly shown in Table 2.

Table 3 lists trace element values, again arranged in decreasing order of concentration for each element. The elements are arranged in alphabetical order of their chemical symbols. Question marks have the same significance as in the other tables. Because of the limited quantity of data available, and because of the uncertainty in the available data, no attempt has been made to locate samples merely in the order of concentration, as in Table 2.

It is in Table 3 that the shortcomings of the present state of so-called standard samples of rocks are most evident. The most striking examples are gold, cadmium and tungsten, for all of which the only values listed are uncertain, and they appply to USGS-W-1, a sample that has been in use for over 20 years.

NOTE

In a compilation such as this, involving so much numerical data, it is almost inevitable that errors will occur. Readers are requested to draw the author's attention to any errors they observe.

ACKNOWLEDGMENT

The author is indebted to J.A. Maxwell for critical reading of the manuscript.

ADDENDUM

After this work was completed, a careful re-examination of some of the published data suggested that, for some trace elements at least, the "outlier" values, which had been rejected in calculating assigned values, were possibly closer to the truth than were the crude means. A similar effect had been observed earlier in connection with the alumina, calcium, sodium and potassium values for the two U.S. Geological Survey's ultrabasic samples, DTS-1 and PCC-1. As a result, additional question marks have been inserted in Table 3, at points where they would not have been used in ordinary circumstances.

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TABLE 1

Compositions of International Reference Samples - "Usuable Values" (Major and Minor Elements)

	USGS AGV-1	USGS BCR-1	CRPG BR	USGS DTS-1	USGS G-2	CRPG GA	CRPG GH	USGS GSP-1	GSJ JB-1	GSJ JG-1	Len NS-1	USGS PCC-1	MRT T-1	USGS W-1	NBS 70a	NBS 99a	BCS 375	BCS 376
SiO_2	58.97	54.36	38.20	40.66	69.22	69.90	75.80	67.27	52.09	72.24	53.34	41.90	62.69	52.64	67.1	65.2	67.1	67.1
Al_2O_3	17.01	13.56	10.20	0.29	15.33	14.50	12.50	15.18	14.53	14.21	21.27	0.73	16.57	14.85	17.9	20.5	19.8	17.7
Fe_2O_3T*	6.73	13.40	12.92	8.59	2.67	2.86	1.33	4.26	9.04	2.21	4.12	8.23	5.94	11.09	0.08	0.06	0.12	0.10
MgO	1.53	3.46	13.28	49.75	0.77	0.95	0.03	0.98	7.70	0.73	0.63	43.37	1.86	6.62		0.02	0.05	0.03
CaO	4.94	6.94	13.80	0.14?	1.98	2.45	0.69	2.06	9.21	2.18	1.72	0.53	5.11	10.96	0.11	2.14	0.89	0.54
Na_2O	4.26	3.26	3.05	0.01	4.06	3.55	3.85	2.77	2.79	3.39	9.85	0.01	4.40	2.15	2.55	6.2	10.4	2.83
K_2O	2.86	1.67	1.40	0.00	4.49	4.03	4.76	5.50	1.42	3.96	6.50	0.00	1.24	0.64	11.8	5.2	0.78	11.2
TiO_2	1.06	2.24	2.60	0.01	0.48	0.38	0.08	0.65	1.34	0.26	1.06	0.01	0.59	1.07	0.01	0.01	0.38	0.01?
MnO	0.10	0.19	0.20	0.13	0.04	0.09	0.05	0.04	0.16	0.06	0.19	0.12	0.11	0.17				
BaO	0.14	0.08	0.11	0.00	0.21	0.10	0.00	0.15	?	?	0.13?	0.00	0.07?	0.02	0.02	0.26		
SrO	0.08	0.04	0.16	0.00	0.06	0.04	0.00	0.03	0.05	0.02	0.15?	0.00	0.05?	0.02				
Cr_2O_3	0.00	0.00	0.06	0.64	0.00	0.00	0.00	0.00	0.06?	0.00?	0.00?	0.44	0.00?	0.02				
NiO	0.00	0.00	0.03	0.31	0.00	0.00	0.00	0.00	?	0.00?	0.00?	0.32	0.00?	0.01				
FeO	2.02	8.97	6.57	6.98	1.45	1.32	0.84	2.34	6.06	1.66	1.58	5.14	2.91	8.72				
Fe_2O_3	4.39	3.45	5.58	0.85	1.01	1.36	0.41	1.60	2.30	0.36	2.38	2.49	2.80	1.40				
H_2O^+	0.60	0.72	2.30	0.41	0.48	0.87	0.46	0.54	1.00	0.53	0.65	4.61	1.51	0.53				
H_2O^-	1.21	0.89	0.50	0.06	0.12	0.09	0.06	0.06	0.98	0.09	0.14	0.59	†	0.16	†	†	†	†
CO_2	0.01	0.02	0.86	0.06	0.08	0.11	0.14	0.12	0.19?	0.09?	0.14	0.16	0.08?	0.06				
P_2O_5	0.49	0.33	1.04	0.00	0.14	0.12	0.01	0.28	0.26	0.10	0.28	0.00	0.14	0.14		0.02		
Cl	0.02	0.01	0.04?	0.00	0.01	0.03	0.01?	0.04				0.01		0.02?				
F	0.04	0.05	0.10	0.00	0.13	0.05	0.30	0.38	?	?	0.14	0.00	0.06?	0.02				
S	0.01	0.04	0.04?	0.00	0.01	?	?	0.04			0.02	0.01	0.01?					
RE_2O_3‡											0.06?							

*Total iron content, expressed as Fe_2O_3

‡Total rare earth oxides

† Analysis on "dry basis"

All figures in per cent

TABLE 2

Major and Minor Elements - "Usuable Values" (per cent), Arranged by Components

SiO_2	Sample
	NIM-G
75.80	GH
72.24	JG-1
69.90	GA
69.22	G-2
67.27	GSP-1
67.1	70a
67.1	375
67.1	376
65.2	99a
	NIM-S
62.69	T-1
58.97	AGV-1
54.36	BCR-1
53.34	NS-1
	NIM-N
52.65?	DR-N
52.64	W-1
	NIM-L
52.09	JB-1
	NIM-P
41.90	PCC-1
40.66	DTS-1
39.40?	UB-N
	MRG-1
	NIM-D
38.30?	MicaMg
38.20	BR
34.40?	MicaFe

Al_2O_3	Sample
21.27	NS-1
20.5	99a
19.8	375
19.40?	MicaFe
17.9	70a
17.7	376
17.42?	DR-N
	NIM-S
17.01	AGV-1
	NIM-N
16.57	T-1
	NIM-L
15.40?	MicaMg
15.33	G-2
15.18	GSP-1
14.85	W-1
14.53	JB-1
14.50	GA
14.21	JG-1
13.56	BCR-1
12.50	GH
	NIM-G
10.20	BR
	NIM-P
	MRG-1
2.99?	UB-N
0.73	PCC-1
	NIM-D
0.29	DTS-1

Fe_2O_3T	Sample
25.81?	MicaFe
	MRG-1
	NIM-D
13.40	BCR-1
12.92	BR
	NIM-P
11.09	W-1
	NIM-L
9.91?	DR-N
9.61?	MicaMg
9.04	JB-1
8.82?	UB-N
	NIM-N
8.59	DTS-1
8.23	PCC-1
6.73	AGV-1
5.94	T-1
4.26	GSP-1
4.12	NS-1
2.86	GA
2.67	G-2
2.21	JG-1
	NIM-G
	NIM-S
1.33	GH
0.12	375
0.10	376
0.08	70a
0.06	99a

MgO	Sample
49.75	DTS-1
43.37	PCC-1
	NIM-D
35.00?	UB-N
	NIM-P
20.40?	MicaMg
	MRG-1
13.28	BR
7.70	JB-1
	NIM-N
6.62	W-1
4.60?	MicaFe
4.50?	DR-N
3.46	BCR-1
1.86	T-1
1.53	AGV-1
0.98	GSP-1
0.95	GA
0.77	G-2
0.73	JG-1
0.63	NS-1
	NIM-S
	NIM-L
0.05	375
	NIM-G
0.03	GH
0.03	376
0.02	99a

CaO	Sample
	MRG-1
13.80	BR
	NIM-N
10.96	W-1
9.21	JB-1
7.08?	DR-N
6.94	BCR-1
5.11	T-1
4.94	AGV-1
	NIM-L
	NIM-P
2.45	GA
2.18	JG-1
2.14	99a
2.06	GSP-1
1.98	G-2
1.72	NS-1
1.12?	UB-N
0.89	375
	NIM-G
0.69	GH
	NIM-S
0.54	376
0.53	PCC-1
0.45?	MicaFe
	NIM-D
0.14?	DTS-1
0.11	70a
0.10?	MicaMg

Na_2O	Sample
10.4	375
9.85	NS-1
	NIM-L
6.2	99a
4.40	T-1
4.26	AGV-1
4.06	G-2
3.85	GH
3.55	GA
3.39	JG-1
3.26	BCR-1
	NIM-G
3.05	BR
3.00?	DR-N
2.83	376
2.79	JB-1
2.77	GSP-1
2.55	70a
	NIM-N
2.15	W-1
	MRG-1
	NIM-S
	NIM-P
0.30?	MicaFe
0.10?	MicaMg
0.10?	UB-N
0.01	DTS-1
0.01	PCC-1
	NIM-D

K_2O	Sample
	NIM-S
11.8	70a
11.2	376
10.00?	MicaMg
8.80?	MicaFe
6.50	NS-1
	NIM-L
5.50	GSP-1
5.2	99a
	NIM-G
4.76	GH
4.49	G-2
4.03	GA
3.96	JG-1
2.86	AGV-1
1.70?	DR-N
1.67	BCR-1
1.42	JB-1
1.40	BR
1.24	T-1
0.78	375
0.64	W-1
	NIM-N
	MRG-1
	NIM-P
0.02?	UB-N

TiO_2	Sample
	MRG-1
2.60	BR
2.55?	MicaFe
2.24	BCR-1
1.67?	MicaMg
1.34	JB-1
1.11?	DR-N
1.07	W-1
1.06	AGV-1
1.06	NS-1
0.65	GSP-1
0.59	T-1
0.48	G-2
0.38	GA
0.38	375
	NIM-L
0.26	JG-1
	NIM-P
	NIM-N
0.12?	UB-N
	NIM-G
0.08	GH
	NIM-S
	NIM-D
0.01	DTS-1
0.01	PCC-1
0.01	70a
0.01?	376
0.01	99a

MnO	Sample
	NIM-L
0.35?	MicaFe
0.26?	MicaMg
0.21?	DR-N
0.20	BR
0.19	BCR-
0.19	NS-1
	NIM-P
0.17	W-1
	MRG-1
0.16	JB-1
	NIM-N
0.13	DTS-1
0.12	PCC-1
0.12?	UB-N
0.11	T-1
0.10	AGV-1
0.09	GA
	NIM-D
0.06	JG-1
0.05	GH
0.04	G-2
0.04	GSP-1
-	NIM-G

BaO	Sample
0.26	99a
0.21	G-2
0.15	GSP-1
0.14	AGV-1
0.13?	NS-1
0.11	BR
0.10	GA
0.08	BCR-1
0.07?	T-1
	JG-1
0.04?	DR-N
0.02	W-1
0.02	70a

SrO	Sample
0.16	BR
0.15?	NS-1
0.08	AGV-1
0.06	G-2
0.05?	T-1
0.05	JB-1
0.04	BCR-1
0.04	GA
0.03	GSP-1
0.02	W-1
0.02	JG-1

TABLE 2 (continued)

Major and Minor Elements - "Usuable Values" (per cent), Arranged by Components

Cr_2O_3	Sample
0.64	DTS-1
0.44	PCC-1
0.32?	UB-N
0.06	BR
0.06?	JB-1
0.02	W-1

NiO	Sample
0.32	PCC-1
0.31	DTS-1
0.25?	UB-N
0.03	BR
0.01	W-1

FeO	Sample
19.17?	MicaFe
	NIM-D
	NIM-P
8.97	BCR-1
8.72	W-1
	MRG-1
	NIM-N
6.98	DTS-1
6.85?	MicaMg
6.57	BR
6.06	JB-1
5.42?	DR-N
5.14	PCC-1
2.91	T-1
2.70?	UB-N
2.34	GSP-1
2.02	AGV-1
1.66	JG-1
1.58	NS-1
1.45	G-2
1.32	GA
	NIM-G
	NIM-L
0.84	GH
	NIM-S

Fe_2O_3	Sample
	MRG-1
	NIM-L
5.58	BR
5.52?	UB-N
4.45?	MicaFe
4.39	AGV-1
3.89?	DR-N
3.45	BCR-1
2.80	T-1
2.49	PCC-1
2.38	NS-1
2.30	JB-1
2.00?	MicaMg
1.60	GSP-1
1.40	W-1
1.36	GA
	NIM-S
	NIM-D
1.01	G-2
0.85	DTS-1
	NIM-N
	NIM-G
	NIM-P
0.41	GH
0.36	JG-1

H_2O^+	Sample
11.00?	UB-N
4.61	PCC-1
2.80?	MicaFe
2.30	BR
	NIM-L
2.09?	DR-N
1.07?	MicaMg
1.51	T-1
	MRG-1
1.00	JB-1
0.87	GA
0.72	BCR-1
0.65	NS-1
0.60	AGV-1
0.54	GSP-1
0.53	W-1
0.53	JG-1
0.48	G-2
0.46	GH
	NIM-G
0.41	DTS-1
	NIM-N
	NIM-D
	NIM-P

H_2O^-	Sample
1.21	AGV-1
1.16?	UB-N
0.98	JB-1
0.89	BCR-1
0.59	PCC-1
0.50	BR
0.30?	MicaFe
0.30?	MicaMg
	NIM-S
0.23?	DR-N
	NIM-L
0.16	W-1
0.14	NS-1
0.12	G-2
	NIM-G
0.09	GA
	MRG-1
0.09	JG-1
	NIM-N
	NIM-P
0.06	DTS-1
0.06	GH
0.06	GSP-1
	NIM-D

CO_2	Sample
	MRG-1
0.86	BR
	NIM-D
0.41?	UB-N
0.20?	MicaMg
0.20?	MicaFe
0.19?	JB-1
0.16	PCC-1
	NIM-L
0.14	GH
0.14	NS-1
0.13?	DR-N
0.12	GSP-1
0.11	GA
	NIM-G
	NIM-N
0.09?	JG-1
0.08	G-2
0.08?	T-1
0.06	DTS-1
0.06	W-1
	NIM-P
0.02	BCR-1
	NIM-S
0.01	AGV-1

P_2O_5	Sample
1.04	BR
0.49	AGV-1
0.45?	MicaFe
0.33	BCR-1
0.28	GSP-1
0.28	NS-1
0.27?	DR-N
0.26	JB-1
0.14	G-2
0.14	T-1
0.14	W-1
0.12	GA
	NIM-S
0.10	JG-1
0.03?	MicaMg
	NIM-L
0.03?	UB-N
0.01	GH
	NIM-N

Cl	Sample
	NIM-G
0.04	GSP-1
0.04	BR
	NIM-D
	NIM-L
	NIM-S
0.03?	GA
	NIM-N
0.02	W-1
	JG-1
	NIM-P
0.01	BCR-1
0.01	G-2
0.01	PCC-1
0.01	GH

F	Sample
2.70?	MicaMg
1.56?	MicaFe
	NIM-L
	NIM-G
0.38	GSP-1
0.30	GH
0.14	NS-1
0.13	G-2
0.10	BR
	JG-1
	T-1
0.05	BCR-1
0.05	GA
0.04	AGV-1
0.02	W-1
	NIM-N
	NIM-D
	NIM-P
	NIM-S

S	Sample
	MRG-1
	NIM-L
0.04	BCR-1
0.04	GSP-1
0.04?	BR
0.02	NS-1
0.01	AGV-1
0.01	G-2
0.01	PCC-1
	NIM-P
	T-1

TABLE 3

Trace elements - "Usable values" (ppm) arranged by components

Ag	Sample
0.05	W-1
0.03?	BCR-1

As	Sample
2.4	W-1

Au	Sample
0.005?	W-1

B	Sample
26?	GA
15?	W-1

Ba	Sample
1840	G-2
1335	GSP-1
1220	AGV-1
1150?	NS-1
1050	BR
850	GA
710	BCR-1
660?	T-1
360?	DR-N
180?	W-1
22	GH

Be	Sample
6?	GH
6?	NS-1
4?	GA
2.6	G-2
1.5?	GSP-1
1	BR
0.8	W-1

Cd	Sample
0.3?	W-1

Ce	Sample
440?	GSP-1
150?	G-2
70?	AGV-1
50?	BCR-1
23?	W-1

Co	Sample
135	DTS-1
110	PCC-1
110?	UB-N
50	BCR-1
50	W-1
39?	JB-1
35?	DR-N
18?	MicaFe
17	AGV-1
13?	T-1
7	GSP-1
7?	NS-1
6	G-2
6?	JG-1
5	GA
2?	GH

Cr	Sample
420	BR
415?	JB-1
120	W-1
90?	MicaFe
50?	JG-1
45?	DR-N
24?	T-1
16	BCR-1
13	GSP-1
12	AGV-1
11?	NS-1
10?	GA
9	G-2
6	GH

Cs	Sample
5?	GA
3.5?	NS-1
1.3	G-2
1.3	AGV-1
1.0	GSP-1
1.0	W-1
1.0	BCR-1

Cu	Sample
110	W-1
70	BR
63	AGV-1
52	DR-N
47?	T-1
35	GSP-1
30?	UB-N
19	BCR-1
14	GA
12	GH
11	G-2
11	PCC-1
10?	NS-1
7	DTS-1
7?	JG-1
4?	MicaFe

Dy	Sample
6.7?	BCR-1
4	W-1

Er	Sample
3?	W-1

Eu	Sample
2.0?	BCR-1
1.1	W-1

Ga	Sample
90?	MicaFe
33?	NS-1
25?	DR-N
23	BCR-1
22	G-2
22	GH
21	GSP-1
21?	T-1
20	AGV-1
20?	BR
16	GA
16	W-1

Gd	Sample
4?	W-1

Ge	Sample
1.7?	W-1
1.5?	BCR-1
1.5?	GA

Hf	Sample
13?	GSP-1
7.5?	G-2
5?	AGV-1
4.5?	BCR-1
2?	W-1

Ho	Sample
1?	W-1

In	Sample
0.07	W-1

La	Sample
205	GSP-1
100	G-2
85?	BR
45?	AGV-1
36?	GA
25	BCR-1
25?	GH
12?	W-1

Li	Sample
1500?	MicaFe
100?	GA
42	GH
37	G-2
34	GSP-1
30?	UB-N
20	NS-1
15	BCR-1
14	AGV-1
12	W-1
12?	BR

Lu	Sample
0.6?	BCR-1
0.35?	AGV-1
0.35?	W-1
0.15?	G-2

Mo	Sample
4?	GH
3?	AGV-1
3?	BCR-1
3?	BR
2?	GSP-1
1.5?	G-2

Nb	Sample
165	NS-1
90?	BR
85?	GH
27	GSP-1
18	AGV-1
17	BCR-1
13?	GA
11	G-2
10	W-1

Nd	Sample
17?	W-1

Ni	Sample
270	BR
78	W-1
40?	MicaFe
17	AGV-1
16?	DR-N
13	BCR-1
13?	T-1
9	GSP-1
7	GA
7?	NS-1
6	G-2
3	GH

Pb	Sample
75?	DR-N
53	GSP-1
50	GH
37?	T-1
36	AGV-1
29	G-2
26	GA
24?	JG-1
17?	MicaFe
16?	BR
15	BCR-1
11	DTS-1
10	PCC-1
8	W-1

Pr	Sample
4	W-1

Rb	Sample
2300?	MicaFe
390	GH
260	GSP-1
215	NS-1
185	JG-1
175	GA
170	G-2
75?	DR-N
70	AGV-1
50	BCR-1
45	BR
40	JG-1
33?	T-1
22	W-1
1?	PCC-1

TABLE 3 (Continued)

Trace elements - "Usable values" (ppm) arranged by components

Sb	Sample
4.3	AGV-1
3.0?	GSP-1
1.1	W-1
1.0?	PCC-1
0.6	BCR-1
0.6?	DTS-1
0.1?	G-2

Sc	Sample
34	BCR-1
34	W-1
26?	BR
12	AGV-1
9	PCC-1
8	GSP-1
7?	GA
4?	DTS-1
4	G-2

Sn	Sample
65?	MicaFe
10?	GH
8?	GSP-1
8?	BR
6?	NS-1
5?	AGV-1
4?	BCR-1
4?	GA
3?	W-1
2.5?	PCC-1
2.3?	DTS-1
1.9?	G-2

Sr	Sample
1350	BR
1300?	NS-1
670	AGV-1
480	G-2
440	JB-1
400?	DR-N
390	T-1
330	BCR-1
305	GA
250	GSP-1
185	JG-1
180	W-1
10	GH
1	PCC-1

Ta	Sample
10?	NS-1
0.8	AGV-1
0.8	BCR-1
0.8	G-2

Tb	Sample
1.3?	GSP-1
1.0?	BCR-1
0.8?	W-1
0.7?	AGV-1
0.5?	G-2

Th	Sample
110	GSP-1
25	G-2
15?	GA
13?	JG-1
7	AGV-1
7	BCR-1
2.4	W-1

Tl	Sample
0.04?	BCR-1
0.13?	W-1

Tm	Sample
0.3	W-1

U	Sample
3.3?	JG-1
2.0	AGV-1
2.0	G-2
2.0	GSP-1
1.8	BCR-1
1.8?	JB-1
0.5	W-1
0.005?	PCC-1
0.004?	DTS-1

V	Sample
410	BCR-1
240	BR
225?	DR-N
160?	MicaFe
125	AGV-1
100?	UB-N
96?	T-1
60	NS-1
49	GSP-1
36	GA
34	G-2
31	PCC-1
13	DTS-1
5?	GH

W	Sample
0.5?	W-1

Y	Sample
70?	GH
46	BCR-1
32	GSP-1
27?	BR
26	AGV-1
25	W-1
18?	GA
12	G-2

Yb	Sample
8?	GH
4?	BR
3.8	BCR-1
2.5	GSP-1
2.5?	GA
2.2	W-1
2.0	AGV-1
0.9	G-2

Zn	Sample
1350?	MicaFe
225?	T-1
160	BR
150?	DR-N
120	BCR-1
105	GSP-1
88	AGV-1
85	G-2
83?	JB-1
82	W-1
80	GH
75	GA
47	DTS-1
44	PCC-1
36?	JG-1

Zr	Sample
650	NS-1
560	GSP-1
310	G-2
240	BR
220	AGV-1
185	BCR-1
170?	T-1
160	GH
140	GA
100	W-1