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STUDIES IN "STANDARD SAMPLES" OF SILICATE ROCKS AND MINERALS. PART 4: 1974 EDITION OF 'USABLE" VALUES

SYDNEY ABBEY

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Energy, Mines and Resources Canada
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STUDIES IN "STANDARD SAMPLES" OF SILICATE ROCKS AND MINERALS.
PART 4: 1974 EDITION OF "USABLE" VALUES

ABSTRACT

Earlier reviews of the state of international reference samples of silicate rocks and minerals have been revised by the addition of new data and correction of errors. Usable values of varying degrees of reliability, calculated on the "dry basis", are assigned where possible for major, minor and trace elements in 48 samples. Methods for deriving usable values are discussed.

RESUME

On a revisé les études sommaires déja publiées sur l'état actuel d'échantillons de roches et de minéraux silicatés proposés comme matériaux de référence internationaux, en ajoutant des données nouvelles et en corrigeant des erreurs. On suggère des valeurs dont on peut se servir à divers niveaux de certitude, basées sur la condition "sèche", pour des éléments majeurs, mineurs et en traces dans 48 échantillons. On discute les méthodes utilisées en déduisant les valeurs utilisées.

INTRODUCTION

In the course of the last 25 years, many geological agencies in a number of countries have prepared selected samples of typical silicate rocks and minerals for use as "standard samples". Generally, the originators have distributed portions of the samples to many laboratories, most of which have contributed analytical results. The originators have then published compilations of the data.

Two unfortunate features have characterized most of those programs:

(a) There has been essentially no co-ordination between different institutions regarding the selection and preparation of such samples, the means of attaining and testing homogeneity, and the interpretation of the resulting analytical data.

(b) There has been an extraordinarily wide range of values reported by different laboratories for individual constituents in individual samples. For example, Flanagan (1969) listed 45 values for silica in sample USGS-GSP-1 ranging from 64.69 to 69.88 per cent, with about two-thirds of the results clustering between 66.9 and 67.5.

Because of the increasing need for standard samples to calibrate instruments, to test new analytical methods, and to compare the performance of different laboratories, it is necessary that reliable concentration values be available for as many constituents in as many samples as possible.

In view of the large discrepancies in the available data, many originators of proposed "standard samples" have been understandably hesitant to assign recommended values. In most of the compilations, all individual results are given, along with arithmetic averages and standard deviations. In some cases, adjusted means are also listed, based on the elimination of values which differ from the crude mean by more than one, two, or three standard deviations. Occasionally, such adjusted means are considered as recommended values, although some of them have been modified by the originators, by applying some knowledgeable subjective judgment.

During the study of large compilations of data on groups of samples from various sources (Abbey, 1970, 1972, 1973) certain conclusions have been drawn, which have met with varying degrees of acceptance by others working in the same field. The conclusions are as follows:

(i) <u>The data cannot be treated by rigorous statistical methods</u>. Although such methods are commonly applied successfully in treating data on proposed standard samples of many other materials, the nature of rock samples precludes their use. Aside from the question of homogeneity, an important peculiarity of rock analysis is the need for the determination of some 13 or 14 major and minor constituents, and of a much larger number of trace elements. Because very few laboratories are equipped to fulfill all of the requirements, it is necessary to involve a much larger number of collaborating laboratories than would be the case for such materials as metals, alloys or ores. Little selectivity can be exercised by the originators in soliciting collaborators, with the inevitable proliferation of uncontrolled variables.

(ii) <u>The average value of all available results is not necessarily a good approximation of the best value for a particular constituent of a particular sample</u>. There are many exceptions to this rule, but it is particularly important for components that occur at unusual levels, or in the presence of unusual levels of some other components. The difficulty may be due, in part, to the use of unsuitable analytical methods.

(iii) The best value for a particular constituent in a particular sample is most easily attained by basing calculations on data obtained from a small number of laboratories whose results show the greatest overall consistency. This is the most controversial conclusion, because many others concentrate their efforts merely on the elimination of a small number of poor results. This conclusion cannot be applied where only a few results are available, hence it has been used mainly for the more commonly determined major and minor elements.

(iv) In a set of values derived for major and minor constituents (based on a large number of analyses), the summation must be close to 100 per cent. Although this conclusion is almost axiomatic, there are hazards in using it. Part of the difficulty lies in the traditional categorization of analytical data on rocks into major, minor and trace elements. Circumstances can arise where elements, which would normally be considered as traces, occur at higher concentrations than some so-called minor elements, a good example being the rôle-reversal of chromium and potassium (in terms of their concentration levels) in going from acidic to ultrabasic rocks. If strontium occurs at a relatively high "trace" level (say 500 ppm or more), it would be expected to be added to the summation. However, some of the analyses in the compilation might have been done by means of classical procedures, with no determinations of trace elements, in which case the strontium would already have been included with the calcium, and should therefore not be added again. The slight positive error in the reported calcium content might not be noticeable. The possibility of the occurrence of some elements in the metallic state in ultrabasic rocks can lead to the inclusion, in the summation, of some oxygen that is not actually present, because of the traditional reporting of the components of rocks as oxides.

(v) The derived values for ferrous, ferric and total iron must be mutually compatible. Essentially all laboratories who analyse for major and minor elements determine total iron present, generally expressed as ferric oxide. Some of them also determine ferrous iron, then derive ferric by difference and report ferrous and ferric. If the apparent ferric, ferrous and total iron content based on a consensus from many analyses are not mutually compatible, the validity of at least one of the values becomes doubtful.

Special Problems

The disparities in results reported by different laboratories have been mentioned above. While these are noticeable even with the common major and minor components normally determined, the most serious discrepancies are likely to occur in the determinations of ferrous iron, "combined" water and carbon dioxide. For one thing, relatively few of these determinations are done because of the increasing use of instrumental methods. With carbon dioxide, matters are further complicated by the failure of some laboratories to distinguish "total carbon", as determined by a combustion method, from "carbonate carbon", as determined by acid evolution. Even in samples which are not expected to contain significant quantities of non-carbonate carbon, noticeable differences have been observed between results obtained by the two methods.

There are still large gaps remaining in our knowledge of the concentrations of a number of trace elements, not all of them particularly "rare"; for example, although sample USGS-W-1 has been available for about 25 years, there is still considerable doubt about its content of boron, bismuth, tungsten, molybdenum, hafnium, germanium, thallium, indium, niobium and some of the rare earths. The number of reported values for selenium and tellurium on all the samples listed in this work is too small to justify the inclusion of either element in the tabulations.

Selection of "Usable" Values

The values listed in Tables 2, 3 and 4 were arrived at in several different ways, as indicated in the descriptive notes about the various issuing agencies. Where the originators have given recommended values, such values are listed in the Tables, with certain exceptions, as outlined below. Where recommended values have not been given by the issuing agencies, an empirical "general method" (described below) has been applied. In some cases, particularly for trace elements, simpler procedures were used, leading to less certain values.

The term "usable values" has been introduced to indicate a level of reliability which is not quite as legalistically established as a "recommended", "certified" or "guaranteed" value (all of which terms have been used by one or another originator of reference samples), but is better than "proposed", "provisional" or "tentative" values.

Proposed General Method

This scheme was first applied (Abbey, 1970) in order to arrive at usable values for major and minor elements in six samples from the U. S. Geological Survey. The raw data are those of Flanagan (1969). The method involves a series of steps:

(1) For each major and minor component of each sample, the arithmetic mean of all available results is calculated.

(2) The twenty per cent of the available results that are farthest removed from the arithmetic mean are eliminated, and a new adjusted mean calculated. In earlier work, the eliminated results were fifteen per cent of the total, but the difference has little effect on the final result.

(3) All results falling within an arbitrary interval of the adjusted mean (generally plus or minus one class interval where the data have been plotted as a histogram) are arbitrarily defined as "good". Those eliminated in (2) are defined as "poor". The remainder are considered "fair".

(4) For each collaborating laboratory which has performed a "complete" analysis for all of the samples in a group, the numbers of good, fair and poor results are expressed as percentages of all results reported by that laboratory. The percentage of good results, minus the percentage of poor results is used as an arbitrary "laboratory rating". Experience has shown the rating to vary over the range of about plus 80 to minus 30.

(5) For each component of each sample, only those values reported by those laboratories whose rating exceeds an arbitrary minimum are used to calculate a "select mean". That result is generally taken as the usable value, except where it is necessary to eliminate one "select" value that differs greatly from the others for a particular component of a particular sample.

Experience has shown that in going through the progressively more selective steps in the above scheme, the summations tend to become progressively closer to 100 per cent, and the three iron oxide figures become more mutually compatible. Values for major and minor elements listed in Tables 2 and 3 with question marks represent concentrations where insufficient data were available to apply the General Method, or where there are other reasons for uncertainty, as listed in the descriptive notes.

Proposed Abridged Method

In cases where a particular program involved only one sample, use of the complete proposed method was not considered justified, and the adjusted means for major and minor elements were taken as usable values, except where subjective considerations required further adjustment.

The same procedure has been applied for trace elements for all samples, mainly because the spread of values and the smaller numbers of results indicated that a more selective method was not justified. With certain of the more common trace elements (e.g. barium, strontium, chromium, nickel, cobalt, copper, zinc, lead, etc.) it may be possible to apply the general method.

The abridged method is ordinarily restricted to those components where at least 10 results are available for a particular component of a sample. Where five to nine results are available, the arithmetic mean is given in the Tables, with a question mark to indicate uncertainty. Where fewer than five results are available, no value is listed.

PRESENTATION OF THE DATA

Table 1 lists all samples in this compilation, arranged alphabetically (and numerically) and indexed to the appropriate descriptive notes. In Table 2, samples are listed roughly in geographic order of the country of origin, starting with Canada, and usable values listed for major and minor elements. The list has been extended to include several elements not ordinarily included in a "complete" analysis, because some of those elements are present in some of the samples at relatively high levels.

Values for major and minor elements are expressed as the traditional oxides, to two decimal places of percentages, except where there is reason to reduce the decimal places to one. All values have been reduced to the "dry basis", in order to place all results on a reproducible footing. Ideally, that should be done by applying a correction for moisture as determined with each set of results. Unfortunately, that was not always possible, so it was necessary to utilize "usable values" of H_2O^-.

In Table 3, the usable values for major and minor elements are listed under the components, with individual samples given in descending order of the content of each component. Values are also listed, with question marks, for some additional samples which are not considered sufficiently well established to be included in Table 2. Some additional values are listed in Table 3 with question marks and blank spaces, merely to indicate their expected position on the concentration ladder. They represent components of some otherwise established samples where too great an uncertainty exists, or samples for which no compilation has been published.

In Table 4, the trace elements are arranged in much the same way as the major and minor elements in Table 3. No attempt has been made to include values in the "blank space and question mark" category. Usable values for trace elements have been rounded to two significant figures, except where the initial figure is unity, in which case a five or a zero may be shown in the third place.

CCRMP - CANADIAN CERTIFIED REFERENCE MATERIALS PROJECT

(Contact: Sydney Abbey, Co-ordinator, Task Force on Rock Samples, CCRMP, c/o Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada, K1A 0E8)

This group, operating originally under the Canadian Association for Applied Spectroscopy (later the Spectroscopy Society of Canada), became an activity of the Mines Branch, Department of Energy, Mines and Resources, Canada, in 1973. Several rock-like samples have been issued, including syenite SY-1, which is now exhausted, and sulphide SU-1, which is of more interest as an ore standard. Samples SY-2 and SY-3 were prepared some years ago, and a trickle of analytical data has been received from various sources. Similarly, the gabbro sample MRG-1 was prepared several years ago, and even fewer results are available on it. Late in 1973, a systematic program of collaborative analysis was instituted for SY-2, SY-3 and MRG-1. Over 60 laboratories in many different countries are involved, and a preliminary report is expected in 1975. Meanwhile, sufficient data have been received to list a few tentative values in Tables 3 and 4.

USGS - UNITED STATES GEOLOGICAL SURVEY

(Contact, F.J. Flanagan, Liaison Officer, Geological Survey, U.S. Department of the Interior, Reston, Va., 22092, U.S.A.)

United States Geological Survey samples G-1 and W-1 were probably the pioneers in this field, early work on them having been published in 1951. G-1 has long been exhausted and has not been included in the work of this series. W-1 ran out relatively recently (Flanagan, 1973) but it is included here, most of the values being based on Flanagan (1973).

Flanagan (1969) published a large compilation of data on the six samples AGV-1, BCR-1, DTS-1, G-2, GSP-1 and PCC-1, but did not recommend values. Abbey (1970) applied the "proposed general method" outlined above to derive values for major and minor elements, and later (Abbey, 1972) the "abridged method" for trace elements. Subsequently, Flanagan (1973) listed "recommended", "average" and "magnitude" values for these samples (and many from other sources). Some contradictions arose between Flanagan's (1973) recommended values and Abbey's (1972) usable values. In the preparation of Part 3 of this series (Abbey, 1973), Flanagan's values were given precedence, except where there were apparent errors, omissions, or other discrepancies. The same policy has been applied in this paper.

A number of other proposed samples of rocks and rock-like glasses have been prepared by the United States Geological Survey, but little information on them has been published. A new report on the subject, by Flanagan, is known to be in press, but it has not appeared at this writing.

Flanagan (1973) reported that the supply of sample DTS-1 is now exhausted.

NBS - NATIONAL BUREAU OF STANDARDS (U.S.A.)

(Contact: Office of Standard Reference Materials, Room B311, Chemistry Building, National Bureau of Standards, Gaithersburg, Md., 20234, U.S.A.)

Of the many standard reference materials issued by the National Bureau of Standards, only the Potash Feldspar 70a and the Soda Feldspar 99a fall within the composition range of silicate rocks. Meinke (1965a, b) gives their compositions as "provisional", but NBS Special Publication 260 (1973 Catalog) gives the same data without qualification. Certificate values are given for most of the major and minor elements, but no information is available on trace elements. Several glass samples are available from NBS, but their chemical compositions and physical form make them of little interest in general rock analysis.

BCS - BRITISH CHEMICAL STANDARDS

(Contact: Bureau of Analyzed Samples, Newham Hall, Newby, Middlesbrough, Teesside TS8 9EA, England)

As is the case with the National Bureau of Standards, only two of the many samples available from this source fall within the composition range of silicate rocks. These are Soda Feldspar 375 and Potash Feldspar 376. In this case, the Certificates of Analysis (Ridsdale, 1970a, b) list all of the analytical data reported by the collaborating laboratories. Here, the number of components determined is quite small, as is the number of analysts. The results are in very good agreement with one another, and their arithmetic means can be taken as usable values without hesitation. The collaborating analysts involved were apparently experts in this particular analytical specialty, thus producing more coherent data than usually results in analysis of rocks, where the need for trace determinations results in the inclusion of a large number of laboratories of varying backgrounds.

QMC - QUEEN MARY COLLEGE (U.K.)

(Contact: Dr. A.B. Poole, Department of Geology, Queen Mary College, University of London, Mile End Road, London E1 4NS, England).

Although earlier studies (Abbey, 1972, 1973) reported that no data were available on the samples from this source, a copy of a "Third Report" (Poole, 1972) was subsequently obtained through the kindness of Dr. B.M. Gunn, of the Université de Montréal. Later, more information was obtained directly from Poole (pers. comm., 1974). The proposed general method was applied to the major and minor elements and the abridged method to the trace elements, yielding the data in Tables 2, 3 and 4.

The samples are Aplitic Granite I-1, Dolerite I-3, Pelitic Schist M-2 and Calcsilicate M-3. Relatively small quantities of these samples were prepared, but some of each sample is apparently still available for distribution (Poole, pers. comm., 1974).

The available analytical data include very few results for H_2O^-. All of the analyses, which did not include that determination, were therefore assumed to have been reported on the dry basis. The resulting uncertainty would significantly affect only those constituents present at relatively high levels. Accordingly, question marks have been included with all usable values that are over 10 per cent.

ASK - ANALYTISK SPORELEMENT KOMITE (Scandinavia)

(Contact: Dr. Olav H.J. Christie, Mass Spectrometric Laboratory, University of Oslo, Box 1048, Oslo 3, Norway)

Two samples from this group, larvikite ASK-1 and schist ASK-2, fall within the composition range of silicate rocks. A third, ASK-3, is an iron sulphide, of more interest in ore analysis. No compilation of analytical data has been published at this writing, but an advance copy of a manuscript on these samples was obtained through the kindness of Dr. F.J. Langmyhr, of the University of Oslo. The manuscript listed recommended values for a number of trace elements, based on round-table discussions by the participating analysts (a highly commendable procedure), and those values are given in Table 4. "Uncertified" values for major and minor elements are given in Table 3 as blank spaces with question marks. However, actual figures are given for some minor components which are listed also as "trace elements" (e. g. manganese, chromium, nickel and zirconium).

ANRT - ASSOCIATION NATIONALE DE LA RECHERCHE TECHNIQUE (France) CRPG - CENTRE DE RECHERCHES PETROGRAPHIQUES ET GEOCHIMIQUES (France)

(Contact for both groups: K. Govindaraju, Centre de Recherches Pétrographiques et Géochimiques, Case officielle n°. 1, 54500 Vandoeuvre-lès-Nancy, France)

The first reference sample produced by CRPG was the experimental granite GR, long since exhausted, and never included among the samples studied in this series of papers. Subsequently, CRPG also produced granites GA and GH, and basalt BR, three of the best-established reference samples. Later, two mica samples were issued, biotite Mica Fe and phlogopite Mica Mg.

More recently, the reference sample program of CRPG has been integrated with that of ANRT, resulting in diorite sample DR-N, serpentine UB-N, synthetic glass VS-N, and most recently, granite GS-N and feldspar FK-N.

The most recent data on the CRPG samples were given by Roubault *et al.* (1970), those on the ANRT samples by de La Roche and Govindaraju (1973a, b). For major and minor elements, these groups have followed the general practice of recommending a value that is the mean of the remaining values after eliminating all values that differ from the overall mean by more than one standard derivation. However, they have on occasion applied some subjective judgment in interpreting such data.

Sample Mica Fe was given recommended values by Roubault *et al.* (1970). However, the number of individual analyses upon which those values were based was rather small, and agreement was not very good. For those reasons no usable values are given in Table 2, and those listed in Tables 3 and 4 are given with question marks. For Mica Mg, Roubault *et al.* (1970) give only "proposed values", presumably based on preliminary analyses in the originators' laboratories. The limited analytical data from other sources are not in good agreement with the proposed values. Accordingly, Mica Mg is listed only with blank spaces and question marks in Table 3, the locations being based on the proposed values.

Both ANRT samples, DR-N and UB-N, are well-established, except for the MgO value in the latter. The recommended MgO value of de La Roche and Govindaraju (1973a) differs noticeably from the adjusted mean of the available data, being based on a subjective interpretation of results produced by a select group of laboratories. Because of that discrepancy, the MgO value for UB-N is given to only one decimal place, with a question mark, in Tables 2 and 3.

Sample VS-N contains high concentrations (hundreds of parts per million) of many "trace elements". With so many elements present at a maximum level in the same sample, questions may arise regarding its usefulness. Usable values given in Table 4 are rounded versions of elemental equivalents of the oxide contents recommended by de La Roche and Govindaraju (1973b). Similarly, values with question marks are based on their "proposed values". Values for major and minor components of VS-N are not intended for standards use, and are therefore not given in Tables 2 and 3.

The two newest samples, GS-N and FK-N, have not been listed in any compilations. Their positions (with blank spaces and question marks) in Table 3 are based on our own analyses.

Two additional ANRT samples, bauxite BX-N and kyanite DT-N, are not included here because their compositions are far removed from those of silicate rocks.

ZGI - ZENTRALES GEOLOGISCHES INSTITUT (East Germany)

(Contact: Prof. Dr. K. Schmidt, Direktor, Zentrales Geologisches Institut, Invalidenstrasse 44, 104 Berlin, Deutsche Demokratische Republik)

Three silicate samples from this source are well-established: granite GM, basalt BM and slate TB. Values for major and minor elements were given by Grassmann (1972) and for trace elements by Schindler (1972). Grassmann gave means, numbers of determinations, standard deviations and 95 per cent confidence limits, with actual recommended values only for silica and alumina. Because individual results were not listed, it was not possible to apply the general or abridged selective procedures. However, Grassmann's confidence limits are such that his values may be considered "usable".

Similarly, Schindler (1972) gave means and numbers of determinations for trace elements. Because individual results were not given, Schindler's means are given as "usable" in Table 4, where 10 or more determinations were reported. Where five to nine determinations were involved, the values are shown with question marks. No values are shown where Schindler's means represent fewer than five individual results.

Two newer samples issued by ZGI are shale TS and feldspar sand FK and they are placed (with blank spaces and question marks) in Table 3, on the basis of the originators' first approximations of their compositions. Two more ZGI samples, anhydrite AN and limestone KH, are not included here because their compositions are far removed from those of silicate rocks.

LEN - LENINGRAD STATE UNIVERSITY (U.S.S.R.)

(Contact: Prof. A.A. Kukharenko, Department of Mineralogy, Leningrad State University, Leningrad V-164, U.S.S.R.)

The nepheline syenite sample NS-1 was originally identified as "Khibiny-Generalnaya". The values in Tables 2, 3 and 4 are based on the compilation by Kukharenko *et al.* (1968), to which the abridged method of selection has been applied. Very few results were reported on trace elements in this sample. It is not known whether the sample is still available, but the Geological Survey of Canada laboratories were supplied with a generous quantity in the original program of collaborative analysis.

IGI - INSTITUTE OF GEOCHEMISTRY, IRKUTSK (U.S.S.R.)

(Contact: Prof. L.V. Tauson, Institute of Geochemistry, P.B. 701, Irkutsk 33, U.S.S.R.)

At this writing, no compilation of results appears to have been published on the three samples, trap IGI-2001, gabbro IGI-2003 and albitized granite IGI-2005. The positioning of the spaces for these samples in Table 3 is based on what limited analytical work has been done in our own laboratories.

GSJ - GEOLOGICAL SURVEY OF JAPAN

(Contact: Dr. Atsushi Ando, Geochemical Research Section, Geological Survey of Japan, 135 Hisamoto-cho, Kawasaki-shi, Japan)

Analytical data for the two samples, basalt JB-1 and granodiorite JG-1, were compiled and published by Ando *et al.* (1971). Using this source, values in Tables 2 and 3 were derived by the proposed general method; those in Table 4 by the abridged method. In earlier papers of this series (Abbey, 1972, 1973) the abridged method had been used for the major and minor elements, but application of the general method has had little effect on the tabulated usable values for most of the components.

MRT - MINERAL RESOURCES DIVISION (Tanzania)

(Contact: Commissioner, Mineral Resources Division, P.O. Box 903, Dodama, Tanzania)

A compilation of results on the tonalite sample T-1 was reported by Thomas and Kempe (1963), based on analyses by 14 laboratories (mainly for major and minor elements). The results were in good agreement, with much lower standard deviations for individual components than has been the case with other rock samples. The values listed in Tables 2, 3 and 4 were all derived by the abridged method.

A note by Bowden and Luena (1966) indicated that the sample was available at that time, but it is not known whether it is available now. Bowden and Luena rightly warned against the indiscriminate use of insufficiently well-established values.

NIM - NATIONAL INSTITUTE OF METALLURGY (South Africa)

(Contact: H.P. Beyers, South African Bureau of Standards, Private Bag 191, Pretoria, South Africa)

Russell *et al.* (1972) listed all available results on the six rock samples: dunite NIM-D, granite NIM-G, lujavrite NIM-L, norite NIM-N, pyroxenite NIM-P and syenite NIM-S. They calculated means, standard deviations and adjusted means, but did not give recommended values for each sample. The values for major and minor elements, listed in Tables 2 and 3, were derived by the proposed general method, those for trace elements in Table 4 by the abridged method. A glance at these Tables will reveal that at least two of the samples, NIM-L and NIM-P, are of unusual composition. Similarly, detailed study of the raw analytical data suggests that some of the collaborating analysts did not pay sufficient attention to the possible effects (or even the determination) of components present at unusually high levels. As a result, considerably more subjective judgment was used in arriving at usable values than was the case with other samples. It follows, then, that some values for these samples are less firmly established than those for other samples, and are likely to undergo some modification as more data become available.

Flanagan (1973) listed averages for most components of the South African samples, based entirely on information from the originators. In this work, it was decided to favour the values derived by our own selective methods over Flanagan's thorough but uncritical listing of averages.

PRECAUTIONARY NOTES REGARDING THE TABLES

A number of citations of values from various compilations have strongly suggested an unfortunate tendency by some workers to accept any tabulated value without attempting to understand how it was derived, or its degree of reliability. It would appear that the time, effort and money going into the establishment of reliable values for reference samples is not universally appreciated or even understood. Although lack of understanding by users may be blamed in some cases, even the originators and the compilers of data are not entirely innocent. For example, it does not help the situation when samples are offered as "standards" with little or no supporting analytical data, or with data from only the originating laboratories, or where the data are presented without sufficient emphasis on the degree of reliability involved.

For the above reasons, footnotes on every page of the Tables in this paper direct the readers' attention to these notes. The presence or absence of question marks in the Tables should be regarded only as a rough guide to the reliability of individual values listed. Better understanding can be attained only by careful study of the original compilations for each group of samples.

Another unfortunate tendency has become apparent in some papers where reference samples have been used in verifying new analytical methods. Some workers consider their results acceptable merely because they fall "within the range" of values listed in a compilation. In fact, such a situation merely indicates that the results in question are not as bad as the worst in the compilation. How bad that can be is clearly indicated in many of the original compilations.

Readers are therefore strongly urged to read the entire text of this paper before using any of the Tables. They are also requested to inform the author of any errors they may observe. Such errors are almost inevitable where so large a volume of numerical data is involved.

In the Tables, Fe_2O_3T means "total iron content, expressed as ferric oxide", Fe_2O_3TR means the usable value of Fe_2O_3T, calculated from results reported as such; Fe_2O_3TC means Fe_2O_3T, calculated from usable values for FeO and Fe_2O_3. RE_2O_3T means "total rare earth" (lanthanide) oxides. SUM has been corrected, where necessary, for fluorine, chlorine and sulphur.

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TABLE 1 - Alphabetical Listing of Samples

Sample No.	Source	Country	Ref. Page
AGV-1	USGS	U. S. A.	4
ASK-1 ASK-2	ASK	Scandinavia	4
BCR-1	USGS	U. S. A.	4
BM	ZGI	East Germany	5
BR	CRPG	France	5
DR-N	ANRT	France	5
DTS-1	USGS	U. S. A.	4
FK	ZGI	East Germany	5
FK-N	ANRT	France	5
G-2	USGS	U. S. A.	4
GA GH	CRPG	France	5
GM	ZGI	East Germany	5
GS-N	ANRT	France	5
GSP-1	USGS	U. S. A.	4
I-1 I-3	QMC	U. K.	4
JB-1 JG-1	GSJ	Japan	6
M-2 M-3	QMC	U. K.	4
Mica Fe Mica Mg	CRPG	France	5
MRG-1	CCRMP	Canada	3
NIM-D NIM-G NIM-L NIM-N NIM-P NIM-S	NIM	South Africa	6
NS-1	LEN	U. S. S. R.	6
PCC-1	USGS	U. S. A.	4
SY-2 SY-3	CCRMP	Canada	3
T-1	MRT	Tanzania	6
TB TS	ZGI	East Germany	5
UB-N VS-N	ANRT	France	5
W-1	USGS	U. S. A.	4
70a 99a	NBS	U. S. A.	4
375 376	BCS	U. K.	4
2001 2003 2005	IGI	U. S. S. R.	6

TABLE 2

"Usable" Values, Major and Minor Components (per cent, dry basis)*

	CCRMP			USGS						
	Gabbro MRG-1	Syenite SY-2	Syenite SY-3	Andesite AGV-1	Basalt BCR-1	Dunite DTS-1	Granite G-2	Grano-diorite GSP-1	Perido-tite PCC-1	Diabase W-1
SiO_2				59.72	54.85	40.68	69.19	67.31	42.15	52.72
Al_2O_3				17.22	13.68	0.29	15.35	15.19	0.73	14.87
Fe_2O_3T				6.84	13.52	8.60	2.67	4.33	8.28	11.11
MgO				1.55	3.49	49.83	0.77	0.96	43.63	6.63
CaO				5.00	6.98	0.15	1.98	2.02	0.53	10.98
Na_2O				4.31	3.29	0.01	4.06	2.80	0.01	2.15
K_2O				2.93	1.68	0.00	4.52	5.53	0.00	0.64
TiO_2				1.05	2.22	0.01	0.50	0.66	0.01	1.07
MnO				0.10	0.19	0.11	0.04	0.04	0.12	0.17
BaO		SEE TABLE 3		0.14	0.08	0.00	0.21	0.15	0.00	0.02
SrO				0.08	0.04	0.00	0.06	0.03	0.00	0.02
Cr_2O_3				0.00	0.00	0.64	0.00	0.00	0.44	0.02
NiO				0.00	0.00	0.31	0.00	0.00	0.32	0.01
ZrO_2				0.03	0.02	0.00	0.04	0.07	0.00	0.01
Nb_2O_5				0.00	0.00	0.00	0.00	0.00	0.00	0.00
RE_2O_3T				0.02?	0.02?	0.00	0.04?	0.10?	0.00	0.01?
FeO				2.08	9.05	6.98	1.45	2.31	5.17	8.73
Fe_2O_3				4.57	3.48	0.85	1.01	1.77	2.50	1.40
H_2O^+				0.82	0.73	0.46	0.55	0.57	4.64	0.53
CO_2				0.01	0.03?	0.06	0.08	0.12	0.16	0.06
P_2O_5				0.50	0.33	0.00	0.14	0.28	0.00	0.14
Cl				0.02	0.01	0.01?	0.01	0.04	0.01?	0.02?
F				0.04?	0.05?	0.00	0.13	0.38	0.00	0.02
S				0.01?	0.04?	0.00	0.00?	0.04	0.01	0.01?
SUM				100.15?	100.19?	100.39?	100.07?	100.16?	100.43?	100.19?
Fe_2O_3TR				6.84	13.52	8.60	2.67	4.33	8.28	11.11
Fe_2O_3TC				6.88	13.54	8.61	2.62	4.34	8.24	11.10

*See "Precautionary Notes ...", p. 6

(cont'd.)

TABLE 2 (cont'd.)

"Usable" Values, Major and Minor Components (per cent, dry basis)*

	NBS		BCS		QMC				ASK	
	K-Feldspar 70a	Na-Feldspar 99a	Na-Feldspar 375	K-Feldspar 376	Aplitic Granite I-1	Dolerite I-3	Pelitic Schist M-2	Calc-Silicate M-3	Larvikite ASK-1	Schist ASK-2
SiO_2	67.1	65.2	67.1	67.1	75.38?	49.75?	48.88?	55.59?		
Al_2O_3	17.9	20.5	19.8	17.7	13.94?	13.10?	24.00?	17.67?		
Fe_2O_3T	0.08	0.06	0.12	0.10	0.53	16.22?	9.25	4.57		
MgO	?	0.02	0.05	0.03	0.10	4.19	2.45	1.20		
CaO	0.11	2.14	0.89	0.54	0.80	8.19	1.75	12.01?		
Na_2O	2.55	6.2	10.4	2.83	4.59	2.92	1.42	2.95		
K_2O	11.8	5.2	0.78	11.2	4.28	1.43	7.91	0.71		
TiO_2	0.01	0.01	0.38	0.01?	0.05	2.60	0.71	0.83		
MnO					0.03.	0.22	0.26	0.28		
BaO	0.02	0.26			0.05?	0.08?	0.18?	?		
SrO					0.02?	0.03	0.02?	0.06?	SEE TABLE 3	
Cr_2O_3						0.00?	0.01?			
NiO						0.00?	0.00?			
ZrO_2					0.01?	0.03?	0.02?	0.04?		
Nb_2O_5										
RE_2O_3T						0.01?				
FeO					0.19?	9.88?	6.32?	3.32?		
Fe_2O_3					0.33?	5.25?	2.26?	0.89?		
H_2O^+	0.40**	0.26**			0.18?	1.76?	3.31?	0.74?		
CO_2								2.98?		
P_2O_5		0.02			0.02?	0.39?	0.51?	0.37?		
Cl										
F										
S										
SUM	99.97?	99.87?	99.52?	99.51?	99.97?	99.83?	100.01?	99.64?		
Fe_2O_3TR					0.53	16.22	9.25	4.57		
Fe_2O_3TC					0.54	16.23?	9.28?	4.58		

*See "Precautionary Notes ...", p. 6

**Loss on ignition

(cont'd.)

TABLE 2 (cont'd.)

"Usable" Values, Major and Minor Components (per cent, dry basis)*

	ANRT				CRPG				
	Diorite DR-N	Feldspar FK-N	Granite GS-N	Serpentine UB-N	Basalt BR	Granite GA	Granite GH	Biotite Mica Fe	Phlogopite Mica Mg
SiO_2	52.88			39.93	38.39	69.96	75.85		
Al_2O_3	17.56			2.97	10.25	14.51	12.51		
Fe_2O_3T	9.69			8.45	12.98	2.86	1.33		
MgO	4.47			35.0 ?	13.35	0.95	0.03		
CaO	7.09			1.18	13.87	2.45	0.69		
Na_2O	3.00			0.10?	3.07	3.55	3.85		
K_2O	1.73			0.02?	1.41	4.03	4.76		
TiO_2	1.10			0.12	2.61	0.38	0.08		
MnO	0.21			0.12	0.20	0.09	0.05		
BaO	0.04	SEE TABLE 3		0.00	0.11	0.10	0.00	SEE TABLE 3	
SrO	0.05			0.00	0.16	0.04	0.00		
Cr_2O_3	0.01			0.33	0.06	0.00	0.00		
NiO	0.00			0.25	0.03	0.00	0.00		
ZrO_2	0.02				0.03	0.02	0.02		
Nb_2O_5					0.01?		0.01?		
RE_2O_3T					0.01?	0.01?	0.01?		
FeO	5.32			2.69	6.60	1.32	0.84		
Fe_2O_3	3.78			5.46	5.61	1.36	0.41		
H_2O^+	2.20			11.28?	2.31	0.87	0.46		
CO_2	0.15?			0.44?	0.86	0.11	0.14		
P_2O_5	0.25			0.03	1.05	0.12	0.01		
Cl					0.04?	0.03	0.01?		
F					0.10	0.05	0.30		
S					0.04?	?	?		
SUM	99.85?			100.36?	100.09?	99.92?	99.90?		
Fe_2O_3TR	9.69			8.45	12.98	2.86	1.33		
Fe_2O_3TC	9.69			8.45	12.94	2.83	1.34		

*See "Precautionary Notes ...", p. 6

(cont'd.)

TABLE 2 (cont'd.)

"Usable" Values, Major and Minor Components (per cent, dry basis)*

	ZGI					LEN	IGI		
	Basalt BM	Feldspar Sand FK	Granite GM	Slate TB	Shale TS	Neph. Syenite NS-1	Trap 2001	Gabbro 2003	Alb. Granite 2005
SiO_2	49.60		73.55	60.30		53.41			
Al_2O_3	16.20		13.50	20.55		21.30			
Fe_2O_3T	9.68		2.02	6.92		4.13			
MgO	7.46		0.38	1.94		0.63			
CaO	6.44		1.02	0.30		1.72			
Na_2O	4.64		3.76	1.31		9.86			
K_2O	0.20		4.74	3.85		6.51			
TiO_2	1.14		0.21	0.93		1.06			
MnO	0.14		0.04	0.05		0.19			
BaO	0.03		0.04	0.08		0.13?			
SrO	0.03	SEE TABLE 3	0.02	0.02	SEE TABLE 3	0.15?		SEE TABLE 3	
Cr_2O_3	0.02		0.00	0.01		0.00			
NiO	0.01		0.00	0.01		0.00			
ZrO_2	0.01		0.02	0.02		0.09			
Nb_2O_5									
RE_2O_3T	0.01?		0.02?	0.03?		0.06			
FeO	7.28		1.14	5.43		1.58			
Fe_2O_3	1.60		0.75	0.91		2.38			
H_2O^+	3.62		0.35	3.82		0.65			
CO_2	1.34?		0.28?	0.13		0.14			
P_2O_5	0.10		0.06	0.10		0.28			
Cl	0.01?		0.01?	0.00					
F	0.03?		0.07?	0.07?		0.14			
S						0.02			
SUM	99.89?		99.93?	99.83?		100.24?			
Fe_2O_3TR	9.68		2.02	6.92		4.13			
Fe_2O_3TC	9.69		2.02	6.94		4.14			

*See "Precautionary Notes ...", p. 6

(cont'd.)

TABLE 2 (cont'd.)

"Usable" Values, Major and Minor Components (per cent, dry basis)*

	GSJ		MRT	NIM					
	Basalt JB-1	Grano-diorite JG-1	Tonalite T-1	Dunite NIM-D	Granite NIM-G	Lujavrite NIM-L	Norite NIM-N	Pyroxenite NIM-P	Syenite NIM-S
SiO_2	52.49	72.31	62.69	38.97	75.73	52.66	52.65	51.18	63.54
Al_2O_3	14.66	14.25	16.57	0.26	12.13	13.57	16.47	4.27	17.16
Fe_2O_3T	9.08	2.21	5.94	16.99	1.96	9.95	8.95	12.78	1.44
MgO	7.80	0.76	1.86	43.68	0.05?	0.23	7.56	25.35	0.48
CaO	9.31	2.15	5.11	0.26	0.77	3.19	11.47	2.67	0.68
Na_2O	2.80	3.37	4.40	0.06?	3.36	8.35	2.47	0.38	0.41
K_2O	1.42	3.92	1.24	0.02	5.04	5.52	0.25	0.09	15.40
TiO_2	1.37	0.25	0.59	0.02	0.09	0.49	0.20	0.20	0.05
MnO	0.16	0.06	0.11	0.21	0.02	0.76	0.18	0.22	0.01
BaO	?	?	0.07?	0.00	0.02?	0.05	0.01	0.01	0.27
SrO	0.05	0.02	0.05?	0.00	0.00	0.54	0.03	0.00	0.01
Cr_2O_3	0.06?	0.01?	0.00	0.41	0.00	0.00	0.01	3.62	0.00
NiO	?	?	0.00	0.29	0.00	0.00	0.02	0.07	0.00
ZrO_2			0.02	0.00	0.04	1.63	0.00	0.00	0.00
Nb_2O_5				0.00	0.00	0.12?	0.00	0.00	0.00
RE_2O_3T					0.04?	0.05?			
FeO	6.16	1.72	2.91	14.67	1.30	1.04	7.49	10.47	0.29
Fe_2O_3	2.24	0.35	2.80	0.70	0.63	8.76	0.62	1.12	1.08
H_2O^+	1.11	0.55	1.51	0.26	0.42	2.44	0.31	0.25	0.23
CO_2	0.19?	0.09?	0.08?	0.42?	0.08?	0.21?	0.10?	0.08?	0.10?
P_2O_5	0.26	0.09	0.14	0.03	0.02	0.07	0.04	0.02	0.14
Cl				0.04?	0.06?	0.11?	0.01?	0.01?	0.02?
F	?	?	0.06?	0.00	0.43?	0.43?	0.04?	0.02?	0.02?
S			0.01?	0.00	0.01?	0.06	0.01?	0.01?	0.01?
SUM	100.09?	99.91?	100.18?	100.29?	100.04?	100.02?	99.91?	100.02?	99.88?
Fe_2O_3TR	9.08	2.21	5.94	16.99	1.96	9.95	8.95	12.78	1.44
Fe_2O_3TC	9.08	2.26	6.03	17.00	2.07	9.91	8.94	12.75	1.40

*See "Precautionary Notes ...", p. 6

TABLE 3

"Usable" Values - Major and Minor Components*

SiO_2		Al_2O_3		Fe_2O_3T		MgO		CaO	
?	FK	24.00?	M-2	25.83?	Mica Fe	49.83	DTS-1	?	MRG-1
75.85	GH	21.30	NS-1	?	MRG-1	43.68	NIM-D	13.87	BR
75.73	NIM-G	20.55	TB	16.99	NIM-D	43.63	PCC-1	12.01?	M-3
75.38?	I-1	20.5	99a	16.22?	I-3	35.0 ?	UB-N	11.47	NIM-N
73.55	GM	19.8	375	?	2001	25.35	NIM-P	10.98	W-1
?	2005	19.46?	Mica Fe	13.52	BCR-1	?	Mica Mg	?	2003
72.31	JB-1	?	ASK-2	12.98	BR	?	MRG-1	?	2001
69.96	GA	?	ASK-1	12.78	NIM-P	13.35	BR	9.31	JB-1
69.19	G2	17.9	70a	?	2003	7.80	JB-1	?	SY-3
67.31	GSP-1	17.7	376	11.11	W-1	7.56	NIM-N	8.19	I-3
67.1	70a	?	FK-N	9.95	NIM-L	7.46	BM	?	SY-2
67.1	375	17.67?	M-3	9.69	DR-N	?	2003	7.09	DR-N
67.1	376	17.56	DR-N	9.68	BM	6.63	W-1	6.98	BCR-1
?	GS-N	17.22	AGV-1	?	Mica Mg	?	2001	6.44	BM
65.2	99a	17.16	NIM-S	9.25	M-2	4.60?	Mica Fe	5.11	T-1
?	FK-N	16.57	T-1	9.08	JB-1	4.47	DR-N	5.00	AGV-1
63.54?	NIM-S	16.47	NIM-N	8.95	NIM-N	4.19	I-3	?	ASK-1
?	TS	16.20	BM	8.60	DTS-1	3.49	BCR-1	3.19	NIM-L
62.69	T-1	?	TS	8.45	UB-N	?	SY-2	2.67	NIM-P
60.30	TB	?	Mica Mg	8.28	PCC-1	?	SY-3	?	GS-N
?	SY-2	15.35	G-2	?	TS	2.45	M-2	2.45	GA
59.72	AGV-1	15.19	GSP-1	6.92	TB	?	GS-N	2.15	JG-1
?	SY-3	14.87	W-1	?	ASK-2	?	ASK-2	2.14	99a
?	ASK-1	?	2003	6.84	AGV-1	1.94	TB	2.02	GSP-1
55.59?	M-3	?	GS-N	?	SY-3	1.86	T-1	1.98	G-2
54.85	BCR-1	14.66	JB-1	?	SY-2	?	TS	1.78	M-2
?	ASK-2	14.51	GA	5.94	T-1	1.55	AGV-1	1.72	NS-1
53.41	NS-1	14.25	JG-1	4.57	M-3	?	ASK-1	1.18	UB-N
52.88	DR-N	13.94?	I-1	?	ASK-1	0.96	GSP-1	1.02	GM
52.72	W-1	?	2003	4.33	GSP-1	0.95	GA	0.89	375
52.66	NIM-L	13.68	BCR-1	4.13	NS-1	0.77	G-2	0.80	I-1
52.65	NIM-N	?	2005	?	GS-N	0.76	JG-1	0.77	NIM-G
52.49	JB-1	13.57	NIM-L	2.86	GA	0.63	NS-1	?	ASK-2
51.18	NIM-P	13.50	GM	2.67	G-2	0.48	NIM-S	0.69	GH
49.75?	I-3	13.02?	I-3	?	2005	0.38	GM	0.68	NIM-S
?	2001	12.51	GH	2.21	JG-1	0.23	NIM-L	0.54	376
49.60	BM	12.13	NIM-G	2.02	GM	?	FK	0.53	PCC-1
48.88?	M-2	?	SY-2	1.96	NIM-G	0.10	I-1	0.45?	Mica Fe
?	2003	?	SY-3	1.44	NIM-S	0.05	375	0.30	TB
42.15	PCC-1	10.25	BR	1.33	GH	0.05?	NIM-G	0.26	NIM-D
40.68	DTS-1	?	MRG-1	0.53	I-1	0.03	GH	?	2005
39.93	UB-N	?	FK	?	FK	0.03	376	?	TS
?	MRG-1	4.27	NIM-P	0.12	375	0.02	99a	0.15	DTS-1
38.97	NIM-D	2.97	UB-N	0.10	376	?	2005	?	FK
38.39	BR	0.73	PCC-1	0.08	70a	?	FK-N	0.11	70a
?	Mica Mg	0.29	DTS-1	?	FK-N			?	Mica Mg
34.50?	Mica Fe	0.26	NIM-D	0.06	99a			?	FK-N

*Per cent, dry basis. See "Precautionary Notes", p. 6

(cont'd.)

TABLE 3 (cont'd.)

"Usable" Values - Major and Minor Components*

Na_2O		K_2O		TiO_2		MnO		BaO	
10.4	375	15.40	NIM-S	?	MRG-1	0.76	NIM-L	0.27	NIM-S
9.86	NS-1	?	FK-N	2.61	BR	0.35?	Mica Fe	0.26	99a
8.35	NIM-L	11.8	70a	2.60	I-3	?	SY-2	0.21	G-2
?	ASK-1	11.2	376	2.56?	Mica Fe	?	SY-3	?	GS-N
6.2	99a	?	Mica Mg	2.22	BCR-1	0.28	M-3	0.18	M-2
?	2005	8.83?	Mica Fe	?	2001	0.26	M-2	0.15	GSP-1
4.64	BM	7.91	M-2	?	Mica Mg	?	Mica Mg	0.14	AGV-1
4.59	I-1	6.51	NS-1	?	2003	0.22	I-3	0.13?	ASK-1
4.40	T-1	5.53	GSP-1	1.37	JB-1	0.22	NIM-P	0.13?	NS-1
?	SY-2	5.52	NIM-L	1.14	BM	?	2001	?	2003
4.31	AGV-1	?	ASK-2	1.10	DR-N	0.21	NIM-D	0.11	BR
4.06	G-2	5.2	99a	1.07	W-1	0.21	DR-N	0.10	GA
?	SY-3	5.04	NIM-G	1.06	NS-1	0.20	BR	0.08	BCR-1
3.85	GH	?	TS	1.05	AGV-1	?	2005	0.08?	I-3
?	GS-N	4.76	GH	?	ASK-1	0.19	NS-1	0.08	TB
3.76	GM	4.74	GM	0.93	TB	0.19	BCR-1	0.07?	T-1
3.55	GA	?	GS-N	?	ASK-2	0.18	NIM-N	?	JG-1
3.37	JG-1	4.50	G-2	0.83	M-3	0.17	W-1	?	SY-2
3.36	NIM-G	?	SY-2	?	TS	?	2003	?	SY-3
3.29	BCR-1	4.28	I-1	0.71	M-2	0.16	JB-1	0.05	NIM-L
3.07	BR	?	ASK-1	0.66	GSP-1	?	MRG-1	0.05?	I-2
3.00	DR-N	?	FK	?	GS-N	0.14	BM	0.04	DR-N
2.95	M-3	?	SY-3	0.59	T-1	0.13	ASK-1	0.04	GM
2.92	I-3	?	2005	0.50	G-2	0.12	PCC-1	0.03	BM
2.83	376	4.03	GA	0.49	NIM-L	0.12	UB-N	?	2001
2.80	GSP-1	3.92	JG-1	0.38	GA	0.11	DTS-1	0.02	NIM-G
2.80	JB-1	3.85	TB	0.38	375	0.11	T-1	0.02	W-1
?	2003	2.93	AGV-1	0.25	JG-1	0.10	AGV-1	0.02	70a
2.55	70a	?	2003	0.21	GM	0.09	GA	0.02?	Mica Fe
?	2001	1.73	DR-N	0.20	NIM-N	0.06	JG-1	?	M-3
?	FK-N	?	2001	0.20	NIM-P	?	GS-N	0.01	NIM-N
2.47	NIM-N	1.68	BCR-1	?	SY-3	0.05	GH	0.01	NIM-P
2.15	W-1	1.43	I-3	?	SY-2	0.05	TB	?	2005
1.42	M-2	1.42	JB-1	0.12	UB-N	0.04	ASK-2		
1.31	TB	1.41	BR	0.09	NIM-G	0.04	G-2		
?	ASK-2	1.24	T-1	0.08	GH	0.04	GSP-1		
?	MRG-1	0.78	375	?	2005	0.04	GM		
0.41	NIM-S	?	2001	?	FK	?	TS		
0.38	NIM-P	0.71	M-3	0.05	I-1	0.03	I-1		
0.30?	Mica Fe	0.64	W-1	0.05	NIM-S	0.02	NIM-G		
?	FK	0.25	NIM-N	0.02	NIM-D	0.01	NIM-S		
?	Mica Mg	0.20	BM	0.01	DTS-1	?	FK		
?	TS	?	MRG-1	0.01	PCC-1	?	FK-N		
0.10?	UB-N	0.09	NIM-P	0.01	70a				
0.06?	NIM-D	0.02	NIM-D	0.01	99a				
0.01	DTS-1	0.02?	UB-N	0.01	376				
0.01	PCC-1								

*Per cent, dry basis. See "Precautionary Notes", p. 6

(cont'd.)

TABLE 3 (cont'd.)

"Usable" Values - Major and Minor Components*

SrO	
0.54	NIM-L
?	2005
0.16	BR
0.15?	NS-1
0.08	AGV-1
0.08?	ASK-1
0.06	G-2
0.06?	M-3
?	GS-N
0.05	DR-N
0.05	JB-1
0.05?	T-1
0.04	BCR-1
0.04	GA
?	SY-3
0.03	BM
0.03	GSP-1
0.03	NIM-N
0.03?	I-3
?	2001
?	SY-2
0.02	GM
0.02	JG-1
0.02	TB
0.02	W-1
0.02?	I-1
0.02?	M-2
0.01?	ASK-2
0.01	NIM-S

Cr_2O_3	
3.62	NIM-P
0.64	DTS-1
0.44	PCC-1
0.41	NIM-D
0.33	UB-N
?	MRG-1
0.06	BR
0.06?	JB-1
0.02	BM
0.02	W-1
?	2001
0.01?	ASK-2
0.01?	ASK-1
0.01	NIM-N
0.01?	TB
0.01?	JG-1
0.01?	M-2
0.01?	Mica Fe
?	GS-N

NiO	
0.32	PCC-1
0.31	DTS-1
0.29	NIM-D
0.25	UB-N
0.07	NIM-P
0.03	BR
0.02?	ASK-2
0.02	NIM-N
?	MRG-1
0.01?	ASK-1
0.01	BM
0.01	TB
0.01	W-1

Nb_2O_5	
0.12?	NIM-L
?	SY-3
0.02	NS-1
0.01?	BR
0.01?	GH

ZrO_2	
1.63	NIM-L
0.09	NS-1
0.07	GSP-1
0.05?	ASK-1
0.04	G-2
0.04	NIM-G
0.04?	M-3
?	SY-2
?	SY-3
0.03	AGV-1
0.03	BR
0.03?	I-3
0.02?	ASK-2
0.02	BCR-1
0.02	DR-N
0.02	GA
0.02	GH
0.02	GM
0.02	T-1
0.02	TB
0.02?	M-2
0.01	BM
0.01	W-1
0.01?	I-1
?	MRG-1

RE_2O_3T	
?	SY-3
0.10?	GSP-1
0.06?	NS-1
0.05?	NIM-L
0.04?	G-2
0.04?	NIM-G
?	SY-2
0.03?	TB
0.02?	AGV-1
0.02?	BCR-1
0.02?	GM
?	MRG-1
0.01?	BM
0.01?	BR
0.01?	GA
0.01?	GH
0.01?	W-1

FeO	
19.23?	Mica Fe
14.67	NIM-D
?	2001
10.47	NIM-P
9.88?	I-3
9.05	BCR-1
8.73	W-1
?	MRG-1
7.49	NIM-N
?	2003
7.28	BM
6.98	DTS-1
?	Mica Mg
6.60	BR
6.32?	M-2
6.16	JB-1
5.43	TB
5.32	DR-N
5.17	PCC-1
?	SY-3
?	SY-2
3.32?	M-3
2.91	T-1
2.69	UB-N
?	2005
2.31	GSP-1
2.08	AGV-1
1.72	JG-1
1.58	NS-1
1.45	G-2
1.32	GA
1.30	NIM-G
1.14	GM
1.04	NIM-L
0.84	GH
?	TS
0.29	NIM-S
0.19?	I-1

Fe_2O_3	
8.76	NIM-L
?	MRG-1
?	TS
5.61	BR
5.46	UB-N
5.25?	I-3
4.57	AGV-1
4.46?	Mica Fe
3.78	DR-N
3.48	BCR-1
?	2003
?	2001
2.80	T-1
2.50	PCC-1
2.38	NS-1
?	SY-3
?	SY-2
2.26?	M-3
2.24	JB-1
?	Mica Mg
1.77	GSP-1
1.60	BM
1.40	W-1
1.36	GA
1.12	NIM-P
1.08	NIM-S
1.01	G-2
0.91	TB
0.89?	M-3
0.85	DTS-1
0.75	GM
0.70	NIM-D
0.63	NIM-G
0.62	NIM-N
0.41	GH
0.35	JG-1
0.33?	I-1
?	2005

*Per cent, dry basis. See "Precautionary Notes", p. 6

(cont'd.)

TABLE 3 (cont'd.)

"Usable" Values - Major and Minor Components*

H_2O^+	CO_2	P_2O_5	Cl	S
11.28? UB-N	2.98? M-3	? 2003	0.11? NIM-L	? SY-3
4.64 PCC-1	1.34? BM	1.05? BR	0.06? NIM-G	0.06 NIM-L
? TS	? MRG-1	? SY-3	0.04 BR	? MRG-1
3.82 TB	0.86 BR	0.51? M-2	0.04 GSP-1	0.04 BCR-1
3.62 BM	? SY-2	0.50? AGV-1	0.04? NIM-D	0.04 GSP-1
3.31? M-2	? SY-3	? SY-2	0.02 AGV-1	0.04? BR
2.8 ? Mica Fe	0.44? UB-N	0.45? Mica Fe	0.02 W-1	0.02 NS-1
2.44 NIM-L	0.42? NIM-D	0.39? I-3	0.02? NIM-S	? SY-2
2.31 BR	0.28? GM	0.37? M-3	0.01 ASK-1	? TS
2.20? DR-N	? 2003	0.33 BCR-1	0.01 BCR-1	0.01 AGV-1
1.76? I-3	? 2005	0.28 GSP-1	0.01 G-2	0.01 PCC-1
? Mica Mg	? 2001	0.28 NS-1	0.01 GH	0.01? NIM-G
1.51 T-1	0.21? NIM-L	? TS	0.01 PCC-1	0.01? NIM-N
? MRG-1	0.20? Mica Fe	0.26 JB-1	0.01? NIM-N	0.01? NIM-P
1.11 JB-1	? Mica Mg	0.25 DR-N	0.01? NIM-P	0.01? NIM-S
? SY-3	0.19? JB-1	? 2001		? T-1
0.87 GA	0.16 PCC-1	0.14 G-2		
0.82 AGV-1	0.15? DR-N	0.14 NIM-S		
0.74? M-3	0.14 GH	0.14 T-1		
0.73 BCR-1	0.14 NS-1	0.14 W-1		
0.65 NS-1	0.13 TB	0.12 GA		
0.57 GSP-1	0.12 GSP-1	0.10 BM		
0.55 G-2	0.11 GA	0.10 TB		
0.55 JG-1	0.10? NIM-N	0.09 JG-1		
0.53 W-1	0.10? NIM-S	? FK		
0.46 DTS-1	0.09? JG-1	? MRG-1		
0.46 GH	0.08 G-2	0.07 NIM-L		
0.42 NIM-G	0.08? NIM-G	0.06 GM		
? FK	0.08? NIM-P	0.04 NIM-N		
0.35 GM	0.08? T-1	0.03 NIM-D		
? SY-2	0.06 DTS-1	0.03 UB-N		
0.31 NIM-N	0.06 W-1	? Mica Mg		
0.26 NIM-D	? TS	0.02 NIM-G		
0.25 NIM-P	0.03? BCR-1	0.02 NIM-P		
0.23 NIM-S	? FK	0.02? I-1		
0.18? I-1	0.01 AGV-1	0.01 GH		
		? 2005		

F
? Mica Mg
1.56? Mica Fe
? SY-3
? SY-2
0.43? NIM-G
0.43? NIM-L
0.38 GSP-1
0.30 GH
0.14 NS-1
0.13 G-2
0.10 BR
0.07? GM
0.07? TB
? JG-1
? T-1
0.05 BCR-1
0.05 GA
0.04 AGV-1
0.04? NIM-N
0.03? BM
0.02 W-1
0.02? NIM-P
0.02? NIM-S
? MRG-1

*Per cent, dry basis. See "Precautionary Notes", p. 6

TABLE 4

"Usable" Values - Arranged by Trace Elements*

Ag

0.11	AGV-1
0.081	W-1
0.03?	BCR-1
0.008	DTS-1
0.005	PCC-1

As

26?	ASK-2
1.9	W-1
0.05?	DTS-1

Au (ppb)

8?	NIM-G
4?	NIM-L
3.7?	W-1
1.6?	GSP-1
1.0?	G-2

B

300?	VS-N
153?	ASK-2
140?	UB-N
92?	TB
15?	W-1
13?	GM

Ba

2400	NIM-S
1850	G-2
1550?	M-2
1300	GSP-1
1200	AGV-1
1150?	NS-1
1130?	ASK-1
1050	BR
900	VS-N
850	GA
770?	I-3
720	TB
680	BCR-1
660?	T-1

Ba (cont'd.)

520?	SY-2
510?	SY-3
450	NIM-L
430?	I-1
380	DR-N
330	GM
260	BM
210	NIM-G
160	W-1
110	NIM-N
48	NIM-P
40?	UB-N
22	GH
20?	NIM-D
2.4	DTS-1

Be

6?	GH
6?	NS-1
4.4?	GM
4?	ASK-1
4?	ASK-2
4?	GA
4?	TB
2.6	G-2
1.5?	GSP-1
1.3?	BM
1	BR
0.8	W-1

Bi

1000?	VS-N
0.057	AGV-1
0.050	BCR-1
0.046?	W-1
0.043	G-2
0.037?	GSP-1
0.013	PCC-1
0.010	DTS-1

Cd

900?	VS-N
0.15	W-1
0.039	G-2

Ce

900?	VS-N
390?	GSP-1
330?	NIM-P
280?	NIM-L
250?	ASK-1
200?	NIM-G
150?	G-2
115?	TB
63?	AGV-1
60?	GM
54	BCR-1
23?	BM
23?	W-1
15?	NIM-N
12?	NIM-S

Co

700	VS-N
200	NIM-D
135	DTS-1
115	NIM-P
110	PCC-1
110	UB-N
61	NIM-N
50	BR
50	W-1
50?	I-1
39?	JB-1
37	BCR-1
35	DR-N
34	BM
27?	ASK-2
18?	Mica Fe
17	AGV-1
?	SY-3
13	TB
13?	T-1
?	SY-2
7	GSP-1
7?	NS-1
6?	ASK-1
6	G-2
6?	JG-1
5	GA
5?	NIM-G
3.5	GM
3	NIM-L
3	NIM-S
2	GH

Cr

700	VS-N
420	BR
420?	JB-1
125	BM
120	W-1
90?	ASK-2
90?	Mica Fe
80	TB
60?	M-2
50?	JG-1
45	DR-N
40?	ASK-1
34	NIM-N
25?	I-3
24?	T-1
16	BCR-1
15	NIM-G
15	NIM-L
13	GSP-1
12	AGV-1
12	NIM-S
11?	NS-1
10	GA
10	GM
?	SY-2
9	G-2
?	SY-3
6	GH

Cs

900?	VS-N
11?	ASK-2
7.6	GM
6.8	TB
6?	NIM-S
5?	GA
3.5?	NS-1
3?	NIM-L
2?	NIM-G
1.7?	BM
1.5?	ASK-1
1.3	AGV-1
1.3	G-2
1.0	GSP-1
0.95	BCR-1
0.9	W-1
0.006	DTS-1
0.006	PCC-1

*Parts per million (except where shown). See "Precautionary Notes", p. 6

TABLE 4 (cont'd.)

"Usable" Values - Arranged by Trace Elements*

Cu

800	VS-N
160?	I-3
120?	ASK-2
110	W-1
70	BR
63	AGV-1
52	DR-N
50	TB
47?	T-1
45	BM
35	GSP-1
30	UB-N
?	SY-3
19	BCR-1
19	NIM-S
15	NIM-L
14	GA
14	NIM-P
13	GM
13	NIM-G
13	NIM-N
12	GH
11	G-2
11	PCC-1
10?	NIM-D
10?	NS-1
7?	ASK-1
7	DTS-1
7?	JG-1
?	SY-2
4?	Mica Fe

Dy

15?	NIM-G
10.5?	ASK-1
6.3	BCR-1
5.4	GSP-1
4	W-1
3.5	AGV-1
2.6	G-2
0.003	DTS-1

Er

5.7?	ASK-1
3.6	BCR-1
2.4	W-1

Eu

4.5?	ASK-1
2.4?	GSP-1
2?	NIM-G
2?	NIM-L
1.9	BCR-1
1.7?	AGV-1
1.5	G-2
1.1	W-1
0.5?	NIM-N
0.5?	NIM-S

Ga

400?	VS-N
90?	Mica Fe
60?	NIM-L
33?	NS-1
30?	NIM-G
29?	ASK-1
25?	ASK-2
25	DR-N
25	TB
23	BCR-1
23	G-2
22	GH
21	GSP-1
21?	T-1
20	AGV-1
20?	BR
20?	NIM-N
18?	I-3
16	GA
16	GM
16	W-1
15	BM
10?	NIM-S
7?	UB-N

Gd

17.5?	ASK-1
6.6	BCR-1
4?	W-1

Ge

2.5?	TB
1.7?	W-1
1.6?	GM
1.5?	BCR-1
1.5?	GA
1.15	G-2
0.93	PCC-1
0.90?	DTS-1

Hf

300?	NIM-L
13?	GSP-1
10?	NIM-G
7.5?	G-2
5.2?	AGV-1
4.5?	BCR-1
2?	W-1

Hg (ppb)

39?	G-2
16?	GSP-1
15?	AGV-1
14?	JB-1
11?	BCR-1
9?	DTS-1
7?	JG-1
7?	PCC-1

Ho

1.7?	ASK-1
1?	W-1
0.003?	DTS-1

In

0.095?	BCR-1
0.065	W-1
0.034?	G-2
0.0025?	DTS-1

Ir (ppb)

5.2?	PCC-1
0.28?	W-1

La

800?	VS-N
200?	GSP-1
200?	NIM-L
125?	ASK-1
100	G-2
100?	NIM-G
85?	BR
70?	NIM-S
56?	TB
45?	AGV-1
36?	GA
35?	GM
25	BCR-1
25?	GH
25?	I-3
12?	W-1
9?	BM
3?	NIM-N
3?	NIM-P

Li

1500?	Mica Fe
500?	VS-N
115	TB
100?	GA
70	BM
51	GM
45	DR-N
42	GH
37	G-2
34	GSP-1
30?	ASK-2
30?	UB-N
20	NS-1
18?	ASK-1
14	AGV-1
13	BCR-1
12	W-1
12?	BR

*Parts per million (except where shown). See "Precautionary Notes", p. 6

TABLE 4 (cont'd.)

"Usable" Values - Arranged by Trace Elements*

Lu	
3?	NIM-G
1?	NIM-L
0.7?	ASK-1
0.55?	BCR-1
0.4?	BM
0.35?	W-1
0.28?	AGV-1
0.23?	GSP-1
0.2?	NIM-N
0.11?	G-2
0.006?	PCC-1

Mo	
700?	VS-N
60?	ASK-2
4?	GH
3?	AGV-1
3?	BCR-1
2?	BR
1.1?	GM
1?	G-2
1?	GSP-1
0.6?	BM
0.6?	W-1

N	
56?	G-2
52?	W-1
48?	GSP-1
44?	AGV-1
43?	PCC-1
30?	BCR-1
27?	DTS-1

Nb	
850?	NIM-L
700	VS-N
165	NS-1
90?	BR
85?	GM
29	GSP-1
15	AGV-1
14	BCR-1
14	G-2
13?	GA
9.5?	W-1

Nd	
190?	GSP-1
96?	ASK-1
70?	NIM-L
60?	G-2
50?	NIM-G
39?	AGV-1
29	BCR-1
15	W-1

Ni	
800	VS-N
570	NIM-P
270	BR
148	ASK-2
120	NIM-N
110?	ASK-1
78	W-1
57	BM
40	TB
40?	Mica Fe
35?	M-2
22	DR-N
17	AGV-1
17?	I-3
?	SY-3
13	BCR-1
13?	T-1
?	SY-2
10?	NIM-G
10?	NIM-L
9	GSP-1
8?	NIM-S
7.5	GM
7	GA
7?	NS-1
6	G-2
3	GH

Os (ppb)	
0.25?	W-1

Pb	
1000	VS-N
?	SY-3
75?	I-1
70	DR-N
53	GSP-1
50	GH
45?	NIM-L
40?	ASK-2
37?	T-1
36	AGV-1
35?	NIM-G
30	GM
29	G-2
26	GA
24?	JG-1
22?	M-3
20?	UB-N
17?	Mica Fe
16?	BR
15	BCR-1
12	BM
11	DTS-1
10	PCC-1
8	W-1
7	TB

Pd (ppb)	
25?	W-1

Pr	
26?	ASK-1
4	W-1

Ra (ppb)	
1.25?	JG-1
0.72?	JB-1
0.71?	G-2
0.69?	AGV-1
0.66?	GSP-1
0.56?	BCR-1
0.0018?	PCC-1
0.0003?	DTS-1

Rb	
2300?	Mica Fe
800?	VS-N
560	NIM-S
390	GH
380?	M-2
340	NIM-G
250	GM
250	GSP-1
215	NS-1
200	NIM-L
?	SY-2
?	SY-3
185	JG-1
180	TB
175?	ASK-2
175	GA
170	G-2
130?	I-1
85?	ASK-1
75	DR-N
67	AGV-1
47	BCR-1
45	BR
40	JB-1
40?	I-3
33?	T-1
23?	M-3
21	W-1
12	BM
0.06?	PCC-1
0.05?	DTS-1

Re (ppb)	
0.8?	BCR-1
0.07?	PCC-1

Rh (ppb)	
1.0?	PCC-1
0.9?	DTS-1
0.2?	BCR-1

Ru (ppb)	
9.5?	PCC-1

*Parts per million (except where shown). See "Precautionary Notes", p. 6

TABLE 4 (cont'd.)

"Usable" Values - Arranged by Trace Elements*

Sb

800?	VS-N
4.3?	AGV-1
3.3?	TB
3.1?	GSP-1
2.0?	BM
1.4	PCC-1
1.0	W-1
1.0?	NIM-P
0.6	BCR-1
0.6?	DTS-1
0.5?	GM
0.5?	NIM-D
0.5?	NIM-G
0.5?	NIM-L
0.5?	NIM-S
0.1?	G-2

Sc

300?	VS-N
40?	NIM-N
35?	W-1
34	BCR-1
34	BM
30?	NIM-P
26?	BR
13.5	TB
12	AGV-1
9	PCC-1
8	GSP-1
7?	ASK-1
7?	GA
5.1?	GM
5?	NIM-D
4	G-2
4?	DTS-1
4?	NIM-S
0.5?	NIM-G
0.5?	NIM-L

Sm

27?	GSP-1
13?	ASK-1
9?	TB
7.3?	G-2
6.6?	BCR-1
6?	GM
5.9?	AGV-1
4.8?	JB-1
4.6?	JG-1
4?	BM
3.6?	W-1

Sn

800?	VS-N
65?	Mica Fe
10?	GH
8?	BR
6?	GSP-1
6?	NS-1
5.7	TB
4.6	GM
4?	AGV-1
4?	BCR-1
4?	GA
3.2	W-1
3?	DTS-1
2?	PCC-1
1.9?	G-2
1.7	BM

Sr

1350	BR
1300?	NS-1
700	VS-N
680?	ASK-1
660	AGV-1
560?	M-3
480	G-2
440	JB-1
400	DR-N
390	T-1
330	BCR-1
300	GA
?	SY-3
?	SY-2
270	NIM-N
260?	I-3
230	BM
230	GSP-1
210?	M-2
190	W-1
185	JG-1
170?	I-1
150	TB
135	GM
100?	ASK-2
76	NIM-S
32	NIM-P
12	NIM-G
10	GH
10?	UB-N
0.4?	PCC-1
0.35?	DTS-1

Ta

900?	VS-N
20?	NIM-L
10?	NS-1
4?	NIM-G
1.0	GSP-1
0.9	AGV-1
0.9	BCR-1
0.9	G-2
0.5	W-1

Tb

3?	NIM-G
1.9?	TB
1.3	GSP-1
1.0	BCR-1
1.0?	NIM-L
0.70	AGV-1
0.65	W-1
0.54	G-2

Th

105	GSP-1
70	NIM-L
57	NIM-G
35?	GM
24	G-2
19?	TB
15?	GA
13?	JG-1
8.9?	JB-1
6.4	AGV-1
6.0	BCR-1
3?	BM
2.4	W-1

Tl

0.3?	BCR-1
0.11?	W-1

Tm

0.75?	ASK-1
0.6	BCR-1
0.3	W-1

U

14	NIM-G
12	NIM-L
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
0.5?	NIM-D
0.5?	NIM-N
0.5?	NIM-P
0.005?	DTS-1
0.005?	PCC-1

V

600?	VS-N
450?	I-3
410	BCR-1
250	NIM-P
240	BR
240	W-1
220	DR-N
220	NIM-N
220?	ASK-2
180	BM
125	AGV-1
105	TB
96?	T-1
79	NIM-L
76	UB-N
60	NS-1
49?	ASK-1
49	GSP-1
42	NIM-D
36	GA
34	G-2
31	PCC-1
13	DTS-1
11	GM
9	NIM-S
5?	GH

W

3?	TB
2?	GM
1?	BM
0.5?	W-1

*Parts per million (except where shown). See "Precautionary Notes", p. 6

TABLE 4 (cont'd.)

"Usable" Values - Arranged by Trace Elements*

Y		Yb		Zn		Zr	
800?	VS-N	900?	VS-N	1350?	Mica Fe	700?	VS-N
120?	NIM-G	10?	NIM-G	800	VS-N	650	NS-1
70?	GH	8?	GH	280?	NIM-L	500	GSP-1
46	BCR-1	4?	ASK-1	?	SY-3	400?	ASK-1
39?	TB	4?	BR	?	SY-2	300	G-2
32	GSP-1	4?	NIM-L	220?	T-1	270?	M-3
27?	BR	4?	TB	165?	ASK-2	260	NIM-G
26	AGV-1	3.8	BCR-1	160	BR	240	BR
26?	BM	3.5?	BM	150	DR-N	220	AGV-1
26?	GM	3?	GM	120	BCR-1	220?	I-3
25	W-1	2.5	GSP-1	115	BM	185	BCR-1
24?	DR-N	2.5?	GA	105?	ASK-1	180	TB
18?	GA	2.1	W-1	100?	I-3	170?	ASK-2
12	G-2	2.0	AGV-1	100?	NIM-P	170?	T-1
		0.9	G-2	98	GSP-1	160	GH
				95	TB	145	GM
				90?	NIM-D	140	GA
				86	W-1	125?	DR-N
				85	G-2	120?	M-2
				85	NIM-N	105	W-1
				85?	UB-N	96	BM
				84	AGV-1	70?	I-1
				83?	JB-1		
				80	GH		
				75	GA		
				60?	NIM-G		
				45	DTS-1		
				40	GM		
				36	PCC-1		
				36?	JG-1		
				20?	I-1		
				20?	NIM-S		

*Parts per million (except where shown). See "Precautionary Notes", p. 6