HANDBOOK OF DIFFERENTIAL THERMAL ANALYSIS

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by

W. J. SMOTHERS, Ph.D.
Assistant Section Manager, Refractories
Homer Research Laboratories
Bethlehem Steel Corporation
Bethlehem, Pennsylvania

and

YAO CHIANG, M.S.
Consultant
formerly on Research Staff
Battelle Memorial Institute
Columbus, Ohio

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Preface

Although this book is a revision of the earlier work entitled *Differential Thermal Analysis: Theory and Practice*, which was published in 1958, it was decided to title this book *Handbook of Differential Thermal Analysis* because it presents more concerning practice than theory. In reviewing a selected field of science the result can be either critical, or somewhat encyclopedic. We have chosen to lean toward the latter, with an attempt occasionally to be critical, because we believe that with such a wide interest in differential thermal analysis this approach will produce a book which will be useful to a greater number of people.

At the time of issue of the previous book the rate of publishing of articles on DTA in the fields of geology, soils, metallurgy, and ceramics was somewhat static. Chemists were becoming aware again of the usefulness of the method, and the rate of published papers in this field has been increasing. The most phenomenal rate of growth in this context has been in the study of polymers. It is primarily because of this interest, and, in general, of that of the organic chemists, that more commercially produced DTA apparatus has been offered for sale in recent years.

Disagreement still continues whether DTA can be considered a quantitative method, but the appearance of many more papers in the last few years in which quantitative results are presented shows that, at least under controlled conditions, fairly good quantitative results can be obtained. Also, the availability of better equipment and apparatus whereby reproducible conditions are more easily attainable, and the high sensitivity of such apparatus at controlled heating rates, makes the results more quantitative.

In addition to a few books on DTA covering somewhat limited areas, the reliability of the method has reached the point that a card index has been prepared by Dr. R. C. Mackenzie of the Macaulay Institute for Soil Research, at Aberdeen, Scotland. Comparisons with the ASTM card index for x-ray diffraction are inevitable, but it must be admitted that the reproducibility of results on various

DTA equipment may be difficult to obtain with precision. Nevertheless, this card index serves a very useful purpose in compiling information on more than 1600 materials. The cards are coded to give information about the DTA peaks, and a mineral classification, as well as literature references. Information on organic and inorganic materials is also included.

To educate scientists about DTA and other thermal techniques, Dr. Saul Gordon, who has been very active in this work, has been holding Thermoanalysis Institutes in the summer at Fairleigh Dickinson University, Madison, New Jersey. In addition to learning of the theory of DTA, the students have laboratory sessions, which give them the opportunity to use required equipment.

In preparing this book we have been mindful of the constructive criticisms of the previous edition and have attempted to answer them by making appropriate changes. In particular, we wish to thank Professor Wilhelm Eitel, of the University of Toledo (Ohio), for his continued interest and kindly help in all of our publications in this field.

As the basic work of P. L. Arens has withstood the test of this relatively short time, it has been presented again in this edition.

Full reference is given to tables and figures presented and we greatly appreciate the permission of authors and publishers to reproduce this material. In particular, Figures 1, 3, 4, 5, and 6 are from *Measurement of High Temperatures* (1912), by Chatelier and Burgess, John Wiley & Sons, Inc.; 7 is from *Introduction to Thermography* (1961), by L. G. Berg; 8, 9, and 31 are from the *Journal of the American Ceramic Society;* 14 is from *Soil Science;* 25 is from the *American Mineralogist;* and 26, 27, and 28 are from *Analytical Chemistry*.

We appreciate also the cooperation of the equipment manufacturers in making information and photographs available to us. In particular, we are happy to acknowledge the help of Professor Megumi Tashiro, of the Institute for Chemical Research at Kyoto University, in obtaining information on Japanese equipment, and for translating some of this information.

The major part of *Appendix 1* was typed by Miss Linda Lou Stocker, of Battelle Memorial Institute, and we are appreciative of her careful work. To the onerous job of alphabetizing and collating, the whole Smothers family was called, with typewriters in hand, and their help and patience are gratefully acknowledged.

This book is meant to introduce differential thermal analysis to those that are not familiar with the method, and sufficient references are given for those that wish to dig deeper and to study the original papers. To those, however, who are working in this field, our attempts to keep *Appendix 3*, which gives alphabetical reference lists for many materials, up-to-date should be useful.

In a book covering such a wide field there may be errors, both of commission and of omission, but we hope that these will not be sufficiently serious to affect its usefulness to those that will consult it.

April 1965

W. J. SMOTHERS
YAO CHIANG

Contents

chapter 1

ORIGINS OF DTA: AN INTRODUCTION

Hannay (1877, 1879) * pointed out that an examination of the rate at which the volatile constituent of a compound is driven off at a constant temperature may afford valuable information as to the constitution of the body so examined, and would bring out the relation between the varying vapor tension of a decomposing body and its chemical constitution. It was intended to extend this method to all kinds of compounds which have a volatile constituent, such as water. Ramsay (1877) suggested that the composition and constitution of many of the amorphous hydrates, such as aluminum oxide and iron oxide hydrate ($Al_2O_3 \cdot xH_2O$ and $Fe_2O_3 \cdot xH_2O$), whose compositions are somewhat indefinite, might be accurately determined by this method, since the vapor tensions of hydroscopic and combined water would differ and a definite distinction could be made between them. Hannay and Ramsay have thus determined the rate of weight loss of water from hydrates while drying at a constant temperature. Both crystalline and amorphous hydrates were studied and included the following: $FeSO_4 \cdot 7H_2O$, $Na_2SO_4 \cdot 10H_2O$, $CaSO_4 \cdot 2H_2O$, $Al_2O_3 \cdot H_2O$, and $Fe_2O_3 \cdot 3H_2O$.

This technique of loss of weight *vs.* time at constant temperature has been gradually developed and reached a climax in the weight loss *vs.* time or temperature curve under uniform rate of heating. This later technique was developed by de Keyser (University of Brussels), who chose to call it *differential thermogravimetry.* Closely allied to this method is that of differential thermal analysis.

The differential thermal method had its origin and significant dates in 1887 (LeChatelier), 1897 (Callendar), and 1898 (Stansfield). The method was perfected by Roberts-Austen (1899), Saladin and LeChatelier (1904), and Carpenter and Keeling (1904, 1907); and was reviewed in great detail by Burgess (1908, 1912) in connection with differential-cooling curves used in metallography.

* All references in the text can be found in APPENDIX I. The number refers to the year of publication. When more than one article by the cited author appeared in the particular year, the specific number in APPENDIX I is also given.

EXPERIMENTS OF LE CHATELIER: ACTION OF HEAT ON PROPERTIES AND CONSTITUTION OF CLAYS

LeChatelier (1887) was interested in measuring the time rate of the transformations under observation. This was done by determining directly the rate of changing temperature dT_s/dt of the material in terms of its temperature T_s. He investigated the behavior of clays on heating to determine their constitution and, if possible, to devise a scheme of classification. The temperatures were measured by means of a thermocouple consisting of pure platinum and platinum containing 10% of rhodium. A photographic method, not previously used in recording heating-curve data, in which the photographic plate remained stationary, was developed and used in these experiments. Sparks from an induction coil were made to pass at intervals of 2 seconds before a slit and gave on the plate, after reflection from the galvanometer mirror, images of the slit whose spacing was a measure of the rate of heating—about 2°C/minute.

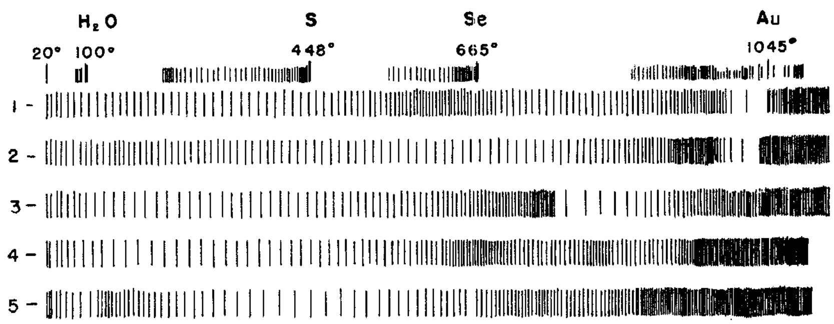

FIG. 1:1. HEATING CURVES OF CLAYS ACCORDING TO LECHATELIER

Roberts–Austen (1891) is credited with developing the method of automatic photographic recording of cooling curves. Kurnakov (1904) described a recording apparatus similar to that of Roberts–Austen except that a sensitized paper mounted on a rotating drum replaced the vertically moving photographic plate.

Figure 1:1 is a reproduction of LeChatelier's negatives from his experiments. The top row gives the graduated reference points of the thermocouple. By this method, he classified a large number of complicated clays into only five well-defined groups:

1) *Halloysite* from Niglos: A feebly marked endotherm (represented by contraction of lines in row 1 of Figure 1:1) at 150°–200°C,

a second well-marked endotherm ending at 700°C, followed by an exotherm (represented by diminution of lines in row 1 of Figure 1:1) at 1000°C;

2) *Allophane* from Saint Antoine: A well-marked endotherm at 150°–220°C, followed by an exotherm at 1000°C (row 2 of Figure 1:1);

3) *Kaolin* from Red Mountain, Colorado: An endotherm at 770°C, followed by a slight exotherm at about 1000°C (row 3 of Figure 1:1);

4) *Pyrophyllite* from Beresow: A well-marked endotherm, ending at 700°C, and a second less strongly marked endotherm at 850°C (row 4 of Figure 1:1);

5) *Montmorillonite* from St. Jean de Cole: A well-marked endotherm at 200°C, a second less strongly marked endotherm at 770°C, and a doubtful endotherm at 950°C (row 5 of Figure 1:1).

When hydrated silica is gently heated, it shows an endotherm between 100° and 200°C. Hydrated alumina precipitated from sodium aluminate shows a first endotherm below 200°C and a second endotherm ending at 360°C; and if precipitated from aluminum salts or prepared by calcination of the nitrate at a moderate temperature, it shows the same endothermic reactions, followed by a sudden acceleration in the rise of temperature at 850°C; bauxite shows an endotherm at 700°C.

From these facts, LeChatelier concluded that free silica cannot be present in pure clays and that the two hydrates of alumina cannot exist in any of the clays examined, whereas the hydrate present in bauxite may be present only in halloysite. The evolution of heat (exothermic) at high temperature is due to a molecular change in the alumina to the insoluble form. Free alumina does not exist in clays, but is liberated by their decomposition and dehydration reactions.

These conclusions, although interesting and important, are limited, because the difference in the rate of heating due to changes in the substance itself cannot be distinguished from those due to external causes. For example, the accidental fluctuations in the heat content not inherent to the sample are observed because no neutral body (Roberts-Austen, 1899) is used.

In order to eliminate the effect of irregularity of outside conditions that influence the rate of heating or cooling, a revised method is commonly used for detecting small transformations. This consists in placing a second thermocouple in the furnace or neutral body,

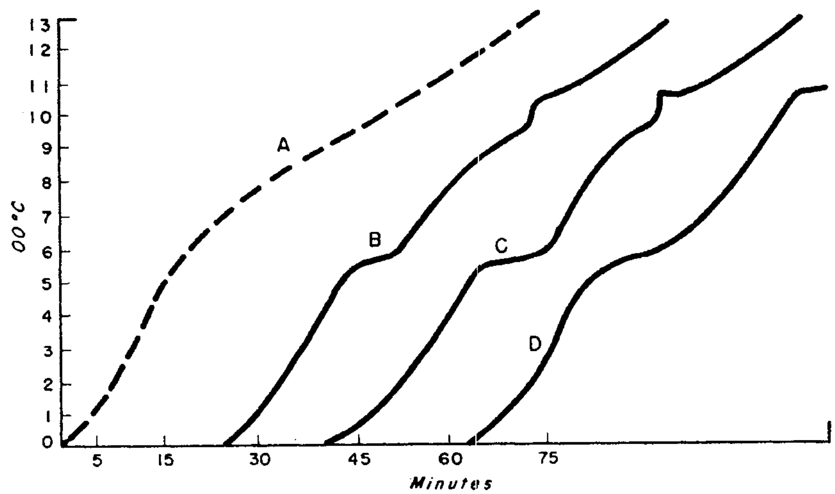

FIG. 1:2. TEMPERATURE VS TIME CURVES BY WOHLIN
A, Furnace heating curve; B, C, D, Furnace-heating rate with thermal reactions for clays superimposed

but sufficiently removed from the substance studied to be uninfluenced by its behavior. Alternate readings on the temperature of the sample (T_s) and of the furnace or neutral body (T_r) are then taken, preferably at definite time intervals. The data are most readily compared by plotting the two temperature-time curves side by side (Mellor, 1911, 1924, 1925; Ashley, 1911; Rieke, 1911; Wohlin, 1913) (Fig. 1:2); or by plotting the difference in temperature $T_s - T_r$

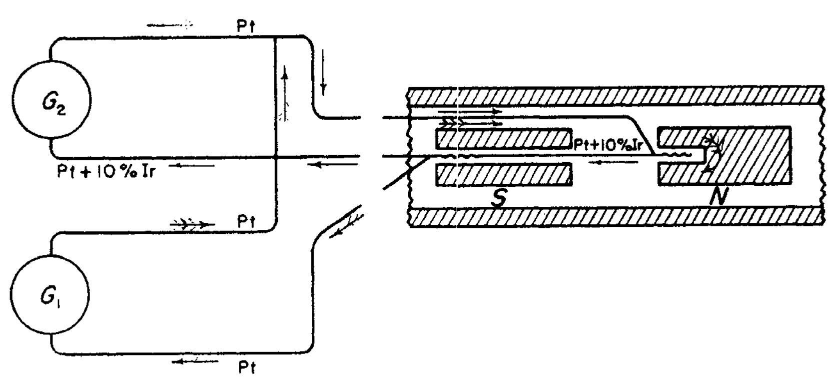

FIG. 1:3. USE OF NEUTRAL BODY (N) IN COMPARISON WITH SAMPLE (S) (ROBERTS-AUSTEN)

against the temperature T_s of the sample. From the latter plotting, it is obvious that the precision of $T_s - T_r$ cannot be greater than that of either T_s or T_r.

TYPES OF APPARATUS

Differential Thermocouple Methods

Roberts–Austen (1899) was the first to modify the preceding arrangement so as to give the difference in temperature between the sample and neutral body ($T_s - T_r$) directly (Fig. 1:3), instead of by computation. It was subsequently simplified by Carpenter and Keeling (1904, 1907) (Fig. 1:4), and by Burgess (1908, 1912), (Fig. 1:5) into an arrangement that is commonly used in modern laboratories (see subsequent chapters).

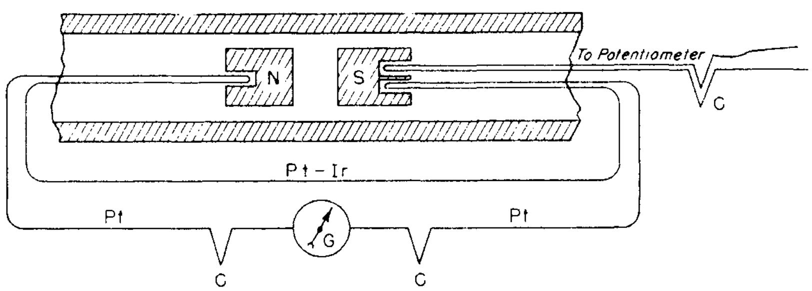

FIG. 1:4. ARRANGEMENT OF THERMOCOUPLES USED BY CARPENTER

In addition, Roberts–Austen was the first to advocate the use of a neutral body so that the accidental variations in the furnace temperature, not inherent to the heat content of the sample, are largely eliminated. The neutral body should be such that it undergoes no physicochemical transformations involving an absorption or evolution of heat within the temperature range investigated, and that its coefficients of thermal diffusivity and emissivity should be nearly the same as those of the sample. It is usually a piece of platinum (in metallurgy) or calcined alumina (in ceramics). Unfortunately, this rigid requirement has never been satisfied completely and needs yet to be explored. This complexity is further augmented by its dependence on the relative heat capacity of the furnace.

The arrangements shown in Figs. 1:3 to 1:5 illustrate an ideal application of the law of symmetry (Béhar, 1951), because every-

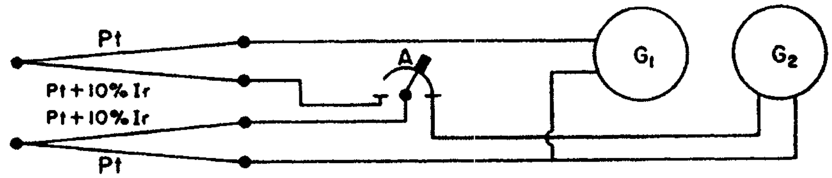

FIG. 1:5. ARRANGEMENT OF THERMOCOUPLES USED BY BURGESS

thing now comes in pairs: materials, temperatures, temperature gradients, potentials, and emf's. The precision of $T_s - T_r$ may thus be made as great as possible as compared with that of T_s, the temperature of the sample, as the latter is measured independently of the differential.

In the thermocouple circuits (Figs. 1:3 to 1:5), the two curves, $T_s - T_r$ *vs.* time and T_s *vs.* time had been recorded autographically on the same sheet of paper by means of a registering galvanometer, made by Siemens and Halske and described by Hoffman and Rothe (1905, 1906, 1907), in connection with their research on the change of state of liquid sulfur. It is evident that by recording the two curves on the same sheet, there is some sacrifice in the ability to detect small and rapid thermal transformations because the spacing has been doubled. Thus, it is sometimes convenient to consider a single chart recording $T_s - T_r$ *vs.* T_s or T_r directly without the time, though the uniform heating (or cooling) rate should be kept in mind constantly.

The Apparatus of Saladin-LeChatelier

Saladin (1903, published 1904) devised the first method of recording photographically the $T_s - T_r$ *vs.* T_s curve directly, using a fixed photographic plate. The arrangement of his apparatus, simplified by LeChatelier (1904) is sketched in Figure 1:6.

A beam of light from the source S strikes and then reflects from the mirror of the sensitive galvanometer G_1, whose deflections measure the difference in temperature $T_s - T_r$ between the sample and the neutral body. These reflections then pass through a total-reflection prism M, placed at an angle of 45° and so arranged as to make the beam oscillate in a vertical plane. The light then falls on the mirror (a total-reflection prism, 10 cm high) of a second galvanometer G_2, whose deflections measure the temperature (T_s) of the sample and whose mirror in its zero position is at right angles to that of G_1. The beam is then reflected horizontally on the stationary photographic plate, at P. Thus, the light has impressed on the plate two motions at right angles to each other, giving a curve whose ordinates (Y), corresponding to the vertical part of the oscillation, are proportional to the differential temperatures $T_s - T_r$, and whose abscissae (X), corresponding to the horizontal part of the oscillation, are proportional to the temperature T_s of the sample. The horizontal motion (X) has a known relation to time, so that the photographic plate P need not be moved. The sensitivity of the

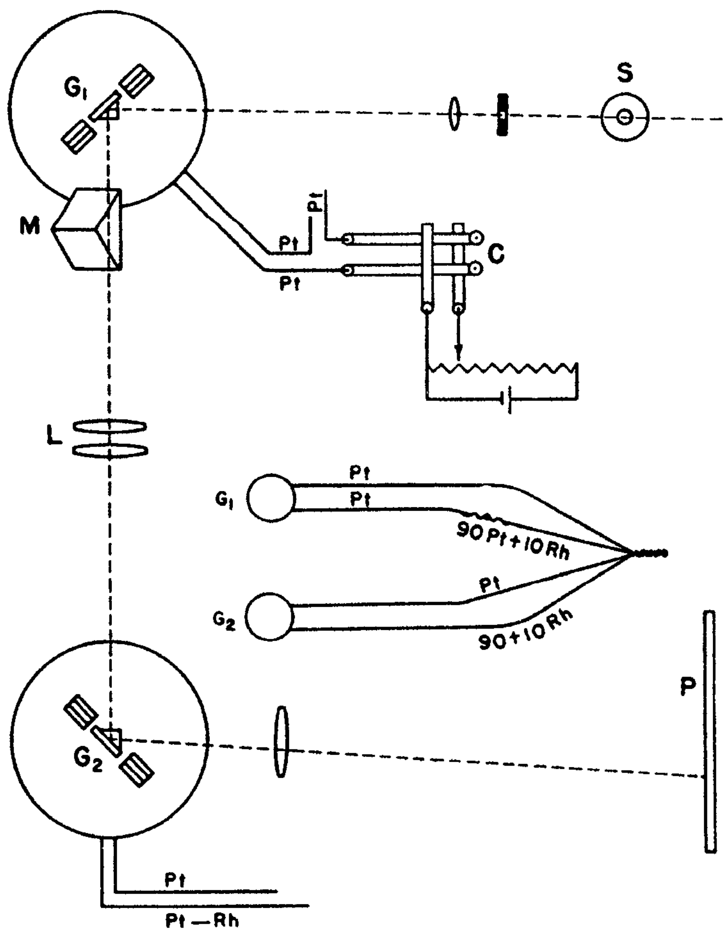

FIG. 1:6. SALADIN'S APPARATUS FOR PHOTOGRAPHIC RECORDING OF DIFFERENTIAL TEMPERATURE

method depends on that of the galvanometers G_1 and G_2. The arrangement of the thermocouple circuits is the same as in Figure 1:4.

The Kurnakov Pyrometer

The Russians have been active in this field practically since its inception and almost all work to date has been accomplished with use of what is called the *Kurnakov Pyrometer*, or with some slight modification of it. A recent representation is shown in Figure 1:7. This apparatus included photographic recording (1) of the reactions taking place in the sample and control being heated in the furnace (3), and the thermostatic ice-bath (2).

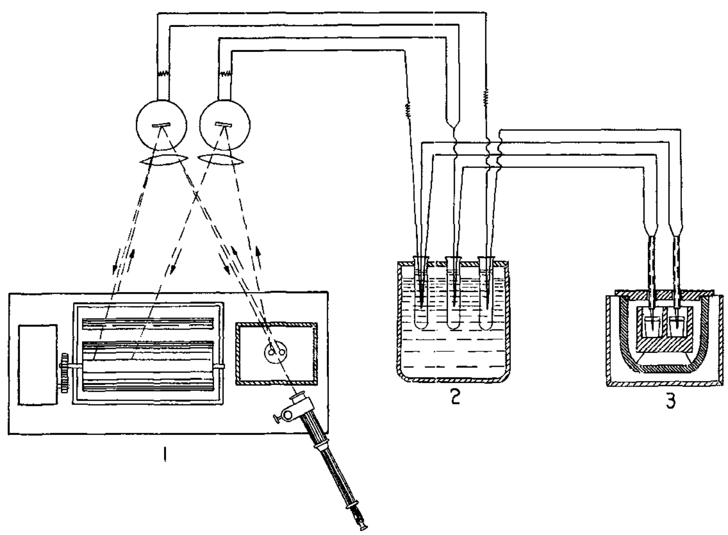

FIG. 1:7. KURNAKOV-TYPE APPARATUS FOR DTA

Other Recorders

In 1909, the Leeds and Northrup Company marketed the first autographic XY recorder. It was a mechanical recorder, tracing directly the $T_s - T_r$ *vs.* T_s curve by means of a double galvanometer system, the paper moving proportionally to the temperature T_s, and the pen proportionally to $T_s - T_r$. The same manufacturer brought out the improved Micromax in 1931. Their Speedomax

X–Y recorder, plus a DC Microvolt amplifier for the differential, has been used in several laboratories.

Béhar (1932) discussed extensively the development and operation of potentiometric recorders, beginning with Leeds and Northrup in 1909, continuing with Wilson–Maeulen in 1929, Uehling in 1930, Brown Company and Leeds and Northrup Micromax in 1931 (see also Weber, 1941, 1950; Foote, Fairchild and Harrison, 1921), and included in his description the photoelectric recorders (see also Payne, 1935, 1936).

DEVELOPMENTS IN USE OF DTA

Metallurgy

The basic foundations of DTA for metallurgy, as perfected by Saladin–LeChatelier and Roberts–Austen, have been applied extensively since their time. See:

Boudouard, 1903, 1904
Portevin *et al.*, 1908, 1913, 1919
Rosenhain *et al.*, 1908, 1910, 1915, 1935
Rengade, 1909
Broniewski *et al.*, 1912, 1913
Burgess *et al.*, 1913, 1916, 1918–19
Foote *et al.*, 1919, 1921 (equip.)
Scott, 1919
Guertler, 1920 (equip.)
Coe, 1935
Payne, 1935, 1936 (equip.)
Sykes *et al.*, 1935 ("double differential cooling curve method" and equip.)
Yatsevitch, 1935
Smith, 1939
Weber, 1941, 1950 (equip.)
Borelius *et al.*, 1943
Ageev, 1944
Desch, 1944 (equip.)
Luzhnikov and Berg, 1948
Wittig, 1950, 1952 (equip.)
ASTM Standards, 1951
Portevin, Albert, 1951, 1952
Wyman, 1951, 1952 (equip.)

For study of a powdered material, the chief addition to the parts of equipment used by earlier metallurgical workers was a container holding both the sample and the neutral body. In many cases, platinum crucibles were employed very satisfactorily.

Ceramics

Although White (1911) used a "dead (or neutral) body" in his studies of high-temperature calorimetry for detecting small heat effects, Fenner (1912) was the first to adopt the metallurgical DTA method in his work on the stability relations of silica minerals. Ceramists, contributing perhaps more than others, are interested not only in the naturally occurring clays and silicate minerals, but also in phase changes of mixed oxides, hydroxides, and fluorides and the differential thermocouples have been used even in firing processes (Segawa, 1949, Grim and Johns, 1951). The following list will cover some of those participating up to the end of World War II:

White, 1911, 1924, 1928 (calorimetry)
Fenner, 1912, 1913, 1919
Wallach, 1913, 1914
Wohlin, 1913
Cobb *et al.*, 1915 (carbonization), 1922–3, 1924
Satoh, 1918, 1921, 1923
Cohn, 1924
Kurnakov *et al.*, 1924, 1926, 1928
Urazov *et al.*, 1924, 1926
Kôzu *et al.*, 1926
MacGee, 1926
Sosman, 1927
Spangenberg, 1927
Krakau *et al.*, 1932
Geller *et al.*, 1934
Granger, 1934
de Lapparent, 1936
Jourdain, 1937
de Keyser, 1938–9 (review and equip.)
Barrett *et al.*, 1938
Trombe, 1938
Norton, 1939 (review and equip.), 1940
Saldau *et al.*, 1939
Harman *et al.*, 1940
Steger, 1942
Yamauchi *et al.*, 1942
Mitchell *et al.*, 1943
Nagai *et al.*, 1943
Pask *et al.*, 1943, 1945
Berkelhamer *et al.*, 1944 (review and equip.), 1945
Favejee, 1944
Grimshaw *et al.*, 1944, 1945 ("double or bi-DTA" and equip.)
Roberts *et al.*, 1944, 1945
Spiel *et al.*, 1945 (theory)

Among the researchers on glass, Tool and his collaborators (1919, 1920, 1925, 1931, 1938, 1948) have consistently favored the use of DTA.

Geology, Mineralogy, Inorganic Chemistry

Shortly after the development and use of DTA in ceramics by Wallach and Fenner, the pure mineralogists Orcel (1926), Kurnakov

(1926), and Syromyatnikov (1926) employed this method in studies of asbestos minerals. Since that time, DTA has become a common method in mineralogy and geology, and it was soon applied to inorganic chemistry by Kracek (1929). The following references will cover the period before the end of World War II.

Kurnakov *et al.*, 1926, 1928, 1937
Orcel *et al.*, 1926, 1927, 1930, 1935 (equip.), 1941
Syromyatnikov, 1926, 1933, 1934, 1935, 1936
Kracek *et al.* (chemistry), 1929, 1930, 1932, 1937
Andreev, 1931
Geilmann *et al.*, 1932
Caillère *et al.*, 1933, 1934, 1936, 1939, 1944, 1945
Geller *et al.*, 1934, 1935
Boullé (chemistry), 1935
Insley *et al.*, 1935 (equip.)
Pavlovitch, 1935
Belyankin *et al.*, 1936, 1938
Lodochnikov, 1936
Taylor *et al.* (chemistry), 1936
Kazakov, 1937
Vasenin, 1937
Aseev, 1938
Jensen *et al.* (chemistry), 1938
de Keyser, 1938–9 (review and equip.)
Parmalee *et al.*, 1938
Trombe, 1938
Bateshev (chemistry), 1939
Berg *et al.* (chemistry), 1939, 1940, 1941, 1942, 1943, 1944, 1945
Conley, 1939
Heindl *et al.*, 1939
Kind *et al.*, 1939
de Leenheer, 1939
Zakharov (chemistry), 1939
Efremov, 1940
Feodot'ev, 1940
Grim *et al.*, 1940, 1942, 1944, 1945
Ivanova, 1940
Faust *et al.*, 1941, 1944
Norin, 1941, 1944
Partridge *et al.*, 1941
Pask *et al.*, 1943, 1945
Balandin *et al.* (chemistry), 1944
Berkelhamer *et al.*, 1944 (review and equip.), 1945
Cuthbert *et al.*, 1944
Leont'eva (chemistry), 1944
Speil *et al.*, 1944 (theory), 1945
Brasseur (chemistry), 1945

Soils

Use of DTA in soils did not begin until 1922 when Matějka detected the presence of kaolinite in soils through use of DTA. Additional work was not done until 1933, when Agafonoff and Pavlovitch used the Saladin-LeChatelier double galvanometer in the study of red lateritic and Mediterranean soils. The following is a short list for the period up to the end of World War II:

Agafonoff *et al.*, 1933, 1934, 1935
Hendricks *et al.*, 1939 (equip.), 1940, 1941
Sedletskiĭ, 1939
Russell *et al.*, 1940, 1942
Page *et al.*, 1942, 1943 (equip.)
Jeffries, 1944 (equip.)
Caillère *et al.*, 1945

Other Fields

Applications of DTA after World War II are so numerous that separate chapters and tables are necessary. Although theories (see Chapter 5) have been gradually unified into a coherent story, it is still far from complete.

Diversified fields of study now include:

Cement—Kalousek *et al.*, 1949, 1951; Gilliland, 1951

White coat plaster—Murray and Fischer, 1951; Wells *et al.*, 1951

Phosphors—Nagy and Lui, 1947; Rice, 1949

Fuel Technology—Widell, 1947, 1949, on peat and wood; Breger and Whitehead, 1950; Smothers and Chiang, 1952; and Gamel and Smothers, 1952, on coal and lignite.

Soaps—Vold *et al.*, 1941, 1945, 1947, 1948, 1949, 1950; Vinogradov, 1947; Stross and Abrams, 1950

Organic Polymers—Brasseur *et al.*, 1946, 1947, 1949; and even proteins, Mishin and Garbuzov, 1951.

As DTA is so useful in so many different fields, each of them with different requirements, it deserves a careful reexamination, and a discussion of the equipment now used in modern laboratories.

chapter 2

EQUIPMENT

SAMPLE HOLDER

Most sample holders have been designed with two holes: one for containing the powdered sample and the other for containing the inert or standard material used for reference or control. A multiple sample holder, however, which contains six samples and a standard, has been described by Kulp and Kerr (1947, 1949) and has been modified slightly by other workers.

Various types of containers are used as sample holders: Orcel (1935) and his associates prefer quartz-glass tubes, and Grimshaw *et al.* (1945) described a ceramic sample block; but most workers in the United States prefer sample holders of high heat-conductivity (nickel, Inconel, platinum). Norton (1939) used a nickel sample holder to neutralize thermal gradients. Berkelhamer (1944, 359) described a stainless-steel block which many laboratories have duplicated for their use.[1]

McConnel and Earley (1951) used an Inconel multiple-sample holder and point out that there are two schools of thought concerning the most desirable characteristics for the sample holder with regard to size and heat capacity. Gruver (1948) used small platinum crucibles, one for the sample and another for the standard. Gruver states that if the heat capacity of the sample holder is very small the sensitivity of the method is increased because there would not be enough metal to absorb heat rapidly during an exothermic reaction and thus reduce the exothermic effect. This statement is said not to take into account certain distinct advantages that may accompany the use of a sample holder of relatively high heat capacity. Furthermore, it should be pointed out that, as the thermal conductivity of the platinum crucibles described by Gruver is very high, one cannot consider the thermal capacity of the furnace,

[1] When the author has more than one paper listed in APPENDIX I for a given year, the reference number is also given to identify the paper cited.

appendix 3

ALPHABETICAL LIST OF MATERIALS STUDIED BY DTA

ALPHABETICAL REFERENCE LIST OF MATERIALS STUDIED BY DTA

Prepared Mineral Mixtures

CHEMICALLY TREATED MINERALS AND MIXTURES

Montmorillonite-Na_3AlO_3, HCl, or NH_4OH mixtures, 433
Montmorillonite, *p*-phenylenediamine salt of, 306
Montmorillonite saturated with various cations, 287, 334, 364, 401
Muscovite treated with molten $LiNO_3$, 2009

Nickel-antigorite, 842
Nickel-montmorillonite, 842, 1035
Nontronite-dye complex, 3920

Organic anions-montmorillonite, 3011

Palygorskite, cations fixed on, 401
Peroxide-treated illite, 1724
Piperidine-saturated bentonite, 2807
Piperidine-saturated illite, 1491, 3631
Piperidine-saturated kaolinite, 1491, 3631
Piperidine-saturated montmorillonite, 1491, 3630, 3631
Piperidine-saturated nontronite, 3631
Piperidine-treated clay, 468, 1254
Phenyl-montmorillonite, 1068
Phosphated halloysite, 441
Potassium-bentonite, 1944
Potassium-kaolinite, 1592
Potassium-montmorillonite, 1107, 1601, 3197
Protein-clay, 1006
Pyridine-montmorillonite, 1005

Sodium-montmorillonite, 1076, 1077, 1107, 1735
Sodium-kaolinite, 1402
Sodium-vermiculite, 854
Silver-bentonite, 1035

Vermiculite with sorbed ions, 1883

White coat plaster, 804, 844

Zinc-bentonite, 1035
Zinc-montmorillonite, 1377, 1915

CHEMICALS, CHEMICAL MIXTURES, ARTIFICIALLY PREPARED COMPOUNDS

Acenaphthalene, 1620
Acetamide, 2748
Acetic acid, 3969
Acetone, 3400, 3773
Aconitic acid, 2748
Adipamide-sebacamide series, 3530
Adipamide-terphthalamide series, 3530
Agar, 3431
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FUELS AND CARBONIZATION PRODUCTS

METALS

MINERALS, MINERAL MIXTURES, AND ROCKS

Material	*Composition*	*Reference*
Acanthite	Ag_2S	3559
Achtaragdite	Serpentine + chlorite + garnet	941
Actinolite	$2CaO \cdot 5(Mg, Fe)O \cdot 8SiO_2 \cdot H_2O$	1852, 3549, 3518
Aegirite	Pyroxene group	3518
Aeschynite	$(Ce, Th)(Nb, Ti)_2(O, OH)_6$	780, 3730
Afwillite	$Ca(SiO_3OH)_2 \cdot 2H_2O$	802, 3421
Aksaite	$2MgO \cdot 5B_2O_3 \cdot 8H_2O$	3754
Alabandite	MnS	651, 2020
Albite	$NaAlSi_3O_8$	310, 641, 981, 1335
Allanite	$Ca_2(Al,Ce,Fe)_3OH(SiO_4)_3$	651, 1165, 1702, 1826, 2727, 3095, 3518
Allevardite	Micaceous (phyllitic) silicate	619, 1994, 2814
*Allophane	$Al_2O_3 \cdot SiO_2 \cdot nH_2O$	61, 359, 394, 723, 855, 1087, 1226, 1510, 2543, 3084
Alstonite	$CaBa(CO_3)_2$	609
Aluminite	$Al_2O_3 \cdot SO_3 \cdot 9H_2O$	261, 1530, 2500, 3518
Alumoferroascharite	$(Mg,Fe)(OH)(B,Al)O_2 \cdot aq.$	1947
Alumogen	$Al(SO_4)_3 \cdot 18H_2O$	759, 873
*Alunite	$KAl_3(OH)_6(SO_4)_2$	261, 276, 413, 545, 2825
Alunite clay	———	413, 545, 635
Amarantite	$FeSO_4OH \cdot 3.5H_2O$	873
Amazonite	Syn. of Amazonstone, a var. of Microcline	3929
Amblygonite	$LiAl(F,OH)PO_4$	670, 3518
Amesite	$(Mg_{1.6}Al_{1.0}Fe_{0.4}{}^{2+})$-$(SiAlO_5)(OH)_4$	244, 732, 1371
Amorphous silica	$SiO_2 \cdot nH_2O$	641
Amosite	Amphibole asbestos	1016
Ampangabéite	$(U,etc.)_2(Nb,etc.)_7O_{18}$	1165
Amphibole	See Hornblende.	212, 246, 848, 1027, 1378, 1852, 2998
Analcite (Analcime)	$NaAlSi_2O_6 \cdot H_2O$	724, 1135, 1842, 3518, 3770, 3910
Anatase	TiO_2	1800, 2023
Anauxite	$Al_2Si_2O_5(OH)_4 \cdot SiO_2$	196, 394, 431, 502, 608, 1911
Andalusite	Al_2SiO_5	112, 1957
Andesite	Medium acid rock	2330, 2835
Anglesite	$PbSO_4$	873, 3336, 3518
Anhydrite	$CaSO_4$	308, 621, 651, 3350, 3368, 3518
Ankerite	Magnesiodolomite-ferrodolomite	609, 686, 836, 1330, 1540, 1788, 2197, 2649, 2730, 2854, 3542, 3518
Annabergite	$Ni_3(AsO_4)_2 \cdot 8H_2O$	1646, 3518
Anorthite	$CaAl_2Si_2O_8$	224, 310, 878, 1335
Anorthosite	Mostly labradorite	388
Anthoinite	$Al(WO_4)(OH) \cdot H_2O$	2234

* The asterisk indicates those materials for which only the important references are given.

Material	*Composition*	*Reference*
Anthophyllite	$(Mg,Fe)_7Si_8O_{22}(OH)_2$	331, 507, 1016, 3153, 3429, 3518
*Antigorite	$Mg_6(OH)_8Si_4O_{10}$	135, 188, 435, 912, 961, 1250, 2455
Antimonite	Sb_2S_3	3866
Antlerite	$3CuO \cdot SO_3 \cdot 2H_2O$	3336
Apatite	$Ca_5(F,Cl,OH)(PO_4)_3$	227, 1832, 2192, 2720, 3277, 3518
Aphrosiderite	See Chlorite.	135, 3575
Apophyllite	$KFCa_4(Si_2O_5)_4 \cdot 8H_2O$	119, 120, 3518, 3571
Aragonite	$CaCO_3$	52, 440, 544, 609, 631, 641, 643, 651, 2610, 3518
Arcanite	K_2SO_4	759
Arfvedsonite	See Amphibole.	1852, 3518, 3549
Argentite	Ag_2S	1550, 3404
Argentojarosite	$AgFe_3(OH)_6(SO_4)_2$	656, 1214
Arsenate belovite	$H_2Ca_2Mg(AsO_4)_2(OH,F)_2 \cdot H_2O$	2015
Arsenopyrite	FeAsS	1810, 2165, 2361, 3404, 3866
Artinite	$Mg_2(OH)_2CO_3 \cdot 3H_2O$	410, 609
Ascharite	$Mg_2B_2O_5 \cdot H_2O$	1680
Asbestos	— — —	1739, 3277
Asbophite	See Chrysotile.	217
Askanite	Montmorillonoid?	489
Astrakanite	$MgSO_4 \cdot Na_2SO_4 \cdot 4H_2O$	302, 3518, 3746
Atacamite	$Cu_2Cl(OH)_3$	633, 3336, 3518
*Attapulgite	$(OH_2)_4 \cdot (OH)_2Mg_5Si_8O_{20} \cdot 4H_2O$	371, 394, 679, 740, 2826, 3553
Augelite	$Al_2(OH)_3PO_4$	670, 3518
Aurichalcite	$(Zn,Cu)_5(OH)_6(CO_3)_2$	609, 741, 3336
Autunite	$CaO \cdot 2UO_3 \cdot P_2O_5 \cdot 8H_2O$	2753, 2789, 3188
Axinite	$6(Ca,Fe,Mn)O \cdot 2Al_2O_3 \cdot B_2O_3 \cdot 8SiO_2 \cdot H_2O$	3310, 3518, 3946
Azurite	$Cu_3(OH)_2(CO_3)_2$	609, 651, 741, 3336, 3518
Bakerite	$8CaO \cdot 5B_2O_3 \cdot 6SiO_2 \cdot 6H_2O$	2034
Barbertonite and Stichtite	— — —	609, 3518
Barite	$BaSO_4$	651, 1110, 3287, 3518
Barrandite	$(Fe,Al)PO_4 \cdot 2H_2O$	4005
Basalt	Extrusive basic magma	2002, 2835, 3405
Bassanite	$CaSO_4 \cdot 0.5H_2O$	4064
Bastnasite	$(Ce,La,Dy)FCO_3$	609, 1105, 3518
*Bauxite	Aluminum hydroxide mixtures	64, 197, 394, 442, 556, 763, 1118, 1244, 2482, 3252, 3277
Bavalite	See Chlorite.	135, 403
Beaverite	(Pb,Cu,Fe) aluminosilicate	2472, 3336
*Beidellite	$(OH)_4(Si_{6.34} \cdot Al_{1.66},Na_{0.66})$-$Al_{4.34}O_{20}$	266, 325, 328, 394, 1391, 2172, 2348, 2506, 3981
Belyankinite	Manganese-bearing titanate	2274
*Bentonite	Essentially montmorillonite	325, 359, 572, 1227, 1941, 2791, 3213, 3277
Berthierine	See Antigorite.	1759
Berthierite	$FeS \cdot Sb_2S_3$	3866

Material	*Composition*	*Reference*
Berlinite	$AlPO_4$	670, 4005
Bertrandite	$4BeO \cdot 2SiO_2 \cdot H_2O$	3078, 3518
Betafite	$(U,Ca)(Nb,Ta,Ti)_3O_9 \cdot nH_2O$	780, 835, 1165, 1166, 2727, 2730
Betpakdalite	$(CaFe_2H_4(As_2Mo_5O_{26}) \cdot 12H_2O$	3460
Beudantite	$PbFe_3(OH)_6AsO_4 \cdot SO_4$	623
Beyerite	$CaBi_2O_2(CO_3)_2$	609
Bieberite	$CoSO_4 \cdot 7H_2O$	358, 873
Bikitaite	$LiAlSi_2O_6 \cdot H_2O$	2129
Bilibinite	$3(Ca,Pb)O \cdot (U,Th)O_2 \cdot 7UO_2 \cdot 10SiO_2 \cdot 19H_2O$	2393
Bindheimite	Hydrous lead antimonate	3815
Biotite	$H_2K(Mg,Fe)_3(Al,Fe)(SiO_4)_3$	470, 575, 1144, 1242, 1252, 1359
Birnessite	MnO_2	3595
Birunite	$8.5CaSiO_3 \cdot 8.5CaCO_3 \cdot CaSO_4 \cdot 15H_2O$	2039
Bischofite	$MgCl_2 \cdot 6H_2O$	3518
Bismuthinite	Bi_2S_3	3404
Bismutite	$Bi_2O_2CO_3$	609, 3518
Bismutotantalite	$(Bi,Sb)(Ta,Nb)O_4$	2130
Bixbyite	$(Mn,Fe)_2O_3$	3449
Bloedite	$Na_2O \cdot MgO \cdot 2SO_34 \cdot H_2O$	873, 2086
Blomstrandite	$(Y,Er,Ce,U)(Ti,Nb)_3O_9$	1165
Bobierrite	$Mg_3P_2O_8 \cdot 8H_2O$	346, 670
*Boehmite	$AlO(OH)$	394, 905, 1056, 1059, 1379, 1537, 3766
Bokite	$KAl_3Fe_6V_6^{+4}(V_{20}^{+5}O_{76}) \cdot 30H_2O$	4004
Bolivarite	$Al_2PO_4(OH)_3 \cdot H_2O$	670
Boltwoodite	$K(H_3O)UO_2(SiO_4) \cdot nH_2O$	3506
Boracite	$Mg_7Cl_2B_{16}O_{30}$	1842, 3539
Borax	$Na_2B_4O_7 \cdot 10H_2O$	291, 1502, 1770, 2034, 2836
Borickite	Hydrated phosphate of Ca and Fe	2680, 3481
Bornite	Cu_4FeS_4	634, 1810
Bosphorite	$Fe_9(PO_4)_6(OH)_9 \cdot 21H_2O$	2340
Botryogen	$MgFe(SO_4)_2OH \cdot 7H_2O$	873
Botryolite	Var. of datolite	3518
Boussingaultite	$(NH_4)_2Mg(SO_4)_2 \cdot 6H_2O$	873
Bowenite	See Serpentine.	383
Bowlingite	See Saponite.	189, 279, 739
Brannerite	Complex uranium-containing mineral	3020, 3625
Braunite	$(Mn,Si)_2O_3$	651, 657, 1723, 2428, 3449, 3518
Bravaisite	Illite (?) and some montmorillonite	431, 771
Breunnerite		609, 686, 892, 3518
Brewsterite	$(Sr,Ba,Ca)O \cdot Al_2O_3 \cdot 6SiO_2 \cdot 5H_2O$	3910
Brochantite	$CuSO_4(OH)_6$	873, 3336
Bronzite	Ferriferous enstatite	4045

Material	*Composition*	*Reference*
Brookite	TiO_2	3634
Brucite	$Mg(OH)_2$	121, 295, 394, 502, 651, 854, 1399, 2159, 3277, 3518
Brugnatellite	$Mg_6Fe(OH)_{13}CO_3 \cdot 4H_2O$	344
Brushite	$CaHPO_4 \cdot 2H_2O$	1899
Calamine	$H_2Zn_2SiO_5$	651, 3518
Calcite	$CaCO_3$	68, 74, 98, 544, 643, 846, 2159, 2316, 2532, 3063
Caledonite	$Cu_2PB_5(SO_4)_3CO_3(OH)_6$	873
Cancrinite	$Na_6Ca_2(SiAlO_4)_6(CO_3)_2$	174, 3518
Carbocernaite	Calcareous rare-earth carbonate	3417
Carnallite	$KMgCl_3 \cdot 6H_2O$	302, 2519, 3518, 3746
Carphosiderite	$Fe_3(SO_4)_2(OH)_5 \cdot 2H_2O$	873
Catapleite	$Na_2Zr(Si_3O_9) \cdot H_2O$	1842
Celadonite	Glauconite	325, 771, 999, 1252, 1359, 1880, 3156, 3510, 3518, 3575
Celestite	$SrSO_4$	651, 2516, 3518
Ceruleolactite	Ca analog of turquois	3246
Cerussite	$PbCO_3$	52, 440, 609, 643, 651, 1266, 1701, 2320, 3269, 3336, 3518, 3979
Cervantite	Sb_2O_4	1020
Chabazite	$CaAl_2Si_4O_{12} \cdot 6H_2O$	1135, 1146, 2369, 3518, 3910, 3921
Chalcanthite	$CuSO_4 \cdot 5H_2O$	358, 873
Chalcedony	SiO_2	799, 1565, 2809, 2954
Chalcocite	Cu_2S	2650, 3404
Chalcopyrite	$CuFeS_2$	1427, 1550, 2165, 2650, 3404, 3866
Chambersite	$Mn_3B_7O_{13}Cl$	3820
Chamosite	See Chlorite.	539, 730, 1001, 1455, 1937, 2207, 2236, 2829, 3002
Chlorargyrite	AgCl	854
*Chlorite	$(Mg,Fe,Al)_6(OH)_8(Si,Al)_4O_{10}$	128, 537, 681, 1259, 2316, 2678
Chloropal	See Nontronite.	948
Chlorophaeite	Mg,Fe aluminosilicate	1951
Chrome-illite	— — —	1888, 2481
Chrome ore	— — —	1931, 3364, 3732
Chromite	$Fe(Cr,Fe)_2O_4$	446, 892, 3518
Chryscolla	$CuSiO_3 \cdot nH_2O$	626, 651, 833, 2314, 3336, 3518
Chrysotile	$(OH)_6Mg_6SiO_4O_{11} \cdot H_2O$	121, 130, 183, 279, 961, 1341, 1359, 1648, 1903, 2000, 2145, 3518, 3584
Chukhrovite	Rare-earth Ca aluminosilicate	3096
Churchite	Rare-earth phosphate	3234
Cimolite	$Al_4Si_9O_{24} \cdot 6H_2O$	325
Cinnabar	HgS	1425
Clausthalite	PbSe	3453
Clinochlore	See Chlorite.	135, 617, 797, 1367, 1608, 3518, 3575

Material	*Composition*	*Reference*
Clinoenstatite	$MgSiO_3$	3044
Clinoptilolite	Complex alkali-alkaline earth aluminosilicate	3207, 3222, 3893
Clinozoisite	$4CaO \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot H_2O$	2499
Cobaltite	CoAsS	1550, 1810, 2361
Coffinite	U silicate	3366
Colemanite	$2CaO \cdot 3B_2O_3 \cdot 5H_2O$	358, 2034, 2836
Collyrite	$Al_4SiO_8 \cdot 9H_2O$	325
Columbite	$(Fe,Mn)O \cdot (Nb,Ta)_2O_5$	2727
Conichalcite	$CaCu(AsO_4)(OH)$	3783
Cookeite	Structure similar to that of chlorite	1101, 1457, 3313, 3518
Copiapite	$MgFe_4(SO_4)_6(OH)_2 \cdot 18H_2O$	873, 3157, 3518
Coquimbite	$Fe_2(SO_4)_3 \cdot 9H_2O$	873, 3762
Cordierite	$Mg_2Al_3(AlSi_5O_{18})$	1125, 2964, 3295
Coronadite	Var. of hollandite	3125, 3518
Corrensite	Chlorite-vermiculite	1345, 1750, 2859, 3518, 3617
Corundophilite	Type of chlorite	1608
Corundum	Al_2O_3	2853
Covellite	CuS	1266, 1550, 1761, 1809, 1810, 2650, 3404
Creedite	$Ca_3Al_2(SO_4)F,OH)_{10} \cdot 2H_2O$	889, 1081, 3518
Crestmoreite	$2CaSiO_3 \cdot 3H_2O$	651
*Cristobalite	SiO_2	1141, 1522, 1795, 2088, 2102, 2263, 2449, 2666, 3473
Crocidolite	Amphibole asbestos	1016, 3434, 3518, 4038
Cronstedite	See Chlorite.	674, 1883
Cryolite	Na_3AlF_6	651, 2836, 3518
Cryptomelane	$K(Mn,Zn,Co)_8O_{16}$	504, 1484, 1997, 2428, 2448, 3239, 3449, 3595, 3830
Cumingtonite	$(Mg,Fe)_7Si_8O_{22}(OH)_2$	1471
Cuspidine	$3CaO \cdot 2SiO_2 \cdot CaF_2$	2657
Cyanotrichite	$Cu_4Al_2(SO_4)(OH)_{12} \cdot 2H_2O$	3452
Cyrtolite	$Zr(SiO_4)_{1-x}(OH)_{4x}$	1097
Danburite	$CaO \cdot B_2O_3 \cdot 2SiO_2$	3145, 3518
Dannemorite	$(Fe_3Mn_2Mg_2)(OH)_2Si_8O_{22}$	3879
Daphnite	$27FeO \cdot 10Al_2O_3 \cdot 18SiO_2 \cdot 28H_2O$	3518
Datolite	$2CaO \cdot 2SiO_2 \cdot B_2O_3 \cdot H_2O$	2800, 3518, 3664
Davidite	$Fe^{2+}(Fe^{3+},Ce)_2Ti_6O_{17}$	780, 2727, 2730, 3610
Dawsonite	$NaAl(OH)_2CO_3$	609
Deweylite	$Mg_3(OH)_4Si_2O_5$ — surplus water	651, 784, 1851, 2830, 3518, 3558, 3791
Diabase	Medium acid rock	2330
Diamond	— — —	1387
*Diaspore	AlO(OH)	103, 295, 359, 388, 905, 998, 1399
Diatomaceous earth	SiO_2	412, 1182, 3727
*Dickite	$Al_4(OH)_8Si_4O_{10}$	196, 266, 394, 828, 2213, 2287, 2935, 3784
Dillnite	Hydrated aluminosilicate	1581

Material	*Composition*	*Reference*
Diopside	$CaMgSi_2O_6$	1034, 1977
Dioptase	$Cu_3Si_3O_9 \cdot 3H_2O$	397, 2314, 3518
Diorite	Medium acid rock	2835
*Dolomite	$CaMg(CO_3)_2$	341, 367, 378, 440, 459, 609, 724, 762, 1046, 1523, 2112, 2627, 3186, 3277, 3740
Donbassite	$Al_2(OH)_2SiO_4$(?)	659, 3518
Dufrenite	$Fe,Fe_4(OH)_5(PO_4)_3 \cdot 2H_2O$	651
Edingtonite	$BaO \cdot Al_2O_3 \cdot 3SiO_2 \cdot 3H_2O$	3910
Ehlite	$5CuO \cdot P_2O_5 \cdot 3H_2O$	624, 1004
Ekmanite	$(Fe,Mn,Mg)O \cdot SiO_2 \cdot H_2O$	1367
Ellsworthite	U — pyrochlore	780, 930, 2174
Endellite	Hydrated halloysite	359, 480, 502, 614, 1190, 1510, 2693, 2848, 3557
Enstatite	$MgSiO_3$	102
Epididymite	$Na[BeSi_3O_7(OH)]$	2279, 3854
Epidote	$Ca_2(Al,Fe)_3OH(SiO_4)_3$	1811, 2498, 2727, 3518
Epistilbite	Zeolite	1135
Epistolite	$5Na_2O \cdot 2Nb_2O_5 \cdot 9(Si,Ti)O_2 \cdot 10H_2O$	3666
Epsomite	$MgSO_4 \cdot 7H_2O$	714, 759, 854, 873, 2915, 3518
Erythrite	$Co_3(AsO_4)_2 \cdot 8H_2O$	1646, 3518
Eschynite	$2(Ca,Fe)O \cdot 2Ce_2O_3 \cdot 8TiO_2 \cdot 3Nb_2O_5$	780, 1165, 2174
Ettringite	$3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$	1432, 1753, 3883
Eudidymite	$HNaBeSi_3O_8$	3854
Euxenite	Niobate and titanate of Y, Er,Ce,U,etc.	780, 1165, 1702, 2174, 2730
Evansite	$[Al(OH)_2]_6(PO_4)_2 \cdot 12H_2O$(?)	670
Ezcurrite	$2Na_2O \cdot 5B_2O_3 \cdot 7H_2O$	2211
Faratsihite	Ferriferrous kaolinite (?) or nontronite (?)	363, 431
Faujasite	$Na_2CaAl_4Si_{10}O_{28} \cdot 20H_2O$	1738, 3910
Fayalite	Fe_2SiO_4	4045
Feldspar	Akali or alkaline earth aluminum silicate	708, 790, 1232, 2861, 3365
Fenghuanite	Metamict apatite-like mineral	3911
Ferberite	$FeWO_4$	3518
Fergusonite	$(Y,Er,Ce,Fe)(Nb,Ta,Ti)O_4$	780, 930, 1165, 1702, 1907, 2174, 3097, 3129
Ferrihalloysite	See Halloysite.	288
Ferrimolybdite	$Fe_2(MoO_4)_3 \cdot nH_2O$	4044
Ferroselite	FeS_2	3404
Fersmite	$CaNb_2O_6$	4051
Fibroferrite	$Fe(SO_4)(OH) \cdot 4.5H_2O$	1215, 2106, 2785, 3518
*Fireclay	Essentially $Al_4(OH)_8Si_4O_{10}$	90, 325, 369, 394, 493, 500, 758, 905, 2081, 2316

Material	*Composition*	*Reference*
Fleischerite	$Pb_3Ge(OH)_4(SO_4)_2 \cdot 4H_2O$	3113
Fluroapatite	See Apatite.	942
Fluroite	CaF_2	651, 1821, 2048, 3518
Flurophlogopite	$KMg_3(Si_3AlO_{10})F_2$	1717, 3228
Foucherite	$Ca_3Fe_5(OH)_6(PO_4)_6 \cdot$ 5–6$Fe(OH)_3 \cdot$ 21–23H_2O	2340, 2680
Francevillite	$(Ba,Pb)(UO_2)_2(VO_4)_2 \cdot 5H_2O$	2062
Francolite	Carbonate apatite	942, 3230
Friedelite	$Mn_8Si_6O_{14}(OH,Cl)_{10}$	3836
Frovolite	$CaO \cdot B_2O_3 \cdot 3.5H_2O$	2250
Fuchsite	Cr mica	3518
Fuller's earth	Hydrous aluminum silicates	380, 394, 1063, 3215
Gadolinite	$(OBeSiO_4)_2Y_2Fe$	1165, 1399, 1907, 3518
Gahnite	Zn spinel	3518
Galapektite	See montmorillonite	2098
Galena	PbS	2545, 3061, 3453
Gargarinite	$Na_2Ca_2Y_3(F,Cl,OH)_{15} \cdot H_2O$	3680
Garnet	*e.g.*, $Ca_3Fe_2Si_3O_{12}$	522, 3963
Garnierite	$(Ni,Mg)_6(OH)_6Si_4O_{11} \cdot H_2O$	190, 640, 2350, 2830, 3518
Gaylussite	$Na_2Ca(CO_3)_2 \cdot 5H_2O$	609
Gearksutite	$2CaF_2 \cdot 3Al_2(OH,F)_6 \cdot 2H_2O$	755, 2631, 3175, 3518
Gedroizite	High alkali, Mg-free vermiculite	313
Gerasimovskite	Nb-bearing titanate	2274
Gersdorffite	NiAsS	3866
*Gibbsite	$Al(OH)_3$	266, 295, 386, 394, 854, 1011, 1048, 1059, 1516, 2142, 2607, 2943, 3321, 3409
Ginorite	Ca borate hydrate	2034
Giorgiosite	Similar to hydromagnesite	343
Gismondite	$CaO \cdot Al_2O_3 \cdot 4SiO_2 \cdot 4H_2O$	3910
Glaserite	$(K,Na)_2SO_4$	302
Glauberite	$Na_2Ca(SO_4)_2$	873, 3518
*Glauconite	$K(Mg,Fe)(Al,Fe)(OH)_2 \cdot Si_4O_{10} + K(Al,Fe)Al(OH)_2Si_3AlO_{10}$	757, 1316, 1317, 2354, 2656, 2895, 3277
Glaucophane	$\begin{bmatrix} Na_2Mg_3Al_2(OH)_2Si_8O_{22} \\ Na_3Mg_3Al_2(OH)Si_8O_{22} \\ Na_2CaMg_3Al_2O_2Si_8O_{22} \end{bmatrix}$	651
Gmelinite	$Na_2O \cdot CaO \cdot 2Al_2O_3 \cdot 6SiO_2 \cdot 10H_2O$	3910
*Goethite	FeOOH	394, 786, 854, 1399, 2480, 3193, 3277
Gorceixite	$BaAl_6(PO_4)_3(OH)_{11} \cdot nH_2O$	2699
Goslarite	$(Zn,Mg,Mn,Cd)SO_4 \cdot 6.65H_2O$	1512, 3336
Gowerlite	$CaO \cdot 3B_2O_3 \cdot 5H_2O$	2767
Graphite	C	691, 1145
Griffithite	Ferroan saponite	1518
Grochanite	Magnesian prochlorite	244

Material	*Composition*	*Reference*
Grossularite	$Ca_3Al_2(SiO_4)_3$	710, 1346
Guanajuatite	Bi_2S_3	3404
*Gypsum	$CaSO_4 \cdot 2H_2O$	759, 958, 1230, 1446, 2612
Gyrolite	$Ca_4(OH)_2Si_6O_{15} \cdot 3H_2O$	2504, 3033, 3421, 3588
Halite	NaCl	309, 358, 854, 2836, 3518
*Halloysite	$Al_4Si_4O_{10}(OH)_8$	266, 394, 441, 502, 554, 1087, 1190, 1300, 1804, 1843, 2072, 2316, 3277
Halotrichite	$FeAl_2(SO_4)_4 \cdot 24H_2O$	873, 3518
Halurgite	$2MgO \cdot 4B_2O_3 \cdot 5H_2O$	3871
Hanksite	$Na_{22}K(SO_4)_9(CO_3)_2Cl$	873
Harmotome	$2BaO \cdot K_2O \cdot 3Al_2O_3 \cdot 26SiO_2 \cdot 20H_2O$	3518, 3910
Hastingite	$(Ca,Na,K)_3(Fe^{2+},Fe^{3+})_5$-$(Si,Al)_8O_{22}(OH)_2$	848, 1027, 3518
Hauerite	MnS_2	1810, 3237
Hausmannite	$MnMn_2O_4$	651, 657, 1723, 2428, 2660, 3449, 3518, 3748
Hectorite	$(OH)_4Si_8(Mg_{5.34}Li,Na_{0.66})$-$O_{20}$	328, 437, 502, 520, 560, 771, 1196, 1359, 1840, 2771
Hematite	Fe_2O_3	227, 359, 482, 538, 641, 2066, 2862, 3193, 3277, 3518, 3733
Hemimorphite	$(OH)_2Zn_4Si_2O_7 \cdot H_2O$	746, 1936, 2344, 3336
Hetite	Hydrated iron oxide	126
Heulandite	$(Ca,Na,K)_6Al_{10}(Al,Si)Si_{29}$-$O_{80} \cdot 25H_2O$	119, 1135, 1336, 3222, 3309, 3518, 3893, 3910, 3921
Hibschite	$Ca_3Al_2(SiO_4)_2(OH)_4$	3229
Hillebrandite	$Ca_2SiO_4 \cdot H_2O$	651, 2646, 2985, 3233, 3518
Hisingerite	$2SiO_2 \cdot Fe_2O_3 \cdot nH_2O$ (canbyite?)	1000, 1001, 2221, 3518, 3718
Hoeferite	$2Na_2O \cdot 5B_2O_3 \cdot 4H_2O$	3436, 3437
Hoernsite	$3MgO \cdot As_2O_5 \cdot 8H_2O$	1646
Hollandite	$Ba(Mn,Co)_8O_{16}$	651, 3449
Holmquistite	Li aluminosilicate	3272, 3518
Hornblende	$Ca_2(Mg,Fe)_4Al(OH)_2 \cdot AlSi_7O_{22}$ + $Ca_2Na(Mg,Fe)_4Al(OH)_2$-$(Al_2Si_6O_{22})$	641, 1852, 3277, 3518, 3549
Howlite	$4CaO \cdot 5B_2O_3 \cdot 2SiO_2 \cdot 5H_2O$	2034
Huebnerite	$MnWO_4$	3518
Humboldtine	$FeC_2O_4 \cdot 1.5H_2O$	1367
Huntite	$Mg_3Ca(CO_3)_4$	1085, 2041, 2705, 2756, 3518
Hureaulite	$5MnO \cdot 2P_2O_5 \cdot 5H_2O$	3082
Huttonite	Fe, Mn rare-earth complex	3853
Hydralsite	Hydrous aluminosilicate	1397
*Hydrargillite	See Gibbsite.	1537, 2930, 2989, 4046
Hydrated halloysite	$Al_4Si_4O_{10}(OH)_8 \cdot 4H_2O$	325, 334, 369, 1001, 1002, 1423, 1975, 2826
Hydrated iron oxide	— — —	250, 295, 325, 641
Hydrobiotite	Interlayer mixture of biotite and vermiculite	843, 3401, 3440

Material	*Composition*	*Reference*
Hydroboracite	$CaMgB_6O_{11} \cdot 6H_2O$	358
Hydrocerussite	$Pb_3(OH)_2(CO_3)$	609
Hydrogarnet	$3CaO \cdot Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	299
Hydrogoethite	— — —	641, 2724
Hydrohematite	— — —	126, 641
Hydronasturan	Pb-bearing uranium mineral	3482
Hydrous mica	See Illite.	250, 260, 641, 1102, 1340, 1549, 1988, 2157, 35677
Hydromagnesite	$Mg_5(OH)_2(CO_3)_4 \cdot 4H_2O$	609, 840
Hydrotalcite	$Mg_6Al_2(OH)_{16}CO_3 \cdot 4H_2O$	143, 361, 362, 609, 3518
Hydrozincite	$Zn_5(OH)_6(CO_3)_2$	609, 651, 741, 2344, 2682, 2741, 3518
Ianthinite	$UO_2 \cdot 5UO_3 \cdot 10.6H_2O$	2793
*Illite	$(OH)_4K_y(Al_4 \cdot Mg_4 \cdot Mg_6)$-$(Si_{8-y} \cdot Al_y)O_{20}$	225, 266, 325, 369, 394, 444, 1558, 2487, 3277, 3464
Illite-montmorillonite	— — —	917, 1495
Ilmenite	$FeTiO_3$	2005, 3518
Inderite	$Mg_2B_6O_{11} \cdot 15H_2O$	358
Innelite	Complex Ba silicate	3550
Inyoite	$2CaO \cdot B_2O_3 \cdot 13H_2O$	1162
Iodargyrite	AgI	854
Iriginite	See moluranite	2766
Iron ore	— — —	1564, 1919, 1926, 2079, 2187, 3355
Ishkyldite	$H_{20}Mg_{15}Si_{11}O_{47}$ (a chrysotile)	205, 222
Istisuite	$(Na,Ca)_7(Si,Al)_8O_{20}(OH)_3$	1563
Itotite	$Pb_3[GeO_2(OH)_2](SO_4)_2$	3113
Jamesonite	$4PbS \cdot FeS \cdot 3Sb_2S_3$	3866
Jarosite	$KF_3(OH)_6(SO_4)_2$	502, 559, 656, 820, 1214, 1257, 1280, 1509, 2006, 2106, 2417, 2839, 3518
Jefferisite	See Vermiculite.	575, 1359, 1799, 3518
Johannsenite	$MnCaSi_2O_6$	1195
Jordanite	Pb arsenate	2447
Kainite	$MgSO_4 \cdot KCl \cdot 3H_2O$	302, 2470
Kaliborite	$KMg_2B_{22}O_{19} \cdot 15H_2O$	358
Kalinite	$KAl(SO_4)_2 \cdot 12H_2O$	2090
Kalistrontite	$K_2Sr(SO_4)_2$	3973
*Kaolin, Kaolinite	$(OH)_8Si_4Al_4O_{10}$ (theoretical)	266, 325, 350, 418, 441, 450, 502, 506, 549, 568, 862, 1041, 1096, 1122, 1140, 1147, 1190, 1300, 1399, 1417, 1490, 1661, 1688, 1804, 1808, 1843, 1883, 2055, 2072, 2339, 2487, 2638, 2732, 2913, 2975, 3201, 3331, 3570, 3672, 3699
Kaolin-illite	— — —	602

Material	*Composition*	*Reference*
Karpinskite	$(Mg,Ni)_2Si_2O_4(OH)_2$	1938
Karpinskyite	$Na_2(Be,Zn,Mg)Al_2Si_6O_{16}$-$(OH)_2$	1952
Kerchenite	Fe phosphate	1766, 2340, 2459, 3518
Kernite	$Na_2O \cdot 2B_2O_3 \cdot 4H_2O$	2034, 2836
Kerolite	MgH_2SiO_4	640, 809, 1685, 1938, 2694, 3518, 3591
Kieserite	$MgSO_4 \cdot H_2O$	873
Kingite	Al phosphate hydrate	2235
Kischtymite	Hydroxyl bastnasite (?)	609
Klockmannite	CuSe	3404
Kobellite	$6PbS \cdot 2Bi_2S_3 \cdot Fe_2S$	3866
Koettigite	$3ZnO \cdot As_2O_5 \cdot 8H_2O$	1646
Kotschubeite	See Chlorite.	135, 2514
Kröhnkite	$Na_2Cu(SO_4)_2 \cdot 2H_2O$	873
Kruzhanovskite	$(Mn,Ca,Mg)Fe_2O_3 \cdot P_2O_5 \cdot 2H_2O$	639
Kukersite	Carbonaceous alumino-silicate	1072
Kupletskite	$(K,Na)_2(Fe,Mn)_4(Ti,Zr)(Si_4O_{14})(OH,F)_2$	1945
Kurgantaite	Strontium Borate	1033
Kurskite	Carbonate apatite	2340
Kutnahorite	$CaMn(CO_3)_2$	1524, 3542
Kyanite	Al_2SiO_5	112, 1957
Labradorite	Lime-soda feldspar	1335
Langbeinite	$K_2Mg_2(SO_4)_3$	358
Langite	$Cu_4(SO_4)(OH)_6 \cdot H_2O$	873
Lansfordite	$MgCO_3 \cdot 5H_2O$	609
Laterite	Contains aluminum and iron hydroxides	197, 651, 1216, 1579, 2001, 3461
Laumonite	Zeolite	1135, 2840, 3518, 3910
Lawsonite	$CaAl_2(Si_2O_7)(OH)_2 \cdot H_2O$	834
Lazulite	$MgAl_2(PO_4)_2(OH)_2$	670, 1428, 3518
Leadhillite	$Pb_4(OH)_2(CO_3)_2SO_4$	609
Leonite	$MgSO_4 \cdot K_2SO_4 \cdot 4H_2O$	302, 358
Lepidocrocite	FeO(OH)	126, 359, 786, 991, 1693, 1701, 1774, 1937, 2381, 2752, 3193
Lepidolite	$K_2Li_3Al_3(F,OH)_4(AlSi_3O_{10})_2$	575, 1252, 1883, 1984, 3082, 3518
Lepidomelane	Trioctahedral mica	1252, 3518
Leuchtenbergite	See Chlorite.	135, 244, 288, 1608, 2237, 2621, 3518
Leucite	$KAlSiO_4$	1842
Leucophosphite	$KF_2(PO_4)_2(OH) \cdot 2H_2O$	4005
Leverrierite	Illite group	1671
Levynite	$CaO \cdot Al_2O_3 \cdot 3SiO_2 \cdot 5H_2O$	3910
Liebigite	$Ca_2U(CO_3)_4 \cdot 10H_2O$	609
Limestone	$CaCO_3$	256, 513, 557, 644, 1022, 1088, 1266, 1374
*Limonite	$Fe_2O_3 \cdot nH_2O$	394, 479, 897, 2225, 3277

Material	*Composition*	*Reference*
Linarite	$PbO \cdot CuO \cdot SO_3 \cdot H_2O$	3336, 3518
Lithiophorite	$LiMn_3Al_2O_9 \cdot 3H_2O$	3449
Lithiophyllite	$Li(Fe,Mn)PO_4$	651
Loellingite	$FeAs_2$	2361
Loess	— — —	870, 991, 1274, 1407, 1408, 1670, 1672, 2695, 3195
Loewigite	Alkaline sulfoaluminate	1017, 1214
Lomonosovite	$Na_2Ti_2Si_2O_9 \cdot Na_3PO_4$	638, 3666
Loparite	Rare-earth titanate	3731
Loranskite	See gadolinite	3463
Ludwigite	$(Mg,Fe)_2FeBO_5$	2123
Lueneburgite	$3MgO \cdot B_2O_3 \cdot P_2O_5 \cdot 8H_2O$	3518
Maghemite	γ-Fe_2O_3	2618, 2640, 2941, 2942
*Magnesite	$MgCO_3$	609, 1416, 2159, 2316, 3063, 3277
Magnesium clay	— — —	266
Magnesium monothermite	— — —	581
Magnetite	$(Fe,Mn,Zn,Mg)Fe_2O_4$	227, 1668, 2186, 3277, 3287, 3518
Malachite	$Cu_2(OH)_2CO_3$	609, 741, 3336, 3518
Manasseite	$Mg_6Al_2(OH)_{16}CO_3 \cdot 4H_2O$	609
Manganese ores	— — —	628, 2051
Manganite	$MnO(OH)$	142, 198, 295, 657, 1188, 1723, 1786, 2448, 3449, 3518
Mansfieldite	Isomorphous with scorodite	1257
Marcasite	FeS_2	369, 1810, 2496, 2650
Margarite	$CaAl_4Si_2O_{10}(OH)_2$	1252, 1531
Marl	Argillaceous calcareous rock	2874, 3303, 3359, 3615, 3671
Marmatite	$ZnO \cdot Fe_2O_3$	1643
Mascagnite	$(NH_4)_2SO_4$	873
Matilidite	$Ag_2S \cdot Bi_2S_3$	3404
Mauritzite	See montmorillonite	2311
Medmontite	Copper-bearing montmorillonite	625
Meerschaum	See Sepiolite.	359
Melanterite	$FeSO_4 \cdot 7H_2O$	1215, 1684, 2417, 3518
Melaphyre	Porphyritic rock	2331, 3000
Mesolite	$Ca_2Na_2Al_6Si_9O_{30} \cdot 8H_2O$	1135, 1639, 3910
Metabentonite	K bentonite	524, 721, 1022
Metahalloysite	See Halloysite.	612, 620, 771, 991
Metavoltine	$K_5Fe_3(SO_4)_6(OH)_2 \cdot 8H_2O$	873
Meyerhofferite	$2CaO \cdot 3B_2O_3 \cdot 7H_2O$	2034
Miargyrite	$3Ag_2S \cdot Sb_2S_3$	3404
Mica	See Muscovite.	119, 309, 335, 426, 606, 691, 1199, 1976, 2487, 3399
Michernerite	BiTe	4032
Microcline	$K_2O \cdot Al_2O_3 \cdot 6SiO_2$	2381
Microlite	$(Na,Ca)_2(Ta,Nb)_2O_4$-(O,OH,F)	780, 930
Miersite	$CuI \cdot 4AgI$	3518
Millerite	NiS	2361

Material	*Composition*	*Reference*
Mimetite	$9PbO \cdot 3As_2O_5 \cdot PbCl_2$	3518
Mirabilite	$Na_2SO_4 \cdot 10H_2O$	3518
Mitridatite	$Ca_4Fe_5(OH)_5(PO_4)_6 \cdot 1.5Fe(OH)_3 \cdot 5.5H_2O$	2340, 2680
Molybdenite	MoS_2	2024, 2585, 3404
Moluranite	$UO_2 \cdot 3UO_3 \cdot 7MoO_3 \cdot 20H_2O$	2766
Monazite	$(Ce,La,Di)_2O_3 \cdot P_2O_5$	2509, 2884, 3518
Monheimite	Var. of smithsonite	3518
Montebrasite	$Al_2O_3 \cdot P_2O_5 \cdot 2Li(OH,F)$	3518
Moraesite	$Be_2PO_4(OH) \cdot 4H_2O$	4060
Morinite	$Ca_4Na_2Al_2(AlOF_3)_2(PO_4)_4 \cdot 5H_2O$	3105
Monothermite	Illite-type clay	579, 580, 641, 745, 779, 1982, 2249, 2575, 3512, 3518
*Montmorillonite	$(OH)_4Si_8(Al_{3.34} \cdot Mg,Na_{0.66})O_{20}$	325, 351, 364, 393, 471, 568, 1107, 1376, 1558, 1688, 2487, 2529, 2826, 3480, 3492
Montroseite	$VO(OH)$	3410
Mordenite	$(Ca,K_2,Na_2)Al_2Si_{10}O_{24} \cdot 7H_2O$	1135, 3910
Morenosite	$NiSO_4 \cdot 7H_2O$	358
Moresnetite	A mixture containing sauconite	746, 2093
Mountainite	$(Ca,Na_2,K_2)_{16}Si_{32}O_{80} \cdot 24H_2O$	2108
Mourite	U, Mo complex	3852
Murmanite	$2Na_2O \cdot (Fe,Mg,Ca)O \cdot 4SiO_2 \cdot 4(Ti,Zr)O_2 \cdot 4H_2O$	3666
*Muscovite	$K_2(Al,Fe,Mg)_4(OH)_4(Si,Al)_8O_{20}$	2099, 2126, 2649
Nacleodovite	Pb alkaline earth aluminocarbonate	2420
Nacrite	$HNaCO_3$	182, 226, 266, 771, 2312
Nahcolite	$(Na,K)Al_3(OH)_6(SO_4)_2$	609
Nasinite	$2Na_2O \cdot 5B_2O_3 \cdot 7H_2O$	3437
Natroalunite	$Na_2Al_2Si_3O_{10} \cdot 2H_2O$	413, 414, 1214, 1470, 1772
Natrochalchite	$NaCu_2(SO_4)_2OH \cdot H_2O$	873
Natrolite	See Brucite.	724, 928, 1135, 1639, 3518, 3910
Naumannite	Ag_2Se	3404
Nefedyevite	Mg aluminosilicate	3057
Nemalite	Hydrous silicate of Mn, containing Mg,Fe,Ca	121, 3518
Nenadkevite	U-bearing silicate	2253
Neotocite	$NaAlSiO_4$	1202, 3023, 3718
Nephelite	$MgCO_3 \cdot 3H_2O$	267, 3000
Nephrite	See Amphibole.	1852
Nepouite	$3(Ni,Mg)O \cdot 2SiO_2 \cdot 2H_2O$	3518
Nesquehonite	$HMgPO_4 \cdot 3H_2O$	609, 2760
Newberyite	$(Ca,Zn)CO_3$	1704
Niccolite	$NiAs$	2361

Material	*Composition*	*Reference*
Nicholsonite	— — —	609
Nickel ore	$(OH)_4(Si_{7.34}\cdot Al,Na_{0.66})$-$Fe_4^{3+}O_{20}$	651, 3076
Nifontovite	$CaO\cdot B_2O_3\cdot 2.3H_2O$	3574
Nitratine	$NaNO_3$	854
Nitrocalcite	$Ca(NO_3)_2\cdot 4H_2O$	854, 2089
*Nontronite	$H_4Fe_2Si_2O_9$	163, 394, 458, 948, 2357, 2826
Nouméite	Siliceous nickel ore	190
Novaculite	SiO_2	651
Nsutite	Mn oxide-hydroxide	4002
Obruchevite	Metamict Ta-Nb complex	2143
Obsidian	Volcanic glass	651, 1422
Oligoclase	Soda-lime feldspar	1335
Oligonite	Mn-Fe mineral	3433
Olivenite	$4CuO\cdot As_2O_5\cdot H_2O$	3518
Olivine	$(Mg,Fe,Mn)_2SiO_4$	651, 2036, 3000, 3169, 3851, 4045
Opal	SiO_2	928, 1606, 2776, 2809, 3277, 3727
Orcelite	Ni_2As	2742
Orthoclase	$KAlSi_3O_8$	234
Osarizawaite	Var. of alunite	3689
Palagonite	See Phlogopite.	1801
Palygorskite	Similar to attapulgite and sepiolite	121, 179, 212, 288, 384, 400, 431, 676, 736, 740, 1233, 1359, 1415, 1731, 2024, 2194, 3951
Pandermite	$4CaO\cdot 5B_2O_3\cdot 7.6H_2O$	511, 2730
Paragasite	See Amphibole	1852, 3549
Paragonite	$NaAl_2(OH)_2AlSi_3O_{10}$	1252, 1773, 2422, 3518
Paratacamite	$Cu_2Cl(OH)_3$	633
Paravauxite	$FeAl_2(PO_4)_2\cdot 8H_2O$	3822
Pentlandite	(Fe,Ni)S	1427, 3844
Peridotite	Rock containing ferro-magnesian minerals	199
Perlite	Volcanic glass	651, 925, 2389, 3997
Petalite	$LiAl(Si_2O_5)_2$	267, 3518
Petzite	Ag_3AuTe_3	2780
Phillipsite	$(Na,K)_2O\cdot CaO\cdot 2Al_2O_3\cdot$-$6SiO_2\cdot 8H_2O$	3910
Pholerite	See Kaolinite.	168, 335
Phlogopite	$Mg_3KAlSi_3O_{10}(OH,F)_2$	1252, 1801, 2542, 3518
Phonolite	Medium acid rock	2330
Phosgenite	$Pb_2Cl_2CO_3$	609
Phosphate rock	— — —	651
Phosphorite	Massive apatite	227
Phosphosiderite	$FePO_4\cdot 2H_2O$	4005
Phosphotridymite	— — —	4005
Phosphouranylite	$3UO_3\cdot P_2O_5\cdot 6H_3O$	2753
Phyllite	Scaly minerals (French)	534, 782, 814
Pickeringite	$MgAl_2(SO_4)_4\cdot 22H_2O$	873
Picotite	Chrome spinel	1674

Material	*Composition*	*Reference*
Picrolite	Serpentine mineral	279, 3518
Picromerite	$K_2Mg(SO_4)_2 \cdot 6H_2O$	873
Picropharmacolite	$3(Ca,Mg)O \cdot As_2O_5 \cdot 6H_2O$	3518, 3620
Pinnoite	$MgB_2O_4 \cdot 3H_2O$	358
Pisanite	$(Fe,Cu)SO_4 \cdot 7H_2O$	873
Pistomesite	$MgCO_3$ — $FeCO_3$	609
Planchéite	Cu silicate hydrate	2314
Planerite	$3Al_2O_3 \cdot 2P_2O_5 \cdot nH_2O$	3426
Plattnerite	PbO_2	3336
Plumbian dolomite	— — —	2131
Plumbojarosite	$Pb[Fe_3(OH)_6(SO_4)_2]_2$	656, 1214, 1280, 1440, 2149
Plumbolimonite	— — —	2664
Polianite	MnO_2	1260
Polycrase	(Y,Ca,Ce,U,Th)-(Ti,Nb,Ta)$_2$O$_6$	780, 960, 2029
Polyhalite	$K_2MgCa_2(SO_4)_4 \cdot 2H_2O$	873, 3518, 4054
Potash clay	Similar to illite and or montmorillonite	266
Powellite	$CaO \cdot (Mo,W)O_3$	3518
Prehnite	$Ca_2Al_2Si_3O_{10}(OH)_2$	309, 3518
Preobrazhenskite	$3MgO \cdot 5V_2O_3 \cdot 4.5H_2O$	2017
Priceite	$Ca_5B_{12}O_{23} \cdot 9H_2O$	243, 358, 2034
Priorite	— — —	780, 2334, 3176
Probertite	$Na_2O \cdot 2CaO \cdot 5B_2O_3 \cdot 10H_2O$	2034
Prochlorite	Syn. of Ripidolite	359, 470, 1359, 1608, 3277
Proustite	$3Ag_2S \cdot As_2S_3$	3404
Pseudowavellite and millisite	— — —	647, 1018
Psilomelane	Black hematite	651, 657, 1188, 1723, 3107, 3518,
Ptilolite	Zeolite	1135
Pumice	Volcanic ash	1499, 1846, 2179, 2219, 2821
Pumpellyite	Glaucophane (?)	834
Priorite	$(Y,Er)(Nb,Ti)_2O_6$	1165
*Pyrite	FeS_2	1809, 1810, 2165, 2496, 2650
Pyroaurite and sjogrenite	$Mg_6Fe_2(OH)_{16}CO_3 \cdot 4H_2O$	143, 609, 3518
Pyrochlore	$(Na,Ca)_2(Nb,Ta)_2O_6F$	930, 1764, 3099, 3114, 3667
Pyrochroite	Zn serpentine	2368
Pyrolusite	MnO_2	504, 628, 651, 657, 970, 1188, 1723, 1786, 1997, 2448, 3144, 3190, 3449, 3595
*Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$	145, 245, 266, 394, 763, 1252, 2239, 2316
Pyroxene	*e.g.*, $(Ca,Fe,Mg)SiO_3$	913
Pyrrhotite	$Fe_{1-x}S$	327, 1148, 1266, 1427, 1550, 1810, 2226, 2361, 2650, 3404
*Quartz	SiO_2	50, 80, 108, 129, 137, 140, 360, 370, 375, 484, 494, 711, 763, 815, 887, 922, 943, 1066, 1404, 1645, 1861, 1902, 2722, 3117

Material	*Composition*	*Reference*
Racewinite	$(Al,Fe)_3Si_5O_{16}\cdot 9H_2O$	325
Ralstonite	$(Na_2Mg)F_2\cdot 3Al(F,OH)_3\cdot 2H_2O$	3955
Ramsdellite	MnO_2	504, 657, 1260, 2448, 3485, 3518, 3595
Realgar	AsS	3404
Revdanskite	Ni serpentine	121, 3518
Reyerite	$CaO\cdot 2SiO_2\cdot 0.5H_2O$	3588
Rhabdophane	Var. of monazite	2947
Rhodesite	$(Ca,Na_2,K_2)_8Si_{16}O_{40}\cdot 11H_2O$	2108
Rhodochrosite	$MnCO_3$	52, 440, 502, 561, 609, 637, 651, 1524, 1701, 1786, 1844, 1883, 2242, 3449
Rhodonite	$Mn_2(SiO_3)_2$	1786, 3449, 3518
Rhodusite	Var. glaucophane	3518
Richterite	$(Na,K)_2(Mg,Mn,Ca)_6Si_8O_{22}(OH)_2$	848, 1027, 3518
Riebeckite	$Na_2O\cdot Fe_2O_3\cdot FeO\cdot 5SiO_2\cdot H_2O$	3518
Rinkite	$Na_2Ca_4CeTiSiO_{15}(F,OH)_3$	2284
Ripidolite	Chlorite group mineral	135, 311, 470, 1860, 3518
Rockbridgeite	$2FeO\cdot 4Fe_2O_3\cdot 3P_2O_5\cdot 5H_2O$	3082
Roemerite	$FeO\cdot Fe_2O_3\cdot 4SO_3\cdot 14H_2O$	873, 3518
Rosasite	$2(Cu,Zn)O\cdot CO_2\cdot H_2O$	3336
Roselite	$3(Ca,Co,Mg)O\cdot As_2O_5\cdot 2H_2O$	3518
Rozenite	$FeSO_4\cdot 4H_2O$	3179
Rubellite	Variety of tourmaline	562
Rusakovite	$(Fe,Al)_5[V,(PO_4)_2](OH)_9\cdot 3H_2O$	3029
Rutherfordite	UO_2CO_3	609
Rutile	TiO_2	102
Samarskite	$(Y,Ce,U,Ca,Fe,Pb,Th)(Nb,Ta,Ti,Sn)_2O_6$	780, 930, 1165, 1702, 2174, 3330
Samiresite	$(U,Pb,etc.)(Nb,Ti)O_4$	1165
Saponite	$(OH)_4(Si_{7.34}\cdot Al,Na_{0.66})Mg_6O_{20}$	279, 502, 608, 641, 739, 746, 954, 1196, 1255, 1418, 1711, 1883, 1890, 2218, 2803
Sassolite	$B_2O_3\cdot 3H_2O$	2034
Satpaevite	$6Al_2O_3\cdot V_2O_4\cdot 3V_{25}O\cdot 30H_2O$	3734
Sauconite	Zn montmorillonite	424, 746, 1706, 2421
Scapolite	$\begin{bmatrix} Na_4ClSi_9Al_3O_{24} \\ Ca_4CO_3Si_6Al_6O_{24} \end{bmatrix}$	651, 1757, 3518
Scheelite	$CaWO_4$	3518
Schoderite	$2Al_2O_3\cdot V_2O_5\cdot P_2O_5\cdot 16H_2O$	3814
Schoenite	$MgSO_4\cdot K_2SO_4\cdot 6H_2O$	302, 1932
Schroeckingerite	$NaCa_3UO_2SO_4(CO_3)_3Fe\cdot 10H_2O$	609, 2035
Schweizerite	Serpentine mineral	279, 1780
Scolecite	$CaAl_2Si_3O_{10}\cdot 3H_2O$	1135, 1639, 3518, 3910
Scorodite	$FeAsO_4\cdot 2H_2O$	1257, 3082, 3336, 3518

Material	*Composition*	*Reference*
Scorzalite	$FeAl_2(PO_4)_2(OH)_2$	1428
Searlesite	$Na_2O \cdot B_2O_3 \cdot 4SiO_2 \cdot 2H_2O$	2034
Selenite	$CaSO_4 \cdot 2H_2O$	3106
Sellaite	MgF_2	902
*Sepiolite	$Si_4O_{11}(Mg \cdot H_2)_3H_2O \cdot 2H_2O$	737, 1149, 1677, 2550, 2976
Serendibite	$Ca_4(Mg,Fe,Al)_6(Al,Fe)_9$-$B_3(Si,Al)_6O_{40}$	2908
Sericite	See Muscovite.	304, 426, 745, 924, 1101, 1131, 1252, 1788, 2162, 2316, 3462
*Serpentine	Chrysotile and/or antigorite	124, 171, 211, 667, 926, 1132, 1399, 2316, 2378, 3584, 3971
Serpierite	$(Cu,Zn,Ca)_5(SO_4)_2(OH)_6 \cdot$-$3H_2O$	873, 3336
Shale	— — —	1362, 1403, 1519, 1526, 1574, 1577, 1846, 1847, 1866, 2065, 2119, 2299, 2554, 2730, 3271, 3701
Shattuckite	$3CuSiO_3 \cdot H_2O$	3687
Sheridanite	Similar to prochlorite	135, 244, 359, 438, 617, 3518
Sibirskite	$Ca_2B_2O_4(OH)_2$	3968
*Siderite	$FeCO_3$	52, 394, 440, 451, 487, 574, 1329, 2475, 2627
Siderose	— — —	1263
Siderotil	$FeSO_4 \cdot 4H_2O$	3884
Sigloite	$Fe_2Al_2(PO_4)_2 \cdot 8H_2O$	3822
Sillimanite	Al_2SiO_5	112, 1617
Sjogrenite and pyroaurite	See Pyroaurite.	609
Slate	Finely foliated rock	1297
Smirnovskite	Metamict rare-earth complex	2118
Smithsonite	$ZnCO_3$	52, 440, 502, 609, 746, 1883, 2683, 2741, 3336, 3518
Sokolovite	$2(Ca,Sr)O \cdot 4Al_2O_3 \cdot P_2O_5 \cdot$-$11H_2O$	2616, 3121
Specularite	See Hematite.	2005
Spencite	$[Y(Ce,Pr,Th)Ca]$-$(Si_2B)O_{12}O$	3828
Sphalerite	$(Zn,Fe)S$	651, 1590, 2495, 3404
Spodumene	$LiAlSi_2O_6$	267, 310, 1991, 2307, 2322, 3518, 3621, 3921
Stainierite	$Co(OH)_2$	2566, 2567
Stannite	$Cu_2S \cdot FeS \cdot SnS_2$	3404
Stellerite	$CaO \cdot Al_2O_3 \cdot 7SiO_2 \cdot 7H_2O$	3518
Stevensite	Similar to saponite, containing Mn	1086, 2771, 2920
Stewartite	$3MnO \cdot P_2O_5 \cdot nH_2O$	3082
Stibiconite	$Sb_2O_4 \cdot H_2O$	1020, 3518
Stibnite	Sb_2S_3	1550
Stichtite and barbertonite	$Mg_6Cr_2(OH)_{16}CO_3 \cdot 4H_2O$	322, 344, 609

Material	*Composition*	*Reference*
Stilbite	$(Ca,Na_2)Al_2Si_7O_{18} \cdot 7H_2O$	1135, 1146, 1336, 3309, 3518, 3910, 3921
Stilpnomelane	$(OH)_{20}K(Fe^{2+}Mg)_9$-$(Fe^{3+}Al)_{5-6}Si_{16}O_{39-40}$	1367, 2221
Strengite	$FePO_4 \cdot 2H_2O$	4005
Strontianite	$SrCO_3$	52, 440, 643, 651, 1883, 3086, 3511, 3518
Strunzite	$MnFe_2(PO_4)_2(OH)_2 \cdot 6H_2O$	3082
Sudoite	Dioctahedral chlorite	3786
Suanite	Magnesium borate	1220
Sulunite	Fe chlorite	2896
Svabite	$Ca_5(AsO_4)_3(OH,F,Cl)$	3700
Syenite	Medium acid rock	2330
Sylvite	KCl	309, 358, 2836, 3518
Symplesite	$3FeO \cdot As_2O_5 \cdot 8H_2O$	1646
Syngenite	$CaSO_4 \cdot K_2SO_4 \cdot H_2O$	873, 2359, 2643
Szaibelyite	$MgBO_2OH$	358, 1220, 1680, 3967
Takovite	$Ni_5(Al_4O_2)(OH)_{18} \cdot 6H_2O$	2531
*Talc	$Mg_3(OH)_2Si_4O_{10}$	145, 193, 394, 518, 1381, 2316, 2949, 2973
Taranakite	Hydrated alkaline aluminophosphate	1899, 4005
Teniolite	$KMg_2Li(Si_4O_{10})F_2$	1717
Tetrahedrite	$Cu_{12}Sb_4S_{13}$	3404, 3497, 3866
Tennantite	$Cu_{12}As_4S_{13}$	3404, 3497
Thaumasite	$CaSiO_3 \cdot CaSO_4 \cdot CaCO_3 \cdot$-15.2$H_2O$	1734, 2039, 2347, 3108, 3518
Thenardite	Na_2SO_4	152, 358, 623, 759, 3518
Thomsonite	$Na_4Ca_8Al_{20}O_{80} \cdot 24H_2O$ (?)	224, 1135, 3518, 3910
Thorite	$ThSiO_4$	1097, 3360, 3518, 3858
Thorogummite	$Th(SiO_4)_{1-x}(OH)_{4x}$	1097
Thuringite	See Chlorite.	135, 329, 1608, 1860, 3518, 3575
Tikhvinite	See Sokolovite	3121
Tincalconite	$Na_2O \cdot 2B_2O_3 \cdot 5H_2O$	2034
Titanite	$CaTiSiO_5$	3518
Titanomagnetite	— — —	2948
Tobermorite	$5CaO \cdot 6SiO_2 \cdot 5H_2O$ (?)	1210, 1347, 1796, 2144, 2740, 3210, 3294, 3421, 3883
Todorokite	Hydrous Mn oxide	3112, 3190, 3302, 3604
Topaz	$Al_2(OH,F)SiO_4$	3518
Torbernite	$CuO \cdot 2UO_3 \cdot P_2O_5 \cdot 12H_2O$	2753, 3082
Tourmaline	$M_7B_2Al_2(AlSi_2O_9)_3$-$(O,OH,F)_4$	651, 658, 1138, 2498, 2956, 3082, 3518
*Tridymite	SiO_2	1141, 1522, 1795, 2088, 2102, 2263, 2450
Triphylite	$Li(Fe,Mn)PO_4$	651
Triplite	$3MnO \cdot P_2O_5 \cdot MnF_2$	3082
Trona	$HNa_3(CO_3)_2 \cdot 2H_2O$	609
Tschermite	$NH_4Al(SO_4)_2 \cdot 12H_2O$	873
Tunellite	$SrO \cdot 3B_2O_3 \cdot 4H_2O$	3458

Material	*Composition*	*Reference*
Tungstenite	WS_2	3404
Tuff	Volcanic ash	2879, 3286, 3413
Turquois	$CuAl_6(OH)_2(PO_4)_4 \cdot 4H_2O$	670, 3426, 3518, 3736
Tyrolite	$5CuO,As_2O_5 \cdot 9H_2O$	3518
Tysonite	$(Ce,La,Dy)F_3$	609
Ufertite	U,Fe,Th,Ti oxide	3573
Ulexite	$NaCaB_5O_9 \cdot 8H_2O$	358, 2034, 2800
Uralborite	$CaB_2O_4 \cdot 2H_2O$	3573
Uramphite	$(NH_4UO_2)PO_4 \cdot 3H_2O$	2229, 2558
Uraninite	UO_2, may contain Pb,Th,Zr	609, 651, 780, 2753
Uranophane	$CaO \cdot 2UO_2 \cdot 2SiO_2 \cdot 6H_2O$	2154, 2753, 3442
Uranothallite	$Ca_2U(CO_3)_4 \cdot 10H_2O$	651
Urgite	U-mineral	3482
Ussingite	$2Na_2O \cdot Al_2O_3 \cdot 6SiO_2 \cdot H_2O$	3518
Vanalite	$4Al_2O_3 \cdot 5V_2O_5 \cdot Na_2O \cdot 30H_2O$	3734
Vanthoffite	$Na_6Mg(SO_4)_4$	358
Vanuxemite	Mixture, hemimorphite and halloysite (?)	746
Variscite	$(Al,Fe)PO_4 \cdot 2H_2O$	670, 3134, 3518, 4005
*Vermiculite	$(Mg,Fe)_4(OH)_4Si_4O_{10} \cdot 4H_2O$ + $(Mg,Fe)_3,(Al,Fe) \cdot (OH)_2Si_3AlO_{10} \cdot 4H_2O$	470, 523, 703, 843, 1090, 1118, 2372, 2826, 3212, 3277
Vesuvianite	$Ca_2Al_2(OH,F)Si_2O_7$	1378, 3173, 3616
Vivianite	$Fe_3P_2O_8 \cdot 8H_2O$	670, 1647, 2340, 3518, 3565, 3736
Volcanic ash	Zeolitic glasses + ?	1047
Volcanic glass	— — —	2564
Volkonskoite	Cr nontronite	288, 1444, 3518, 3756
Wagnerite	Mg_2FPO_4	651
Wardite	$Na_4CaAl_{12}(OH)_{18}(PO_4)_8 \cdot 6H_2O$	670
Wavellite	$Al_6(F,OH)_6(PO_4)_4 \cdot 9H_2O$	651, 670, 3082, 3518, 3736, 4005
Whewellite	$CaC_2O_4 \cdot H_2O$	1597
Wiikite	See euxenite	3393, 3463
Willemite	$ZnSiO_4$	3518
Witherite	$BaCO_3$	52, 74, 440, 643, 651, 1110, 1883, 3518
Wolframite	$(Fe,Mn)O \cdot WO_3$	3518
Wollastonite	$CaSiO_3$	2333, 3518, 4080
Wulfenite	$PbO \cdot MoO_3$	3518, 3767
Wyartite	$3CaO \cdot UO_2 \cdot 6UO_3 \cdot 2CO_2 \cdot 12–14H_2O$	2793
Xonotlite	$Ca_3Si_3O_8(OH)_2$	1881, 2614, 2740, 2985, 2986, 3033, 3421, 3518
Xylotile	See Sepiolite.	478
Yoderite	Hydrous Mg-Fe aluminosilicate	2863

Material	*Composition*	*Reference*
Yttrialite	$(Y,Ce,Th,Ca,Mn)_2(Si_2O_7)$	3919
Zanthosiderite	Hydrated iron oxide	126
Zermatite	Serpentine mineral	279
Zincian dolomite	— — —	2131, 3018
Zinciferous berthierine	Phyllite type	1782
Zinciferous phyllite	Phyllite type	1782
Zincite	ZnO	3518
Zincsilite	$Zn_3Si_4O_{10}(OH)_2 \cdot nH_2O$	3293
Zinkenite	$PbS \cdot Sb_2S_3$	3866
Zinnwaldite	Trioctahedral mica	1252, 1883, 3518
Zircon	$ZrSiO_4$	930, 1097, 1165, 3285, 3518
Zirconolite	$CaZrTi_2O_7$	1748, 3065
Zirkelite	$(Ce,Fe,Ca)O \cdot 2(Zr,Ti,Th)O_2$	3518
Zoisite	$5CaO \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot H_2O$	3518
Zunyite	$Al_{13}Si_5O_{20}(OH,F,Cl)_{19}$	1001

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