Distribution of the Elements in Some Major Units of the Earth’s Crust

Abstract: This paper presents a table of abundances of the elements in the various major units of the Earth's lithic crust with a documentation of the sources and a discussion of the choice of units and data.

CONTENTS

<table>
<thead>
<tr>
<th>Contents</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>175</td>
</tr>
<tr>
<td>Choice of units</td>
<td>175</td>
</tr>
<tr>
<td>General statement</td>
<td>175</td>
</tr>
<tr>
<td>&quot;Igneous&quot; rocks</td>
<td>175</td>
</tr>
<tr>
<td>Sedimentary rocks</td>
<td>176</td>
</tr>
<tr>
<td>Deep-sea sediments</td>
<td>176</td>
</tr>
<tr>
<td>Metamorphic rocks</td>
<td>177</td>
</tr>
<tr>
<td>Choice of data</td>
<td>177</td>
</tr>
<tr>
<td>References cited</td>
<td>187</td>
</tr>
<tr>
<td>Table</td>
<td></td>
</tr>
<tr>
<td>1. Estimation of hafnium concentrations in &quot;igneous&quot; rocks</td>
<td>183</td>
</tr>
<tr>
<td>2. Distribution of the elements in the Earth’s crust</td>
<td>Facing 186</td>
</tr>
</tbody>
</table>

INTRODUCTION

Several tables of the crustal abundances of the elements have been published to date (Rankama and Sahama, 1950; Goldschmidt, 1954; Fleischer, 1953; Vinogradov, 1956; Mason, 1958) either as parts of treatises on the geochemistry of the elements or as attempts to compile a list for general use. In addition, Green (1959) and Vinogradov (1956) have published charts of the distribution of many elements in various units of the Earth’s crust.

We have found these tables deficient in some aspects. This awareness arose when the two of us independently were preparing articles on the geochemical distribution of the elements for the Encyclopedia of Science and Technology published by McGraw-Hill (Turekian, 1960) and for the new edition of Lehrbuch der Geologie, Teil I. by E. Kayser and R. Brinkmann, to be published by F. Enke, Stuttgart (Wedepohl).

The individual tables in these two works have been modified and collated here (Table 2) with a fuller description of the plan used in compiling the data since a brief summary article of the sort required for the encyclopedias offered no possibility of presenting the sources of information used.

Any compilation is necessarily subject to great uncertainties in the reliability of the analytical work, the sampling, and the interpretations, both of the original investigator and the compiler. Hence the accompanying table should be accepted not so much as a doctrine but as a motion on the floor to be debated, and amended or rejected.

CHOICE OF UNITS

General Statement

With the wide diversity of rock types available for sampling in the Earth’s crust the choice of units for a compilation must to some degree be arbitrary. We have chosen three major groups for the presentation of the data, "igneous" rocks, sedimentary rocks, and deep-sea sediments.

"Igneous" Rocks

Under this heading we include some ultrabasic rocks and all basaltic rocks as being of undoubted igneous origin. Granitic and syenitic rocks, even though they do not all show unequivocal evidence for igneous origin, are included under "igneous" rocks for the sake of simplicity.

Peridotitic rocks were chosen whenever pos-
sible to represent the ultrabasic group. Ultrabasic rocks with unusual metamorphic histories were generally avoided in compiling the trace-element data. Serpentines were also avoided because several elements (boron, arsenic, and germanium, etc.) are notably enriched in these altered rocks relative to dunites and peridotites.

The basaltic rocks include all manifestations of rocks of basaltic composition, i.e., gabbros, dolerites, and basalts. Concentrations of some elements show differences between the intrusive and the extrusive or hypabyssal representatives. In only a few cases were the differences significant in terms of the information available. In those cases the extrusive and hypabyssal rocks were weighted more heavily than the intrusive rocks to arrive at the figure in Table 2.

The granitic rocks afford some difficulty in classification. All rocks associated with a granitic terrane are considered granitic rocks although local or wider variations yield a variety of rock types such as granodiorite, quartz monzonite, etc. With such a wide variety of possibilities in rock types and the vagaries of meaning of some of the nomenclature presented in the literature, we decided that two categories of granitic rocks were all that were practical for the present compilation. Under the bias of a previous such consideration necessary in evaluating the geochemistry of strontium (Turekian and Kulp, 1956), we have chosen the groups in terms of their expected calcium concentrations. viz., high-calcium granitic rocks with a mean gross chemical composition of a granodiorite, and low-calcium granitic rocks with a composition approaching that of an ideal granite. This choice is arbitrary. The presented data are just not any better than this gross classification.

According to the experience of field geologists, granites, granodiorites, and basaltic rocks are by far the most common rock types. We include the syenites as a type in spite of their subordinate abundance. We have generally tried to weight the values toward the syenite rather than the nepheline syenite end because the latter type is the rarer.

In the case of the granitic and syenitic rocks we have avoided using their extrusive equivalents in computing the averages. For several trace elements the extrusive acidic rocks are very different in their abundance from the intrusive chemical equivalent. Rhyolites have variable and perhaps unusual affinities.

**Sedimentary Rocks**

The standard breakdown of sedimentary rocks is into shales, sandstones, and carbonate rocks as end members, and other rocks as mixtures of these. This classification is based on sequences associated with Kay's (1951) miogeosynclinal areas where reasonably thorough chemical degradation of the original source rock is supposed to have occurred. There are, of course, vast amounts of sedimentary rocks which are composed to a large degree of poorly sorted more or less degraded minerals, viz., conglomerates, arkoses, and graywackes. These rocks represent a great problem in the presentation of data on sedimentary rocks. It is not possible to dismiss them as the mechanical degradation products of weathering and sedimentation since in these processes a chemical differentiation from the original rocks must have taken place. However, because of the great complexity of these rock types and an uncertainty as to their manner of origin they are not included in the accompanying table. It must be noted that this is an omission because of lack of information rather than because of unimportance. Macpherson (1958) reports that Canadian Precambrian argillites and low-grade schists have the same composition for many trace elements as associated graywackes. In addition, Weber's (1960) data seem to indicate that a wide range of graywackes have similar composition with regard to most of the trace elements (zirconium seems to be an exception).

**Deep-Sea Sediments**

Deep-sea sediments cannot rightly be classified under the term "rock" since much of the sampling is done on material which exists permeated continuously by sea water and has not yet been subjected to lithification or extreme diagenesis.

Two end members only are considered: the pelagic clay, essentially free of calcium carbonate; and the carbonate-rich sediment in its purest sampled form containing about 10 per cent clay fraction. Further, following Goldberg and Arrhenius (1958), we assume that the dissolved solids in the water permeating the sediment are part of the sediment rather than of the hydrosphere. This means that analyses on unwashed samples are preferred. Estimating the abundance of several of the elements in the deep-sea material is complicated by the fact...
that their concentration is greater in the Pacific sediments than in the Atlantic. Although the Pacific is roughly three times larger than the Atlantic in area, the rate of sedimentation may be about three times greater in the Atlantic basin (Wedepohl, 1960) than in the Pacific. This being the case, where the above disparity is observed, a simple average of the Atlantic and Pacific values was used for the abundance table.

Metamorphic Rocks

We have assumed that metamorphic rocks generally retain a chemical composition similar to their unmetamorphosed equivalent. However, often a schist is sampled free of quartzofeldspathic segregations. In such a case the schist will be higher than the original rock in the concentrations of the elements associated with the mafic minerals. The whole rock, however, will probably show the composition of the original unmetamorphosed rock. Where metamorphism grades into granitization, the granitized rock is placed in the chemical category of granitic rocks, hence not treated separately.

CHOICE OF DATA

Generally the newest information was used to construct the table whenever available. Much new work has been done on the trace elements since the end of World War II and particularly since 1950.

The following is an element-by-element discussion of the sources of the information of Table 2. We have deliberately used the first person in writing because the table represents solely our judgement in compilation. There is always the risk that when such a table is published the sources and uncertainties in it may be forgotten and "the table" quoted uncritically. This must be avoided.

Lithium: The data are primarily from Horstman (1957). However, his ultrabasic value of 26 ppm is not used since it is considerably higher than that of Strock (1936), who gives 2 ppm, and that of Pinson, Ahrens, and Franck (1953), who give <0.3 ppm. The value for carbonates is an upper limit, and the value of carbonate deep-sea cores is based on the assumption that even the purest pelagic calcareous cores have approximately 10 percent clay fraction which contributes the lithium.

Beryllium: The data for granitic and basaltic rocks are taken from Sandell (1952). Merrill, Honda, and Arnold (1958) report 3.3 ppm for G-1 standard granite and 0.68 ppm for W-1 standard diabase. The nepheline syenite value is from Borodin (1956). This is lower than the concentrations given by Goldschmidt (1954) and Holser et al. (1951). Merrill et al. (1960) have analyzed four pelagic clay cores from the Pacific and one from the Atlantic and find very small variations in the beryllium concentration. Their average of 2.6 ppm is used here. Other data appearing in the literature for pelagic clays range from 1.1 ppm (Goel et al., 1957) to 8 ppm (Tatsumoto, 1957). Since the beryllium concentrations of the Atlantic and Pacific pelagic sediments are not different, although the Atlantic and Pacific have different accumulation rates, we assume that the beryllium is closely associated with the clay minerals. Hence we have assumed that shales will have the same composition as pelagic clays rather than the 6 ppm reported by Goldschmidt (1954).

Goldschmidt's data seem high for this element in all rock types compared to the current data. The sandstone, carbonate, and carbonate deep-sea sediment data are lacking, but probably the abundance in each rock type is of the order of tenths of parts per million.

Boron: The ultrabasic, basaltic, granitic, and syenitic values are from Harder (1959a; 1959b). The granitic rocks present some problems of interpretation. Sahama's (See Rankama and Sahama, 1950) low values (3-10 ppm) for Fennoscandian rocks may be compared to Wasserstein's (1951) values for some South African granites which run up to 150 ppm. Okada (1955; 1956) found boron concentrations in Japanese granite rocks ranging from 1 to 160 ppm. Since boron is a highly mobile element during metamorphic and igneous activity, the wide range of values may be expected. Granitic rocks from roof areas of intrusive rocks and granitic migmatites generally have higher concentrations of boron. Degens, Williams, and Keith (1957) and Harder give an average value for shales of 100 ppm. The deep-sea clay value is the average of the boron content of Pacific clays (Goldberg and Arrhenius, 1958) and Atlantic clays analyzed by Harder (1959b). The carbonate deep-sea sediment value is based on a few analyses of Atlantic material made by Harder, and the sandstone and carbonate rock values are also his.

Nitrogen: There are two current sets of de-
terminations of the nitrogen content of some igneous rocks. F. Wlotzka (1960, Ph.D. thesis, Göttingen Univ.) reports about 30 ppm for basaltic rocks and 20 ppm for granitic rocks. R. S. Scalan (1959, Ph.D. thesis, Univ. of Arkansas), in studying the isotope geochemistry of nitrogen, determined the composition of a number of ultrabasic (average 6 ppm) and basaltic (average 17 ppm) rocks. Because of the wide range of values within each rock type we have chosen a value of 20 ppm for each igneous rock except for ultrabasic rocks, for which Scalan's average of 6 ppm is used, and syenites, for which Wlotzka's average of 30 ppm N is used. Both investigators indicate that the main form of the nitrogen is as the NH$_4^+$ ion.

Since sediments have greatly variable nitrogen concentrations, mainly a function of the organic content of the sediment, these estimates are not included in the table.

**Fluorine:** Most of the values in Table 2 are from Koritnig (1951) as modified in the following cases by information from other workers. R. H. Seraphim (1951, Ph.D. thesis, Mass. Inst. of Technology) and Kokubu (1956) list 820 ppm and 830 ppm respectively for granitic rocks they analyzed; this agrees closely with Koritnig's value. On the other hand Kokubu (most of whose rocks were Japanese) found a low value of 280 ppm for basaltic rocks, whereas Seraphim reported a value of 540 ppm, which is higher than Koritnig's. Koritnig's value of 520 ppm for granodioritic rocks is used, although the average of alkali granitic and dioritic values of other authors leads to a higher value. The syenite value is the average of Koritnig's (950 ppm) and Seraphim's (1480 ppm) values. The carbonate value is the average of Koritnig's limestone and dolomite analyses. Kokubu reports considerably lower values for limestones (100 ppm). The values for deep-sea sediments are taken from Scalan. They are based only on Atlantic Ocean sediments. Shepherd's (1940) figures on sediments from the Pacific (clay, 660 ppm) seem too low.

**Sodium:** The igneous-rock data except basalt are from Nockolds (1954), using the averages for alkali granite (his Table 1, column III), granodiorite (Table 2, column III), peridotite (Table 9, column I), and alkali syenite (Table 3, column IV). The basaltic value is an average of Green and Poldervaart's (1955) compiled mean tholeiitic and mean olivine basaltic rock. The sedimentary-rock data are Clarke's (1924). The deep-sea sediments provide some difficulty since all the cores are rich in sodium chloride derived from interstitial sea water. Goldberg and Arrhenius (1958) present compelling reasons for accepting the bulk composition of the core, including the interstitial salts, as representative of the sediment, and this is done in the table. The data for pelagic clays are from Goldberg and Arrhenius (1958). The data for the carbonate deep-sea cores are more difficult to obtain. Broecker, Turekian, and Heezen (1958) report an average of 5 per cent NaCl in dry, unleached carbonate core material. This corresponds to a sodium concentration of around 20,000 ppm and a chlorine concentration of 30,000 ppm. The highest carbonate core reported by Goldberg and Arrhenius (1958) has 16,000 ppm Na.

**Magnesium:** Igneous-rock data are from Nockolds (1954) and Green and Poldevaart (1955), as above. Sedimentary-rock data are from Clarke (1924). The pelagic-clay value is from Clarke (1924) and Goldberg and Arrhenius (1958). Carbonate deep-sea-core data are from P. J. Wangersky (1958, Ph.D. thesis, Yale Univ.) and Turekian and Feely (1956), who agree very well for Atlantic Equatorial cores.

**Aluminum and silicon:** Igneous-rock data are from Nockolds (1954) and Green and Poldevaart (1955) as above; sedimentary-rock data from Clarke (1924); pelagic clay from Goldberg and Arrhenius (1958); and carbonate deep-sea-core data from the analysis of Atlantic Equatorial Core A180-74 by P. J. Wangersky (1958, Ph.D. thesis, Yale Univ.).

**Phosphorus:** The igneous-rock data are from Nockolds (1954) and Green and Poldevaart (1955) as described above. The sandstone and carbonate-rock data are from Koritnig (1951). The shale value is the average previously reported by Wedepohl (1960).

Correns (1937) reports 1500 ppm for Atlantic pelagic clays, which is probably a minimum for these sediments. He also found that clay-free calcareous sediments from the Atlantic had about 350 ppm phosphorus. We use his values for deep-sea sediments.

**Sulfur:** Because of the various possible forms of sulfur incorporation in geological materials, it is difficult to assess the significance of the various data reported in the literature on this element. The earliest paper giving a large amount of data on sulfur in igneous rocks is by Tröger (1934) and is that used in the compilation by Rankama and Sahama (1950) and others. Sandell and Goldich (1943) report three
values for sulfur in Minnesota rocks ("granite," "diorite," and "diabase"), which have a range of 200 to 400 ppm with no obvious relationship to rock type, and two diabases from New England with a value of 1200 ppm. Ricke (1960, in press) reports about 270 ppm S for granites and 250 ppm S for basalts. He found that olivine contains about 30 ppm sulfur, but since ultrabasic rocks have a variable sulfide component this number cannot be used with certainty. Ricke also reports 400 ppm S for granodioritic rocks and 440 ppm S for syenites. Although one of us (Wedepohl) feels that these numbers represent the abundance of sulfur in the various igneous-rock types, we have assigned a common value for all "igneous" rock types, viz. 300 ppm S, because it may be that the variations within the rock types in a wider sampling would exceed that between units. One of us (Turekian) believes that this value based on Ricke's data probably has only order of magnitude reliability, but even then it is lower than some of Tröger's values.

The information on sediments and sedimentary rocks is in no better shape. Clarke (1924) reports an average value of 2600 ppm for shales, whereas Ricke (in press) gets an average of 2200 ppm for his sampling. Higher values have been reported by Tourtelot (1957) for the Pierre shale (5500 ppm) and by other authors (including Minami, 1935a; Vinogradov and Ronov, 1956) for carbonaceous shales. We choose the average of Clarke's and Ricke's values for all the sedimentary-rock types. Information on the sulfur concentration of deep-sea sediments is from Edgington and Byers (1942). Ricke got essentially the same value for pelagic clays. The sulfur concentration is obviously that of sea-salt contribution to the sediment.

Chlorine: Correns (1956) has recently compiled the available data on the halogens.

The ultrabasic value is the average of the anhydrous dunite analysis by Kuroda and Sandell (1954). These authors give a wide range of values for igneous rocks with averages all about 200 ppm for the various rock types, except syenitic rocks. We have used the data of Behne (1953), however, for all the rock types except the ultrabasic and syenitic. The deep-sea-sediment data are contingent on the arguments presented under sodium. However, the clay fraction probably has some sodium in excess of the stoichiometric amount necessary to balance the chloride. Behne reports 21,000 ppm chlorine for pelagic clays. The same value is assumed for the carbonate sediments.

Potassium: We have chosen the low average value of Holyk and Ahrens (1953) for ultrabasic rocks. Nockolds (1954) gives an average of about 2000 ppm K, but this may either include mica or feldspar-rich ultrabasic rocks such as kimberlite or include analyses erroneously high in potassium. The remaining igneous-rock data are from Nockolds (1954) and Green and Poldervaart (1955); sedimentary-rock data are from Clarke (1924). The pelagic-clay value is from Goldberg and Arrhenius (1958). The deep-sea carbonate value is based on the assumption that the potassium is in the 10 per cent clay fraction plus about 400 ppm K in the soluble salts.

Calcium: Igneous-rock data are from Nockolds (1954) and Green and Poldervaart (1955); sedimentary-rock data from Clarke (1924), whose sandstone average may be high; pelagic-clay data from Goldberg and Arrhenius (1958); carbonate deep-sea-sediment data from Turekian and Feely (1956) and P. J. Wangersky (1958, Ph.D. thesis, Yale Univ.) who have similar results on Atlantic Equatorial cores.

Scandium: The ultrabasic value is from Pinson, Ahrens, and Franck (1953). Both Nockolds and Allen (1956) and Ahrens (1954) report mean values in basaltic rocks of about 30 ppm. The data for low-calcium and high-calcium granitic rocks are from Ahrens (1954). He reports a value of 11 ppm for granites. If these granites can be regarded as a one-to-one mixture of low-calcium and high-calcium granitic rocks, as seems likely, and if the Sc is greater by a factor of two in the more calcic granitic rocks than in the low-calcium granitic rocks, then low-calcium granitic rocks have 7 ppm and high-calcium granitic rocks have 14 ppm Sc; Sahama (1945) reports 1 ppm Sc for Finnish granites and Hugi (1956) 12 ppm Sc for Swiss granites. The Sc content of syenitic rocks given is that of Sahama (1945) for Finnish rocks which compares with the analysis of an Arkansas nepheline syenite (Gordon and Murata, 1952). The shale value is from Wedepohl (1960); it compares with that of Shaw (1954) for the Littleton formation primarily. The pelagic-clay value is the average of Pacific and Atlantic values from Goldberg and Arrhenius (1958) and Wedepohl (1960) respectively. The carbonate deep-sea-core value is based on a 10 per cent red-clay fraction contributing the Sc. The value for sandstones is Sahama's (1945) quartzite average, and that for limestones is guessed at, assuming that they contain approximately 10 per cent clay.
Titanium: The igneous-rock data are from Nockolds (1954) and Green and Poldervaart (1955). Sandstone and carbonate-rock data are from Clarke (1924). The shale value is the average used by Wedepohl (1960). The pelagic-clay value is the average of the figures given by Wedepohl (1960) and Goldberg and Arrhenius (1958), and the deep-sea carbonate sediment value is from P. J. Wangersky (1958, Ph.D. thesis, Yale Univ.).

Vanadium: The ultrabasic value is derived from the data of Ross, Foster, and Myers (1954), who list values for vanadium in separated minerals from ultrabasic rocks. Using a ratio of 60 per cent olivine, 20 per cent enstatite, 10 per cent chrome diopside, and 10 per cent plagioclase we arrive at 40 ppm V. The value for basaltic rocks is from an average of all basaltic rocks (72) analyzed by Nockolds and Allen (1956). This figure corresponds with a one-to-one average of tholeiitic basalts (330 ppm V) and olivine basalts (140 ppm V) from unpublished results of Wedepohl. The granitic values are derived from Ahrens (1954), using the same assumptions as those used to derive the scandium numbers. Hügi (1956) gets 80 ppm V for granitic rocks of the Aare-massiv. For syenitic rocks Suhama (1945) reports 30 ppm V; Butler (1954) got less than 10 ppm in one sample. Gordon and Murata (1952) list a value of 47 ppm for an Arkansas nepheline syenite. We choose 30 ppm for this rock type.

The shale value is from Wedepohl (1960); it corresponds with Jost's (1932) and Shaw's (1954). Degens, Williams, and Keith (1957) report a lower value for Carboniferous shales of Pennsylvania (44 ppm). The data for sandstones and limestones are from Goldschmidt (1954), who quotes the data of Jost primarily. The limestone value agrees with the average of eight British limestones analyzed by Hirst and Nicholls (1958). The pelagic-clay value is from Goldberg and Arrhenius (1958) and Wedepohl (1960). The carbonate deep-sea-sediment value lies between 1 and 3 ppm V (Wedepohl, 1955); hence we choose an average of 2 ppm.

Chromium: The ultrabasic value for chromium is derived from the data in Ross, Foster, and Myers (1954). These authors give chromium values for separated minerals from ultrabasic rocks. There is not much variation for any one mineral type. We again use the arbitrarily defined ultrabasic rock of the following mineralogic composition: 60 per cent olivine, 20 per cent enstatite, 10 per cent chrome diopside, and 10 per cent plagioclase. The resulting value of 1600 ppm Cr may be too low if chromite is a very important accessory. A single analysis of a dunite by activation analysis reported by Turekian and Carr (1960), however, confirms this low value. The basalt value is from Turekian (1956). Fröhlich (in press) reports 70 ppm for tholeiitic basalt and 280 ppm for olivine basalt. The low-calcium granitic value is from Turekian and Carr (1960) based on neutron activation analyzed rocks. The high-calcium value has been changed from our previous 27 ppm Cr reported in the paper just cited to 22 ppm Cr as the result of additional work to be published soon. These numbers are lower than those of Ahrens (1954). The syenitic rock value is from Gordon and Murata (1952) and Butler (1954). The shale value is an average of the data of Shaw (1954), Fröhlich (in press), and Turekian (unpublished). Fröhlich reports an average of 15 ppm Cr for 98 limestones, whereas Turekian and Carr (in press) find an average of 11 ppm for three carbonate rocks analyzed by neutron activation and Hirst and Nicholls (1958) report an average of 8 ppm for eight British limestones by a spectrographic technique. We use the average of these three sets of data, 11 ppm Cr. The sandstone value of 35 ppm Cr is the average of Fröhlich's 53 sandstone and quartzite samples. Turekian and Carr (in press) report an average of 7 ppm Cr for two determinations by neutron activation. The pelagic-clay value is from Goldberg and Arrhenius (1958) and Fröhlich (1959), and the carbonate deep-sea-sediment value is from Turekian and Feely (1956).

Manganese: The igneous-rock data are from Nockolds (1954) and Green and Poldervaart (1955). The shale value is the average of the values reported by Shaw (1954), Tourtelot (1957), and Wedepohl (1960). Ostrom (1957) reports an average of 1400 ppm Mn for Carboniferous limestone samples from Illinois, and Runnels and Schleicher (1956) report an average of 850 ppm Mn for some Kansas limestones. We use these two values to arrive at an average of 1100 ppm Mn, which is higher than most previous estimates. The sandstone order-of-magnitude value is a guess. The pelagic-clay value is from Goldberg and Arrhenius (1958) and Wedepohl (1960), and the carbonate deep-sea-sediment value is from P. J. Wangersky (1958, Ph.D. thesis, Yale Univ.). Both Correns (1937) and Wedepohl (1955) report that the clay-free deep-sea carbonate tests contain about 200 ppm Mn.

Iron: The igneous-rock data are from Nock-
olds (1954) and Green and Poldervaart (1955); the sedimentary-rock data are from Clarke (1924); the pelagic-clay value is from Goldberg and Arrhenius (1958); and the carbonate deep-sea-sediment value is from P. J. Wangersky (1958, Ph.D. thesis, Yale Univ.).

Cobalt: Most of the values are from Carr and Turekian (in press), who used a combined neutron-activation and spectrographic technique to analyze a large number of specimens. The ultrabasic value is similar to the value obtained from the weighted average of ultrabasic mineral analyses by Ross, Foster, and Myers (1954) in the manner described under chromium. The basaltic-rock value agrees with the average of 72 basaltic rocks by Nockolds and Allen (1956), Ahrens' (1954) value for North American rocks, and Smales, Mapper, and Wood's (1957) value for oceanic islands. From Sandell and Goldich's (1943) data, 13 low-calcium granitic rocks give an average of 2.7 ppm, whereas two high-calcium granitic rocks give an average of 5.8 ppm. The syenite value is a guess based on Gordon and Murata's (1952) data. The shale value is similar to that of Shaw (1954). Hirst and Nicholls (1958) find an average of 10 ppm for eight British limestones, which we consider too high. The pelagic-clay value is an average of high values for the Pacific and low values for the Atlantic (Goldberg and Arrhenius, 1958; Smals, Mapper, and Wood, 1957; Hutchinson et al., 1955; Wedepohl, 1960). If the carbonate deep-sea-sediment value is based on a 90 per cent CaCO₃ Atlantic Equatorial core, a calculation from the data of Smals, Mapper, and Wood (1957) on a 67 per cent CaCO₃ Atlantic Equatorial core containing an average of 11 ppm Co will give 4 ppm, which compares with the value of 6 ppm obtained by Carr and Turekian (in press) for deep-sea carbonate sediments.

Nickel: The ultrabasic value was gotten in the manner described under chromium from the data of Ross, Foster, and Myers (1954). The basaltic value is from Turekian (1956). The granitic-rock values are derived from Sandell and Goldich's (1943) data on 13 low-calcium granitic rocks and two high-calcium rocks. The syenite value is a guess based on the few scattered data on this rock type (Sahama, 1945; Butler, 1954; Gordon and Murata, 1952). The shale value is the intermediate between Shaw's (1954) average of 64 ppm and Turekian and Carr's (1960) average of 71 ppm. The sandstone value is from Sahama's (1945) data on Finnish quartzites. Hirst and Nicholls (1958) report an average of 27 ppm Ni in eight limestones. Runnels and Schleicher (1956) report 10 ppm for some limestone from Kansas, and Wedepohl reports (unpublished) 25 ppm on a limestone composite made by Goldschmidt. A value of 20 ppm is chosen for limestones considering these data. The nickel values in pelagic-clay and carbonate deep-sea sediments are based on the same type of argument used for cobalt, and the values derived are from the same sources.

Copper: The ultrabasic value is based on a dunite from St. Paul's Rock in the Atlantic Ocean analyzed by Smals, Mapper, and Wood (1957) by neutron activation. Two peridotites of Morita (1955) have Cu up to 20 ppm. The basalt value is from Turekian (1956) and corresponds with that of Morita for Japanese rocks. The granitic values are derived from several scattered sources and represent the best estimate possible from the manner in which the data are reported. The sources are: Sandell and Goldich (1943), North American granitic rocks; Sugawara and Morita (1950) and Kuroda (1957), Japanese granitic rocks; and Smales (1955), analysis of G-1 granite. The syenite value is a guess.

The shale value is the average of six sets of data: Shaw (1954), Littleton formation, Devonian, 18 ppm; Degens, Williams, and Keith (1957), Carboniferous shales of Pennsylvania, 73 ppm; Turekian (unpublished), Fox Hills formation, Cretaceous, 18 ppm; Sugawara and Morita (1950), Mesozoic of Japan, 55 ppm, Paleozoic of Japan, 40 ppm, and Paleozoic of Europe, 65 ppm—all composites. Heide and Singer (1950) report 105 ppm for the Röt shale of Jena. No data are available for sandstones. The X indicates the probable order of magnitude for sandstones. The limestone value is from three composites (93 samples) of German limestones of Paleozoic and Mesozoic age (Wedepohl, 1955) averaging 2 ppm Cu and from data on the calcareous portions of rocks from the Hanover mining district, New Mexico, reported by Barnes (1957) with 5 ppm Cu. Heide and Singer (1950) report 5 ppm for the Muschelkalk limestone of Jena.

The deep-sea-clay and -carbonate data are from the same sources as cobalt and nickel, and the same method of calculation is used.

Zinc: The igneous-rock data are from Wedepohl (1953 and unpublished), Sandell and Goldich (1943), Morita (1955), and Tauson and Pevtsova (1955), and agree in general with each other quite well. The syenite value is from
Morita. The shale value is from Wedepohl (1960). Sugawara and Morita (1950) report an average of 110 ppm on the same composites used in the copper determination; Heide and Singer (1950) report a value of 103 ppm for the Röt shale of Jena, and Barnes (1957) reports 70 ppm for limeless shales near Hanover, New Mexico. The sandstone value is from Wedepohl (1953), and the limestone value is the average of Wedepohl’s and Barnes’ data. The pelagic-clay value is from Wedepohl (1960), and that for the deep-sea carbonate is from unpublished data by the same author.

**Gallium:** Sandell (1949) reports 1 ppm Ga for ultrabasic rocks, whereas Borisenok and Saukov (1960) report an average of 2 ppm. We have used the average of these two values. The data of the different workers on the Ga concentration of the other igneous rocks agree on the whole, but subtle differences exist. For basaltic rocks Borisenok and Saukov report 15 ppm Ga, and C. K. Bell (1953, Ph.D. thesis, Mass. Inst. of Technology) reports 17 ppm Ga, whereas Fleischer’s (1955) average of a large number of data from different workers on rocks ranging in 45-55 per cent SiO₂ is 20 ppm Ga. We choose the average value of 17 ppm Ga for basalts. For high-calcium granite rocks Borisenok and Saukov report 16 ppm, whereas Bell reports 17 ppm and Fleischer reports 20 ppm as an average of rocks ranging from 55-65 per cent SiO₂. We use a value of 17 which is similar to the basaltic value. The low-calcium granite rock values range from 16.5 ppm (Fleischer’s average for rocks with greater than 65 per cent SiO₂) to Bell’s 17 ppm, to Borisenok and Saukov’s 19 ppm. We choose 17 ppm Ga for this rock type. The syenitic rocks range from 20 ppm (Bell) to 40 ppm (Borisenok and Saukov), and we choose a value of 30 ppm.

The shale value is from Bell, Shaw (1954), and Wedepohl (1960), who find the same average value. Bell reports an average of 14 ppm Ga for four sandstones and 6 ppm for a quartzite, giving an average of 12 ppm. The limestone value and the carbonate deep-sea core value are from estimates in Goldschmidt (1954). Borisenok and Saukov report 10–30 ppm Ga for “marine oozes.” The pelagic-clay value is from Goldberg and Arrehenius (1958) and Wedepohl (1960).

**Germanium:** The data are from El Wardani (1957) and Onishi (1956), who generally agree. El Wardani gives about 1.2 ppm for shales, whereas Onishi (1956) gives 2 ppm. We have chosen an intermediate value. The lime-

stone and carbonate deep-sea-sediment values are calculated on the basis of 10 per cent clay fraction. Pure *Globigerina* tests have 0.0 ppm Ge (El Wardani, 1958). The pelagic-clay average is that of El Wardani; Onishi reported 1.6 ppm Ge.

**Arsenic:** The data for arsenic are all from Onishi and Sandell (1955a). They report that silicic volcanic rocks and serpentines have about 4 ppm As, which is considerably higher than the value for the usual igneous-rock types. Correns (1937) reports 7 ppm As for six samples of Atlantic pelagic clay.

**Selenium:** The values of all units except the sediments are calculated from the sulfur abundances using a S to Se ratio of 6000, reported by Goldschmidt and Strock (1935) and Goldschmidt (1954), and have order of magnitude of significance only. The shale value is from Minami (1935a). Sandstone and limestone values are those of Goldschmidt and Strock (1935). The deep-sea-sediment values are from Edgington and Byers (1942).

**Bromine:** The data are all from Behne (1953). Assuming that all the bromine of the deep-sea sediments is in the sea salt (*Globigerina* shell sample ≤ 1 ppm Br) for the deep-sea carbonate, we have also used Behne’s pelagic clay value.

**Rubidium:** The ultrabasic value is calculated to give a Rb/K ratio the same as in basalts. All the other igneous-rock values and the shale and sandstone values are from Horstman (1957). Isotope-dilution analyses of composite basalts and granitic rocks by Gast (1960) give very close to the same values. The carbonate deep-sea-sediment value is from Smale and Salmon (1955) and Horstman (1957), and the pelagic-clay value is from Wedepohl (1960) and Horstman (1957) and an extrapolation of Smale and Salmon’s (1955) data on deep-sea-carbonate-sediment samples with varying amounts of clay.

**Strontium:** The ultrabasic value is based on the data of Pinson, Ahrens, and Franck (1953); the pelagic-clay value is from Goldberg and Arrehenius (1958) and Wedepohl (1960) for carbonate-free sediment. All other values are from Turekian and Kulp (1956).

**Yttrium:** The data for yttrium will influence the values for the rare-earth elements, since little or no information is available for most of the rare-earth elements in the common rock types.

The ultrabasic yttrium value is not known but is probably of the order of tenths of a part per million. The basaltic value is from 72
basaltic rocks reported by Nockolds and Allen (1956). A confirmatory unpublished value for a one-to-one average of olivine basalts and tholeiitic basalts is 25 ppm Y (Wedepohl). The granitic values are from Fleischer's (1955) compilation, omitting the data of Laboratory #4 of his tables. The values are the average of the maximum and the minimum values he reports. Wedepohl (unpublished) gets 43 ppm Y for 17 German granites and G-1. The syenite value is an average of Wedepohl's 22 nepheline syenites and Butler's (1954) value for a Norwegian quartz-free syenite having 20 ppm Y. Gordon and Murata (1952) report a value of 130 ppm for an Arkansas nepheline syenite. The shale value is from Minami's (1935b) data. Wedepohl (1960) reports about the same figure. The sandstone value is a guess. Sahama (1945) reports a low value of 2 ppm for quartzite, but his figures for granites (<10 ppm Y) and syenites (<10 ppm Y) are also low. The reason such a high value was chosen is because most resistant deposits must contain a considerable amount of resistant rare-earth minerals. One can compare yttrium in this sense with zirconium, for which data are available. If we assume that the ratio of yttrium in sandstones relative to shales is the same as for zirconium, we get 40 ppm Y. Wedepohl's unpublished result for three limestone composites (93 samples) is 30 ppm Y. The pelagic-clay value is from Goldberg and Arrhenius (1958) and Wedepohl (1960). The carbonate deep-sea-sediment value is that of Wedepohl's unpublished data on the Atlantic.

**Zirconium and hafnium:** The data for all rock types except the deep-sea clays are from Degenhardt (1957). His values generally agree with those of other workers. The pelagic-clay value is from Goldberg and Arrhenius (1958) and Wedepohl (1960).

Very little information on the hafnium abundance in common rocks is available. We can, however, use the coherence of hafnium and zirconium as a method of estimating the hafnium content of rocks from the zirconium content. The Zr/Hf ratio varies in zirconium with the rock type. If zircon and the mafic minerals are the main carriers of both the zirconium and hafnium, and if the Zr/Hf ratio of coexisting zircon and the mafic minerals is the same, then a method of approximation is available to us. Gottfried, Waring, and Worthing (1956) and Kosterin, Zuev, and Shevaleevskii (1958) have determined the Zr/Hf ratio of zircon from various rock types. The only difference in the two sets of data is in syenitic rocks where Gottfried, Waring, and Worthing report a higher ratio. Table 1 gives an estimate of the hafnium content of the various rock types based on the Degenhardt and Kosterin, Zuev, and Shevaleevskii data.

**Table 1.—Estimation of Hafnium Concentrations in "Igneous" Rocks**

<table>
<thead>
<tr>
<th></th>
<th>ppm Zr (in rock)</th>
<th>Zr/Hf (in zircons)</th>
<th>ppm Hf (in rock)</th>
</tr>
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<tr>
<td>Ultrabasic rocks</td>
<td>45</td>
<td>70</td>
<td>0.6</td>
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<tr>
<td>Gabbro</td>
<td>140</td>
<td>70</td>
<td>2.0</td>
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<tr>
<td>Granodiorite</td>
<td>140</td>
<td>60</td>
<td>2.3</td>
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<tr>
<td>Granite</td>
<td>175</td>
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<tr>
<td>Syenite</td>
<td>500</td>
<td>45</td>
<td>11.1</td>
</tr>
</tbody>
</table>

Cooley et al. (1953) provide data which give a Zr/Hf average ratio of 44, indicating perhaps that most of their zirconium numbers were of granitic or syenitic affinity.

**Niobium and tantalum:** The igneous-rock data of Rankama (1944; 1948) generally agree with those of Znamenski (1957) except for the high-calcium granitic rocks. For these Rankama reports 3.6 ppm Nb and 0.7 ppm Ta for six Scandinavian dioritic rocks. Znamenski gets an average of 20 ppm Nb and 3.6 ppm Ta for this rock type, and we shall use his values. Grimaldi (1960) reports 22 ppm Nb for standard granite G-1 and 9.6 ppm Nb for standard diabase W-1. The sedimentary-rock and deep-sea-sediment data are from Rankama.

**Molybdenum:** The igneous-rock values are the averages of the data on each rock type reported by Kuroda and Sandell (1954) and Vinogradov, Vainshtein, and Pavlenko (1958). The latter's values, determined spectrophotometrically on Russian rocks, are generally higher (except for ultrabasic rocks) than Kuroda and Sandell's, determined colorimetrically. Ishimori (1951) reports a value of 0.9 ppm Mo for the average of 10 Japanese basalts, which is comparable to the low value Kuroda and Sandell derived for basaltic rocks.

The sedimentary-rock data are from Kuroda and Sandell (1954). They also report 3 ppm Mo for both carbonate and clay deep-sea sediments. Goldberg and Arrhenius (1958), however, report 45 ppm for East Pacific pelagic clay samples, and Wedepohl (1960) reports 9
ppm for Atlantic pelagic-clay samples. We use the average of these two last values, although we cannot explain the discrepancy with Kuroda and Sandell. We use Kuroda and Sandell’s carbonate deep-sea sediment value, however.

**Palladium:** The few new data available are from Vincent and Smales (1956), who determined palladium by neutron activation. The granitic-rock values are probably of the order of magnitude indicated.

**Silver:** All the silver data, where numbers are listed, are from Hamaguchi and Kuroda (1959), who analyzed primarily Japanese rocks. The unpublished data of A. Kvalheim quoted by Goldschmidt (1954) appear to be too low. The high values for diabases from Ontario reported by Fairbairn, Ahrens, and Gorfinke (1953) are probably characteristic of that region only and not applicable generally.

**Cadmium:** No data could be found for ultrabasic rocks, but the order of magnitude listed is probably correct. The igneous-rock data are from Sandell and Goldich (1943). Preuss (1940) got 0.2 ppm Cd for a granitic composite and 0.3 ppm Cd for a shale composite. The deep-sea-sediment data are calculated from Mullin and Riley (1956). Their average of recent calcium carbonate shells is 0.035 ppm which we use for the limestone value although this is undoubtedly a lower limit since other contributing phases in a normal limestone have not been considered.

**Indium:** The data are from Shaw (1952b). However, there are some uncertainties here. The high-calcium granitic rocks have a value much lower than either the low-calcium granitic rocks or the basaltic rocks. Wagner, Smit, and Irving (1958) report neutron-activation values for indium in W-1 standard diabase and the chill zone from the Skærgaard complex, Greenland, as 0.064 and 0.058 ppm respectively. These numbers are lower than the values chosen for the table.

**Tin:** The tin data are primarily from Onishi and Sandell (1957). The high-calcium granitic rocks were arbitrarily assigned a value of 1.5 ppm. Degens, Williams, and Keith (1957) give 3.2 ppm for the value of their Carboniferous shales, and Wedepohl (unpublished) finds a value of 5 ppm for shales. The value of Onishi and Sandell for shales (11 ppm) has been averaged with the above authors’ to give the value in the table.

**Antimony:** The data are all from Onishi and Sandell (1955b). These authors were not completely satisfied with their results and claim they should be taken tentatively. In the absence of any later information these are the best estimates available.

**Iodine:** The estimates for all the rock types except the deep-sea-sediment data are based on the monograph “Geochemistry of Iodine” (Chilean Iodine Educational Bureau, 1956). The deep-sea-sediment data are based on the chlorine content of these sediments as inferred above and the I/Cl ratio of the sea (≈ 2.27 x 10⁻⁶). These values may be too low, since there is a correlation of organic content of shales and iodine, so some of the iodine may be enriched in sediments relative to the sea.

**Cesium:** The cesium concentrations in ultrabasic rocks, limestones, and sandstones are not known except that they are all probably less than 1 ppm (Horstman, 1957). The granitic value is calculated from Gast (1960), who analyzed two granitic composites. From the values he obtained for Li and Sr, it appears that the composites could be resolved into one part low-calcium to one part high-calcium granite rock with the assumed values listed to give the observed value of 3.2 ppm. Horstman (1957) reports 1 ppm Cs as an average of a composite of 66 samples. The syenite value is from the average of three syenite rocks from East Greenland analyzed by Liebenberg (1956). The shale value is from Horstman, Canney’s (1952): average seems to be rather high. The deep-sea data are from Smales and Salmon (1955). They report a value of 0.4 ppm for 90 per cent calcium carbonate sediment increasing to 1.5 ppm for the portion of the core analyzed which has 80 per cent CaCO₃. By extrapolation to 0 per cent calcium carbonate, a value of about 6 ppm is obtained. This compares with Horstman’s (1957) value for a pelagic-clay composite. The basaltic value is the average of cesium values determined by Gast (1960) on three basalt composites by isotope dilution. Cabell and Smales’ (1957) value for W-1 standard diabase (1.08 ppm Cs) agrees, whereas their value for the Skærgaard chilled marginal gabbro (0.10 ppm Cs) is low.

**Barium:** The value used for ultrabasic rocks is a single activation analysis of a dunite made by Hamaguchi, Reed, and Turkevich (1957); it is considerably lower than the 6 ppm reported by Pinson, Ahrens, and Franck (1953). Von Engelhardt’s (1936) figures for olivine scatter around 1 ppm. Gast (1960) reports an average of 333 ppm for three basalt composites analyzed by isotope dilution. Hamaguchi, Reed, and Turkevich (1957) get 310 ppm for a
single activation analysis of a Hawaiian basalt. The basaltic value from Nockolds and Allen (1956) for 72 basaltic rocks is 180 ppm, considerably lower. The granitic values are calculated from Gast's (1960) average granitic value of 620 ppm as described under cesium. The syenite value is the average of the values of von Engelhardt (1936) and of Sahama (1945). The shale value is the average of data from five different studies: Degens, Williams, and Keith (1957), Carboniferous shales, 450 ppm Ba; Tourtelot (1957), Pierre (Cretaceous) shale, 720 ppm Ba; Macpherson (1958), Precambrian graywackes, argillites, and low-grade schists, 440 ppm Ba; Shaw (1957), Littleton formation (Devonian) pelitic rocks, 580 ppm; and Wedepohl (1960) Japanese and European shales, 700 ppm. The limestone value is based on modern molluscan shells (Turekian and Armstrong, 1960). The sandstone value is a guess. Quartz generally has very low barium, but the presence of heavy minerals and BaSO$_4$ cement will raise the figure. We have assumed that von Engelhardt's values of 170 ppm Ba for sandstones and 120 ppm Ba for limestones are too high. The value for deep-sea clays from the Atlantic is 700 ppm (Wedepohl, 1960) and from the Pacific 4000 ppm (Goldberg and Arrhenius, 1958). The average of these values is used. The Pacific has a strong barium sulfate component either dispersed or in the form of concretions (Goldberg and Arrhenius, 1958). The carbonate deep-sea-sediment value is an unpublished result for four "Globigerina oozes" cores from the Atlantic (Wedepohl).

**Lanthanum:** The ultrabasic value is a guess. The basalt value is that for Ontario diabase from Fairbairn, Ahrens, and Gorfinkle (1953). For granites, Nockolds and Allen (1953), Sahama (1945), and Ahrens (1954) report the same averages, around 55 ppm La. The granodiorite average is from Nockolds and Allen (1953). The same authors report (1954) 95 ppm La in trachytes, whereas Sahama (1945) got 50 ppm in syenites. An intermediate figure is used. Nepheline syenites are again much higher (Gordon and Murata, 1952).

Wedepohl checked Minami's (1935b) La determinations and found his shale averages too low (this concerns only the La values of his report, however). Wedepohl (1960) reports 92 ppm La as an average of shales, which we have used. The deep-sea-clay value is again a one-to-one average of that for Pacific (Goldberg and Arrhenius, 1958): 130 ppm, and Atlantic samples (Wedepohl, 1960): 98 ppm. For the carbonate deep-sea-sediment, 10 per cent of the clay value is assumed.

**Other rare-earth elements:** The other rare-earth values for most of the rock types are based on the assumption that the ratio of each of the rare-earth elements to yttrium is the same as it is in shales as determined by Minami (1935b). Data on Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Er, and Yb in granites are reported by Sahama (1945). Except for a low cerium value of Sahama, there is a good agreement with our computed values. In pelagic clays from the Pacific, 100 ppm Nd and 12 ppm Yb could be estimated (Wedepohl, unpublished), also in close correspondence to our prediction. A few small deviations from our values result if one uses the considerations of Masuda (1957) as a base for the computations.

**Tungsten:** The ultrabasic value is from Vinogradov, Vainshtein, and Pavlenko (1958). The basaltic, granitic, and syenitic values are intermediate between the averages of these authors and those of Sandell (1946). In all but the syenitic rocks Sandell's values are lower. Jeffery (1959) reports 10 ppm for the average of alkali rocks from Uganda. We consider this too high for a general average for syenitic rocks. His average for granites, however, (undistinguished as to low or high calcium), 1.4 ppm, is comparable to the value we have chosen. The shale and sandstone values are the analyses made by Vinogradov, Vainshtein, and Pavlenko of composites of several thousand samples of these rock types prepared by Ronov. The limestone value is the average of seven analyses on African limestones by Jeffery. Unfortunately no data are as yet available for deep-sea sediments, and so order of magnitude guesses have been made.

**Gold:** The only recent data are neutron-activation determinations by Vincent and Crockett (1960) and Crockett, Vincent, and Wager (1958) on some ultrabasic rocks, basaltic rocks, and standard granite G-1. The values for these igneous-rock types are from their data. It is assumed that the gold content of all other rocks will be of the same order of magnitude, although Clarke (1924) reported 0.03 ppm Au for sandstones and 0.005-0.009 ppm for limestones.

**Mercury:** The values for the igneous rocks where any are listed and shales are averages of the determination of Stock and Cucuel (1934) and Preuss (1940) on the same composites of German rocks prepared by Goldschmидt. The two sets of values agree fairly well. The lime-
stone value is the average of the determinations on the Muschelkalk by Stock and Cucuel (1934) (one analysis, 0.033 ppm Hg) and Heide and Böhm (1957) (average of several specimens, 0.048 ppm Hg). The latter authors also report 0.19 ppm for the underlying red shale ("Röt") near Jena. The sandstone value is from a single analysis by Stock and Cucuel. The other values are order of magnitude guesses.

Thallium: The data are from Shaw (1952a), Ishimori and Takashima (1955), and Preuss (1940). The reported value for ultrabasic rocks and syenites is from Shaw, that for basalts is the average of Shaw's (0.13 ppm), Ishimori's (0.3 ppm), and Preuss' (0.3 ppm) data. The granodiorite value is intermediate between Shaw's (0.43 ppm) and Ishimori's (1.0 ppm).

For a composite of German granites, Preuss got 3 ppm. Shaw reports 3.1 ppm as an average for granites and Ishimori 0.9 ppm for Japanese granites, resulting in an average of 2.3 ppm Tl. Preuss and Ishimori get the same value for the same composite of European carbonaceous shales, 2 ppm Tl; Shaw reports a shale average of about 0.8 ppm. We use the average of these two. Canney (1952) reports a value of about 0.4 ppm Tl for shales. For Pacific pelagic clay Shaw reports 1.2 ppm Tl, whereas Atlantic clay has 0.42 ppm Tl. Reed, Kigoshi, and Turkevich (1958) report a value of 0.94 ppm Tl for a perthite from a granite and of 0.07 ppm Tl for a basalt using neutron activation. These numbers are slightly lower than Shaw's.

Lead: The ultrabasic value is based on the range (0.01 to 0.01 ppm) reported by Tilton and Reed (1960). The rest of the data are primarily from Wedepohl (1956). The Atlantic pelagic clays have a value of 45 ppm (Wedepohl, 1960), the Pacific clays a value of 110 ppm. Goldberg and Arhenius (1958) got 140 ppm for the Pacific. Hence again there are differences in the chemistry of the sediments of the two oceans. The average of the two is used. The carbonate deep-sea-sediment value is 0.1 per cent of the average pelagic-clay value as before. Turekian and Feely (1956) report a mean value of 4 ppm for an Atlantic Equatorial carbonate core. The granitic-rock data are confirmed by Ahrens (1954) for North American rocks of low-calcium and high-calcium granitic composition. Gordon and Murata (1952) report a value of 7 ppm for an Arkansas nepheline syenite. Shaw (1954) lists a value of 16 ppm for pelitic rocks, which compares with Wedepohl's data. Degens, Williams, and Keith (1957) on the other hand find 35 ppm for Carboniferous shales of Pennsylvania. Heide and Lerz (1955) report a value of 21 ppm for the Röt shale near Jena and 7.9 ppm for the Muschelkalk limestone.

Bismuth: Data for granites and shales are from Preuss (1940). Reed, Kigoshi, and Turkevich (1958), as a byproduct of their work on meteorites, have published Bi values for a perthite from a granite and a basalt (from the Snake River region, U.S.). These numbers are included in Table 2 on the premise that some idea of the possible value for the abundance of Bi in a rock type may be better than no idea. There are other values in the literature, but they all appear high. Preuss (1940), for example, reports 2 ppm Bi for a composite of German granites and 1 ppm Bi for shales. Brooks, Ahrens, and Taylor (1960) report a wide range of values for a variety of rocks in a preliminary report.

Thorium and uranium: The ultrabasic value for thorium is derived from the uranium value (which is used for this rock type) of a single dunite by Hamaguchi, Reed, and Turkevich (1957) and assuming a Th/U ratio of 4. These low values have also been found for chondrites. The basaltic and syenitic values are from Evans and Goodman (1941). The granite values are from Whitfield, Rogers, and Adams (1959). The shale and limestone values are from Adams and Weaver (1958) and the sandstone value from Murray and Adams (1958). The uranium value for deep-sea-clay sediments is derived from Starik et al. (1958). On a clay core from the southern part of the Indian Ocean they find an average of 1.3 ppm U.

For a core with about 40 per cent CaCO₃ these workers found the same value for uranium and a high value for thorium (13.5 ppm). Others have found very low concentrations of uranium in the carbonate fraction (<1 ppm U, W. S. Broecker, personal communication) indicating that the uranium value for average carbonate deep-sea sediments is the order of magnitude indicated in Table 2 rather than the high value mentioned above. Picciotto and Wilgus (1954) report an average of about 5 ppm Th for a Central Pacific pelagic-clay core. The average between this and the higher value obtained by Starik and his coworkers on Indian Ocean sediments serves as our choice for the abundance of thorium in pelagic clays. The carbonate deep-sea-sediment values for Th from the literature are widely divergent, and so we indicate only an order of magnitude estimate.
| 1. Hydrogen | H  |
| 2. Helium   | He |
| 3. Lithium  | Li |
| 4. Beryllium| Be |
| 5. Boron    | B  |
| 6. Carbon   | C  |
| 7. Nitrogen | N  |
| 8. Oxygen   | O  |
| 9. Fluorine | F  |
| 10. Neon    | Ne |
| 11. Sodium  | Na |
| 12. Magnesium| Mg  |
| 13. Aluminum| Al |
| 14. Silicon | Si |
| 15. Phosphorus| P  |
| 16. Sulfur  | S  |
| 17. Chlorine| Cl |
| 18. Argon   | Ar |
| 19. Potassium| K |
| 20. Calcium | Ca |

Ultr.
REFERENCES CITED


### Table 2—Distribution of the Elements in the Earth's Crust

(Expressed in parts per million)  

<table>
<thead>
<tr>
<th>Element</th>
<th>Ionization</th>
<th>Rock Type</th>
<th>Sedimentary Rocks</th>
<th>Carbonaceous</th>
<th>Clay</th>
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<td></td>
<td>&quot;Igneous&quot;</td>
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<td>Rn+++</td>
<td>Rn++++</td>
<td>Rn+++++</td>
</tr>
<tr>
<td>Th</td>
<td>Th+</td>
<td>Th++</td>
<td>Th+++</td>
<td>Th++++</td>
<td>Th+++++</td>
</tr>
<tr>
<td>U</td>
<td>U+</td>
<td>U++</td>
<td>U+++</td>
<td>U++++</td>
<td>U+++++</td>
</tr>
<tr>
<td>Pu</td>
<td>Pu+</td>
<td>Pu++</td>
<td>Pu+++</td>
<td>Pu++++</td>
<td>Pu+++++</td>
</tr>
</tbody>
</table>

**In some cases, only order of magnitude estimates could be made. These are indicated by an asterisk.*

*These elements are the basic constituents of the biosphere, hydro sphere, and atmosphere. The argon and helium contents of rocks will vary with their age owing to the effect of radioactive decay.

The estimated rare-gas contents of igneous rocks are in ppm by weight of rock. He, 6 x 10^4; Ne, 0.0018; Ar, 0.0016; Kr, 0.0001 (calculated from isotopic composition of 40Ar). The production of argon by U and Th is also but very small, as is produced by the radioactive decay of 40Ar in U and Th. They are also of the rare gas which are not produced by the radioactive decay of 3He and 21Ne. As produced by the radioactive decay of 3He and 21Ne.

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