CHART

SHOWING

THE CHEMICAL RELATIONSHIPS IN THE MINERAL KINGDOM

PALMER COSSLETT PUTNAM, M.S.

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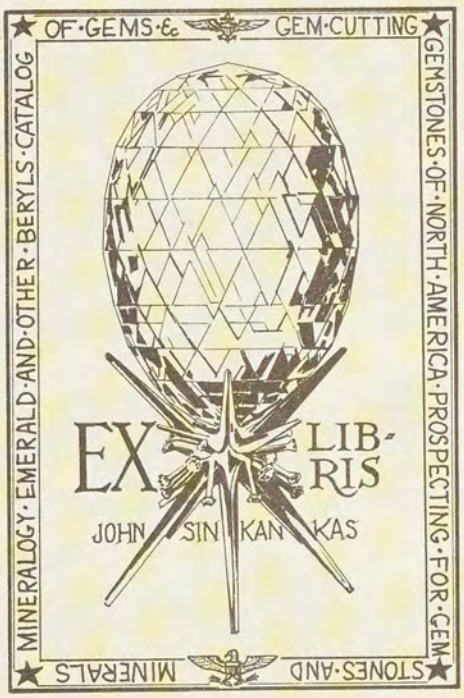

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BY

PALMER COSSLETT PUTNAM, M.S.

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A CHART SHOWING THE CHEMICAL RELATIONSHIPS IN THE MINERAL KINGDOM

THE PURPOSE OF THE CHART

The purpose of the chart is three-fold:

(A) To serve as a ready reference aid to the man who would know quickly, whether for an economic or a scientific purpose, the answer to such questions as: "How many and what are the minerals containing germanium, and what are their compositions?"; or, "Does silver occur with oxygen in any mineral?"; or, "Do phosphides or silicides occur as minerals?".

(B) To serve as an aid in Determinative Mineralogy, especially in the case of rare minerals, where either the small amount of the unknown substance, or the lack of laboratory facilities (as when in the field), precludes the possibility of making more than a few specific tests. It may also serve as a complement to microchemical methods in the laboratory, and as a reminder to verify the presence or absence of minute quantities of certain interesting replacing elements.[a]

(C) To form a mechanical stimulus to speculation upon the chemistry of the earth, by affording upon one sheet a statistical survey of the affinities and the antipathies which hold sway in the mineral kingdom.

THE SCOPE OF THE CHART

(A) **The Elements**—The eighty-four major active elements are listed. The eight omitted include: three of the five inert noble gases, krypton, xenon and neon, known only in traces in the atmosphere; polonium and actinium, whose presence may be assumed whenever uranium is reported; the little known rare-earth, celtium; and two of the unknown elements, numbers 85 and 87, which quite possibly are mere transitional atomic configurations, whose stability is of a low order even in terms of actinium C. (Numbers 43 (eka-manganese), 61, and 75, elements as yet awaiting their discoverer, have been supplied with columns.)

The thirty or more known products of radio-active disintegration are not listed, but are assumed to be present whenever the respective parents of the three most important series are reported, and are included in the subscript "etc." to U, Th and Ra respectively. The latter, though but a stage in the U series, is so important as to justify its emphasis by specific mention.

[a] See page 6, *et seq.*

The eight common inorganic radicals are listed.

The water molecule is listed.

Neodymium, (Nd), and praseodymium, (Pr), always occur together, and are inclusively symbolized by Di, the abbreviation for " didymium," their former joint name.

Save in the case of iron, no differentiation is made between the various valencies.

(B) **The Minerals.**—A mineral is here understood to be an aggregate of atoms whose physical state is the solid,[a] whose crystallographic[b] and optical constants vary within specific limits, whose chemical composition varies within specific limits, and which has been formed in nature under cosmic, atmospheric or telluric conditions of electro-chemical equilibrium.

All minerals described before July, 1924, in the literature mentioned under " References," are entered. This includes a number of sub-species, a number of doubtful species, many varieties based upon chemical composition, and the liquid, native mercury. Optical and crystallographic data, so far as possible, were the criteria of the individuality of a given mineral. The minerals are sixteen hundred and eleven in number.

THE MECHANICS OF THE CHART

(A) **The Coördinates:**

1. The right- and left-hand vertical margins; i.e., the termini of the horizontal columns.

   Here is included:

   I. Each element, (and the ammonium radical), which occurs in nature as the *dominant electro-positive* constituent of a mineral. (Ca in calcite, $CaCO_3$).

   II. Each element which occurs uncombined, but in mineral form. (Pd in allopalladium, Pd.)

2. The top and bottom horizontal margins; i.e., the termini of the vertical columns:

   Here are included:

   I. All the elements, (and the ammonium radical), occurring in nature in the *electro-positive* state, but as *minor* constituents of minerals. Since every active electro-positive element occurs in subordinate amount in at least one mineral, all are here entered.

[a] Exceptions to this are the elements Hg, He, and A. Mercury is the sole constituent of the metallic liquid, native mercury; helium is a gaseous product of radio-active disintegration, found in many minerals; and the gas argon, also possibly a disintegration product, is known in a few minerals.

[b] With the obvious exception of thirty or forty hardened colloid gels.

II. Those elements occurring in nature as the *electro-negative* constituents of minerals, whether *dominantly or subordinately so.* (Te, dominant, S, subordinate, in sulfurous tetradymite, Bi (Te, S)).
III. The common electro-negative radicals.
IV. The water molecule.
V. Three of the unknown elements, entered by their atomic numbers.
VI. A column designated " Nat. El," for the native elements.

In effect, then we have the *dominant electro-positive* elements plotted against *all* the *electro-positive* elements and *all* the *elecro-negative* elements, and against the *common radicals.*

(B) **The Data**:

1. Each number refers to a mineral. The numbers are chosen arbitrarily, and are listed numerically in Index II.

2. The minerals are entered in the chart according to their composition. A hydrous neutral ferrous sulfate, $FeSO_4 \cdot 7H_2O$, (No. 536), is entered in the horizontal Fe″ column, in the SO_4 box and in the H_2O box. An aluminum silicate, Al_2SiO_5, (No. 236), is entered, in the horizontal Al column, in the Si_xO_y box.

3. Complex minerals are entered as follows:

   A mineral containing more than one electro-positive element, as a ferro-magnesian silicate, is entered in the horizontal column of the dominant electro-positive element; i.e., that one present in the greatest percentage weight. Should the analysis, (No. 1592), record 31% Fe″ and 32% Mg, the mineral would be entered in the horizontal Mg column, and would pick up Fe″ in the Fe″ box, and silica in the Si_xO_y box.

4. Certain oxygenated radicals, not specifically listed as coördinates, (the arsenates, antimonates, borates, tellurites, mellates, etc.), are indicated thus:

   In the case of a ferric tellurite, Fe_2TeO_5, (No. 1233), the mineral is entered in the horizontal Fe‴ column, in the O box and in the Te box. In other words, if there is any oxygen in a mineral not accounted for in a specific radical, as the SO_4 or Si_xO_y radical, an entry is made in the O box of the appropriate horizontal column.

5. It will be noted that certain of the radicals are written with x and y as subscripts, in lieu of numerals. This is to indicate that

more than one acid is represented. Si_xO_y, for instance, indicates that SiO_2 is the salt of not merely H_2SiO_3, but of one or more acids in addition.

THE ACCURACY OF THE CHART

The sources of error may be divided into three groups:

(A) Errors in original data.
  1. Typographical.
  2. Analytical.
    I. Of omission.
    II. Of commission.

(B) Errors in interpretation of original data.

(C) Mechanical errors in transcription of these data.

(A) **Probable Errors in Original Data**:

1. *Typographical.*
Although cross references were used, few typographical errors in analytical data were detected, and in most cases it could be determined which was the correct information.

2. *Analytical.*
These fall into two groups:

I. *Errors of Omission.*

The analyst either failed to weigh one or more oxides, as shown by the fact that his results fell short of 100 by an amount greater than his experimental error, or he unwittingly precipitated two or more oxides together, but weighed them as one, obtaining an apparently satisfactory analysis. Errors of the first type are not common, since the curiosity of the investigator usually did not permit the discrepancy to remain long a puzzle. Errors of the second type were fairly common prior to 1886, but after this date they were practically confined to two groups of elements, the radio-active and the rare-earth groups. It has been possible largely to correct for the errors of omission occurring in these two groups. The correction has been made as follows:
Radio-active Group: Whenever uranium was reported, the presence was assumed of radium and helium. The other fifteen or more products of disintegration were also

present, but are grouped under the subscripts " etc." Uranium lead was also undoubtedly present, but unless in quantity sufficient to be detected analytically, has not been reported, in order not to confuse the determinative work.

Whenever thorium was reported, the presence of the commercial mesothorium, along with the other ten or more products of this series, was assumed, and is indicated in the subscript " etc."

Rare-earth Group: Where the phrase " Ce_2O_3 etc." occurred in the analysis, it was assumed that all the elements of this group were present. Where the phrase " Yt_2O_3 etc." occurred, the same assumption was made for this group. Where oxides of one group only were reported, it was assumed that members of the other group were not present. This is not strictly so, since the two groups merge into one another through the medium of the Terbium group, and since scandium is known[a] to occur, once at least, solely with the yttrium earths. Until more accurate analytical data are available, however, this assumption, in conjunction with the following classification[b] of the elements, would appear to be the closest approximation to the truth:

Cerium Group			*Yttrium Group*	
Cerium	Ce		Celtium	Ct[e] ?
Europium	Eu[c]		Dysprosium	Dy
Gadolinium	Gd[c]		Erbium	Er
Lanthanum	La		Holmium	Ho
Neodymium	Nd	Di[d]	Lutecium	Lu
Praseodymium	Pr	Di[d]	Terbium	Tb[c]
Samarium	Sm		Thulium	Th
Scandium	Sc		Ytterbium	Yb
			Yttrium	Yt

[a] Thortveitite, No. 813.

[b] The author is not a student of rare-earth chemistry, and borrowed this classification from Browning's " Introduction to the Rarer Elements." The original articles containing the analyses were not consulted in most instances, and, had this been done, more satisfactory data might have been obtained.

[c] These are sometimes grouped together as the Terbium group.

[d] These two elements, before differentiation, were considered to be one element, " didymium." Since they invariably occur together, and to save space, they are here grouped together under their former symbol, (Di).

[e] The recent discovery of hafnium, atomic number 72, has made the position of celtium obscure. The latter is known only spectroscopically, while some zircons contain 14% Hf.

II. *Errors of Commission*

Especially in certain of the older analyses, when mechanical methods of separation were not highly developed, products of alteration and adventitious material probably were present in a regrettably large amount. This error is large, indeterminate, but nearly negligible so far as the virtue of this chart is concerned, and has been partially rectified, as indicated in the next paragraph.

(B) **Probable Errors in the Interpretation of Data:**

It is hoped that the author's interpretation of doubtful data minimized rather than augmented the indigenous errors. When the chart was first made, in 1920, only those elements occurring in a formula as given in the standard works were included, and only about 900 minerals were plotted. When the chart was expanded to include all minerals described up to July, 1924, many of the replacing elements were included. The criteria of the legitimacy of the rôle played by a minor constituent were developed as follows:

An arbitrary distinction was made between two types of element, which we may designate the "aluminum" type and the "indium" type, respectively. To the former type belong such common elements as Na, K, Mg, Ca, Al, O, Fe″, Fe‴ and, to a certain extent, Si, Ti and Mn. To the latter type belong such mineralogically rare and interesting elements as A, N, Li, Rb, Cs, Cd, Sc, Ga, In, Tl, Ge, Zr, Sn, Cr, Co and Ni, the isotopes of Pb, and the significant He.

A great many analyses, especially of non-metallics, show the presence of one or more of the *first* type in amounts ranging from a trace to two or three per cent. In general these quantities have been assumed to be adventitious and have been *disregarded* unless:

1. There is evidence that the analysis was of exceptionally pure material.

   Example: (Rare.)

2. That the occurrence was consistent in a number of analyses from different localities.

   Example: Small quantities of Ni in serpentine.

3. That the element was an isomorphous replacement of one with which it is often associated.

   Example: Small quantities of Na in orthoclase.

Many of the second type, however, are only to be detected spectroscopically and their relationship to their host is not certain. In the case of A and He, they are certainly uncombined and in the gaseous state, yet their occurrence in minerals is so rare, and their significance so great, that they have been duly entered where recorded in the literature.

As for such elements as In and Ga, we note their wide diffusion in nature, (few spectrographs of minerals lack the In lines, for instance), and we also note their great reluctance to concentrate themselves into palpable organizations. But the important and interesting phenomenon is, that they are not promiscuous in their associations, but *do* concentrate themselves slightly in certain favored hosts. So whatever the rôle of indium within the atomic aggregation which we are pleased to call sphalerite, for instance, it has been duly entered as a minor constituent and thus with other similar elements, though perhaps only present spectroscopically.

The differentiation between minor elements actually entering into the chemical structure of the mineral, those that are adsorbed, those that are occluded, those that are inert, and yet owe their existence to some radioactive parent in the mineral, and those that are merely mechanically adventitious, was assuredly not complete, and is therefore a source of error of indeterminate magnitude.

A source of error of a different sort is the differentiation between O, H, OH, and H_2O. The significance of H and OH is, except in certain obvious cases, purely academic. A complex formula is often written as an algebraic expression, with no indication of molecular structure. When the term " basic " is then applied to such a formula, it is not clear whether it is the oxygen ratio in the acid from which the given salt was derived which is referred to, or the actual presence of the OH radical. The term " acid " leads to the same confusion. And in many cases (*cf.* the zeolites), the structure is still a matter for discussion. In general, entries have been made in the H_2O column when water is lost below a red heat, and in the O and OH columns when lost only above a red heat. Entries have been made in the H column when the water given off, (below a red heat), is acid and in the OH column when basic, in addition to the entry in the H_2O column.

(C) **Probable Mechanical Errors in Transcription of Data:**

Errors from this source are largely due to astigmatism; to the entry of a number in a box immediately contiguous to the proper box. The chart was checked back to original sources in part six times, in part four times and, in part, only twice. Each one of these checkings revealed errors, progressively fewer. It is believed that the error due to this source is not greater than about 0.1%,

and probably less. This amounts to not more than ten individual entries. Further, it is an error usually quite obvious.

Recapitulation.

It is believed that the chart fairly faithfully represents the author's interpretation of the data in the literature; that errors of omission in a few of the older analyses are fairly common; that these latter have in part been corrected in the chart; that errors of commission were somewhat more common in certain of the older analyses; that the corrections of this type of error were probably not so effective as of the former type; that the greatest source of error, therefore, lies in this type of analysis and in the author's interpretation of it. The total percentage error is undoubtedly greater than it will be after a revision, but it is thought that its present accuracy is such that the chart may begin to function.

THE USES OF THE CHART

These are indicated on p. 1, and are largely self-explanatory, yet a few examples might not be amiss.

(A) The chart serves the first purpose as follows:

Example 1.—It is desired to know the occurrence of germanium, and its associations. Inspection of the right-hand margin reveals that Ge is not known to occur as a *dominant electro-positive* constituent of a mineral, and therefore occurs always as an accessory. Turning, then, to the vertical column headed by Ge, one thumbs down the chart and notes that the following minerals *always* or *usually* contain Ge:

In the Ag[a] box, numbers 55, 146;
In the Cu box, number 1291;
In the Fe″ box, numbers 208, 795;
In the Pb box, number 1116;
In the Sn box, number 157;
In the Yt box, numbers 297, 306, 327, 717;
In the Zn box, number 764.

Turning to the numerical index, these numbers are found to refer respectively to:

Argyrodite, (55)	Cassiterite, (157)
Canfieldite (146)	Euxenite, (297)
Germanite, (1291)	Fergusonite, (306)
Columbite, (208)	Gadolinite, (327)
Tantalite, (795)	Samarskite, (717)
Ultrabasite, (1116)	Sphalerite, (764)

[a] A line under a chemical symbol indicates that it is the horizontal column of that element which is referred to, and not its vertical column, in which case there is no underline.

To find the complete composition of each of these, including other rare constituents not usually recorded in mineralogical texts, inspect to the right and left of each number for further entries. This is facilitated by the arrangement of all the numbers of a given box in numerical order. Thus 55, for instance, is found to appear only in the S box, in addition to its entry in the Ge box. Since these entries are in the Ag horizontal column, it follows that argyrodite is a silver germanium sulphide, the silver dominating the germanium in percentage weight.

Example 2.—What minerals, if any, contain thallium as a major constituent? Inspection of the right-hand margin shows that Tl *does* form the dominant electro-positive constituent of some minerals, and running along this horizontal column we find:

In the Ag box, number 912;
In the As box, numbers 508, 866, 912;
In the Pb box, number 912;
In the S box, numbers 508, 866, 912;
In the Sb box, number 866.

In the numerical index, these numbers refer to:

Lorandite, (508)
Vrbaite, (866)
Hutchinsonite, (912).

If information is desired concerning the occurrence of Tl as an accessory constituent, one proceeds as with Ge and finds that:

In the Al box, numbers 26, 487;
In the Au box, number 787;
In the Cu box, numbers 98, 175, 226;
In the Fe″ box, numbers 523, 672;
In the Fe‴ box, number 388;
In the K box, number 149;
In the Mn box, number 125;
In the Zn box, number 764;

have been reported to carry traces or more of Tl.

In the numerical index, these numbers refer to:

Alunite, (26)
Lepidolite, (487)
Sylvanite, (787)
Berzelianite, (98)
Chalcopyrite, (175)
Crookesite, (226)
Marcasite, (523)
Pyrite, (672)
Hematite, (388)
Carnallite, (149)
Braunite, (125)
Sphalerite, (764)

(B) The use of the chart as an aid to Determinative Mineralogy is illustrated by the following two examples:

Example 1.—A minute quantity of a yellow, earthy incrustation on barite was to be tested. A fine closed-tube test was run. Vapours of iodine, and possibly of other halogens, were given off. Inspection showed:

Ag box	431	Iodobromite
	432	Iodyrite
	555	Miersite
Ca box	258	Dietzite
	1393	Lautarite
Cu box	1437	Marshite
Pb box	732	Schwartzembergite

to be the iodides occurring in nature. A reference to a descriptive text often will give physical data which may aid in eliminating some of these minerals, and thus further reducing the number of microchemical or blow-pipe tests required to determine the mineral or to suggest that it is a mixture or a new species. In the case under discussion, the physical data were inconclusive. In order to prove the unknown to be one of these iodides, tests had to be run for Ag, Cu, Ca and Pb. The tip of the C. T. was pulverized and introduced into a three-inch test-tube. Warmed with a few drops of $6N \cdot HNO_3$, the assay went completely into solution with no effervescence. Addition of NH_4OH produced no ppt. nor the formation of a distinctive colour. The NH_4OH was gently expelled and some $(NH_4)_2C_2O_4$ added. No CaC_2O_4 was formed. A few drops of HCl were added, and no ppt. formed immediately, suggesting the absence of Ag. After six hours' standing, a fine white ppt. formed. Upon heating, it went back into solution, ruling out AgCl, but, in the cold, it recrystallized. Under the glass the crystals were seen to be fine prismatic needles, with adamantine luster, and were presumably $PbCl_2$. Thus schwartzembergite was indicated qualitatively, and later checked optically.

Example 2.—During the course of a preliminary geological survey of Uganda[14], Wayland and his assistants had occasion to determine a mineral occurring in and on fossilized wood from the Mount Elgon (Pliocene?), volcanic series. Their laboratory facilities being scanty, they were able to make only limited qualitative tests.

". . . , but the behaviour of the acicular mineral associated with the wood seems to indicate that it must be a true mineral substance and not a mixture.

"Some of the patches of acicular crystals are pure white but mostly they are a dirty yellowish colour. They occur in tufts thickly covering the cavities and rest on a massive incrustation of the same composition. . . . . In cold dilute HCl they are only slightly acted upon, but on warming, they are soluble with effervescence of CO_2. On putting aside after five or six hours the whole solution sets to a jelly. . . . . On heating in the closed tube the crystals become opaque, transparent ones becoming white and the yellowish ones becoming black. Water is evolved and this water vapour when it condenses on the tube gives an alkaline reaction with litmus paper. Heated in a tube with lime, ammonia is evolved and a good alkaline reaction is obtained. In the blowpipe the crystals are fusible at the ends to an enamel. With fusion mixture (*sic*) on charcoal and then cobalt nitrate a strong blue aluminum colour [a] is given. A flame test for calcium could not be obtained. The tests above given show the presence of Aluminum,[a] Ammonium, a Carbonate and Silicate, with hydroxyl, and the mineral species to which such a compound can be referred is doubtful. . . . . It is not clear that a hydrous silicate can enter into combination with a carbonate."

These data applied to the chart, yield the following results in two or three minutes:

1. There are six hydrous silicates known to contain carbonate:

Al	1037	Cancrinite
	1038	Sulfatic cancrinite
	1214	Davyne
Ca	806	Thaumasite
	1539	Plazolite
Yt	164	Cenosite

2. Though these hydrous silicates contain carbonate, no one of them contains ammonium.

3. Ammonium occurs with water, but not in the presence of hydroxyl, carbonate, or silicate.

4. Ammonium occurs with carbonate, but not in the presence of silica, water, or hydroxyl.

Thus, were the "acicular mineral," (as tested), truly homogeneous, it would be a new mineral; but it would not only be a new mineral; it would represent a new chemical type; and not only one new type, but three new types! The probability that the material tested was a mixture is thus strongly emphasized.

[a] *Most fusible* or *fluxed* silicates and many other *fusible* minerals give a good blue colour when heated with $Co(NO_3)_2$, in addition to those *infusible* numerals whose blue colour is a specific test for aluminum compounds or the zinc silicates.

(C) The mechanical presentation upon one sheet of the affinities and antipathies which hold sway in the mineral kingdom is instructive, and aids in emphasizing many interesting inter-relationships which it might prove difficult to grasp in another way.

The array of numbers in the $\underline{\text{Al}}$ Si_xO_y box, for instance, emphasizes visually the importance of such minerals in the scheme of things. The great affinity of Ca for Al in the presence of Si_xO_y is brought out, as also the even greater (statistical) affinity of Na for Al under the same conditions.

Many other suggestive relationships among less common elements are indicated. There is no need of enumerating them here.

These relationships are only crudely quantitative, since the entries were made by percentage weight, and not by molecular proportions, and since the individual minerals have not been weighted according to their occurrence in the earth's crust.

Further, this method of presentation serves to emphasize in a clearcut manner the distinction between elements of the "indium" type, which, above a certain low saturation point, prefer the company of others to that of themselves, and those of the "aluminum" type, which show greater development of the herd instinct, for, when present at all, they are usually present in large quantities.

NOTICE OF A DETERMINATIVE SCHEME

It is obvious that a *determinative scheme*, embracing the mineral kingdom, and developed on the plan of successively testing for specific elements, by blowpipe and wet chemical methods, would be the logical complement to this chart. Such a scheme was indeed developed during the winter and spring of 1920, for use by the author in the elementary course of mineralogy given by Dr. Warren at the Massachusetts Institute of Technology. It included about 350 of the common minerals. In the summer of 1920, it was made to include about 900 minerals, and in 1923 was submitted as partial fulfilment of the requirements for the degree of Bachelor of Science. It has since been in use by the author, in the laboratories of the Department of Geology at the Institute, and in 1924 was tested out under the supervision of Dr. Lindgren. It is now being further revised, and expanded so as to include all minerals. Some refinements in the specific tests for elements are being tried out, and it is hoped to bring the entire scheme to completion within a year.

Bingham Canyon,
Aug. 23, 1924.

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688. Realgar
689. Reddingite
690. Reinite
691. Remingtonite
692. Retzian
693. Rezbanyite
694. Rhabdophanite
695. Rhagite
696. Rhodizite
697. Rhodochrosite
698. Rhodonite
699. Richterite
700. Rickardite
701. Riebeckite
702. Rinkite
703. Rinneite
704. Foresite
705. Risörite
706. Frigidite
707. Roeblingite
708. Roepperite
709. Roemerite
710. Roscoelite
711. Roselite
712. Rosiérésite
713. Spinel (normal "ruby")
714. Rutile
715. Safflorite
716. Sal-ammonia (salammonite)
717. Samarskite
718. Samirésite
719. Samsonite
720. Saponite
721. Sapphirine
722. Sarcolite
723. Sarkinite
724. Sartorite
725. Sassolite
726. Schapbachite
727. Scheelite
728. Schefferite
729. Schirmerite
730. Schorlomite
731. Schroetterite
732. Schwartzembergite
733. Schwatzite
734. Scolecite
735. Scorodite
736. Searlesite
737. Selenium
738. Selen-tellurium
739. Sellaite
740. Semseyite
741. Senarmontite
742. Sepiolite
743. Zinc-copper-melanterite
744. Seybertite
745. Sicklerite
746. Siderite
747. Sideronatrite
748. Sillimanite
749. Silver
750. Sipylite
751. Skemmatite
752. Skutterudite
753. Smaltite
754. Smithsonite
755. Soda niter
756. Sodalite
757. Soumansite
758. Spadaite
759. Spangolite
760. Sperrylite
761. Spessartite
762. Spherite
763. Spherocobaltite
764. Sphalerite
765. Zinc-copper-chalcanthite
766. Spodumene
767. Spurrite

768. Stannite
769. Staurolite
770. Stephanite
771. Stercorite
772. Sternbergite
773. Stibiconite
774. Stibiotantalite
775. Stibnite
776. Stilbite
777. Stilpnomelane
778. Stolzite
779. Strengite
780. Strontianite
781. Struvite
782. Styloptypite
783. Sulfoborite
784. Sulfohalite
785. Sulfurite
786. Sussexite
787. Sylvanite
788. Sylvite
789. Symplesite
790. Synadelphite
791. Sapphire
792. Syngenite
793. Szmikite
794. Talc
795. Tantalite
796. Tantalum
797. Gold, cupriferous
798. Tellurium
799. Duftite
800. Tennantite
801. Tephroite
802. Terlinguaite
803. Teschemacherite
804. Tetradymite
805. Tetrahedrite
806. Thaumasite
807. Thernardite
808. Thermonatrite
809. Thomsenolite
810. Thomsonite
811. Thorianite
812. Thorite
813. Thortveitite
814. Thuringite
815. Tiemannite
816. Tilasite
817. Tin
818. Titanite
819. Topaz
820. Tourmaline, chromic
821. Tremolite
822. Trichalcite
823. Tridymite
824. Trimerite
825. Triphylite
826. Triplite
827. Triploidite
828. Tritomite
829. Troegerite
830. Troilite
831. Trona
832. Tscheffkinite (chevnikite)
833. Tsumebite
834. Tungstite
835. Turyite
836. Turquois
837. Tychite
838. Tyrolite
839. Tysonite
840. Ulexite
841. Ullmannite
842. Uraninite
843. Uranocircite
844. Uranophane
845. Uranopilite
846. Uranospinite
847. Uranothallite
848. Urbanite
849. Ussingite
850. Hoelite
851. Uvanite
852. Uvarovite
853. Valentinite
854. Vanadinite
855. Variscite
856. Vashegyite
857. Vauquelinite
858. Vermiculite
859. Vesuvianite
860. Veszelyite
861. Vivianite
862. Voglite
863. Volborthite
864. Voltaite
865. Voltzite
866. Vrbaite
867. Picrochromite
868. Xanthochroite
869. Wagnerite
870. Walpurgite
871. Wapplerite
872. Wardite
873. Weinschenkite
874. Warwickite
875. Wavellite
876. Wellsite
877. Wernerite
878. Whitneyite
879. Wiikite
880. Wilkeite
881. Willemite
882. Willyamite
883. Witherite
884. Wittichenite
885. Woehlerite
886. Wolfachite
887. Wolframite
888. Wollastonite
889. Wulfenite
890. Wurtzite
891. Xanthoconite
892. Xanthophyllite
893. Rhodonite, ferriferous
894. Xenotime
895. Yttrrocerite
896. Yttrotantalite
897. Yukonite
898. Zaratite
899. Zepharovichite
900. Zeunerite
901. Lorettoite
902. Zincaluminite
903. Zincite
904. Zinkenite
905. Zinnwaldite
906. Zircon
907. Zirkelite
908. Zoisite
909. Zorgite
910. Zunyite
911. Yttergranat
912. Hutchinsonite
913. Joseite
914. Lengenbrachite
915. Lithargite
916. Nitrocalcite
917. Nitroglauberite
918. Nitromagnesite
919. Whewellite
920. Misenite
921. Merrillite
922. Plumboniobite
923. Platinite
924. Seligmannite
925. Tripkeite
926. Uranospherite
927. Bayldonite
928. Barthite
929. Oliveiraite
930. Tarbuttite
931. Tavistockite
932. Taylorite
933. Teallite
934. Pisanite
935. Zeyringite
936. Yttrogummite
937. Yttrofluorite
938. Siderite, manganiferous
939. Yttrialite
940. Adularia
941. Aegirite-augite
942. Aegirite, vanadiferous
943. Akermannite
944. Weibullite
945. Akrochordite
946. Alaitel
947. Tantaic ochre
948. Albertite
949. Rhodocrosite, ferriferous
950. Allactite
951. Allemontite
952. Allopalldadium
953. Almeriite
954. Aloisite
955. Iron pyrochroite
956. Alshedite
957. Alurgite
958.
959. Amesite
960. Ammiolite
961. Basobismutite
962. Anatase
963. Bavenite
964. Anemousite
965. Angaralite
966. Tennantite, bismuthiferous
967. Margarosanite
968. Anthracite
969. Antigorite
970. Antlerite

971. Aphrosiderite
972. Arakawaite
973. Arcanite
974. Arduinite
975. Argentojarosite
976. Armangite
977. Arquerite
978. Arsenobismite
979. Asbolite
980. Ascharite
981. Dolomite, manganiferous
982. Astrolite
983. Attacolite
984. Auerlite
985. Augelite
986. Bäckströmite
987. Cyprine
988. Barbierite
989. Baricalcite
990. Barkevikite
991. Barsowite
992. Barobismutite
993. Barylite
994. Barysilite
995. Ferrierite
996. Bassanite
997. Bassetite
998. Bastite
999. Batchelorite
1000. Bathvillite
1001. Bacquerelite
1002. Beldongrite
1003. Berlinite
1004. Berthonite
1005. Berzeliite
1006. Quartz, beta
1007. Beyrichite
1008. Bilinite
1009. Bisbeeite
1010. Bischoffite
1011. Bismuth, gold
1012. Bismutoplagionite
1013. Bismutosmaltite
1014. Dolomite, ferriferous
1015. Bituminous coal
1016. Bityite
1017. Brostenite
1018. Blomstrandine
1019. Bolivarite
1020. Bort
1021. Bowlingite
1022. Brannerite
1023. Bravoite
1024. Bromcarnallite
1025. Breunnerite
1026. Britholite
1027. Brugnatelite
1028. Brunsvigite
1029. Bushmanite
1030. Bustamite
1031. Bytownite
1032. Calciobiotite
1033. Cadmium oxide
1034. Calcium lazulite
1035. Campylite
1036. Camsellite
1037. Cancrinite
1038. Sulfatic cancrinite
1039. Manganandalusite
1040. Cappelenite
1041.
1042. Carbonado
1043. Xanthoxenite
1044. Anapaïte
1045. Rhodium gold
1046. Platinum, magnetic
1047. Celsian
1048. Ceruleite
1049. Coeruleofibrite
1050. Cesarolite
1051. Parsettensite
1052. Racewinite
1053. Chalcolamprite
1054. Chalcomenite
1055.
1056. Chathamite
1057. Chiastolite
1058. Chilenite
1059. Chillagite
1060. Chlormanganokalite
1061. Chlor-apatite
1062. Chloralluminite
1063. Chloromagnesite
1064. Chloromelanite
1065. Christobolite
1066. Chrome-clinochlore
1067. Chrome-diopside
1068. Cleavelandite
1069. Chromitite
1070. Chromohercynite
1071. Chrysocolla
1072. Chrysotile
1073. Cleveite
1074. Cliftonite
1075. Clinoenstatite
1076. Dolomite, cobaltiferous
1077. Cobalt chalcanthite
1078. Cobaltoadamite
1079. Cobaltocalcite
1080. Cobaltomenite
1081. Cobaltiferous lampadite
1082. Cocinerite
1083. Coeruleolactite
1084. Cohenite
1085. Colerainite
1086. Collophanite
1087. Columbium
1088.
1089. Connarite
1090. Copalite
1091. Cordierite
1092. Cornuite
1093. Coronadite
1094. Covellite
1095. Crandallite
1096. Creedite
1097. Crestmorite
1098. Crossite
1099. Cryptohalite
1100. Vredenburgite
1101. Topaz, oriental
1102. Vonsenite
1103. Voglianite
1104. Voelckerite
1105. Viridine
1106. Villiaumite
1107. Cobaltiferous gahnite
1108. Vilateite
1109. Vernadskite
1110. Velardeñite
1111. Vegasite
1112. Vanthoffite
1113. Uranospathite
1114. Uraconite
1115. Umangite
1116. Ultrabasite
1117. Uhligite
1118. Tyuyamunite
1119. Torbernite
1120. Torendrikite
1121. Törnebohmite
1122. Tourmaline, iron
1123. Mackensite
1124. Trechmanite
1125. Trigonite
1126. Tripuhyite
1127. Trolleite
1128. Troostite
1129. Tschermigite
1130. Tungstenite
1131. Turanite
1132. Thorogummite
1133. Thulite
1134. Titanhydroclinohumite
1135. Tachyhydrite
1136. Taeniolite
1137. Taenite
1138. Tagilite
1139. Talctriplite
1140. Tallingite
1141. Tapiolite
1142. Taramellite
1143. Tarnowitzite
1144. Tartarkaite
1145. Tasmanite
1146. Tawmawite
1147. Tellurite
1148. Tellurobismutite
1149. Tenorite
1150. Termierite
1151. Tetradymite-sulfurous
1152. Thalenite
1153. Sulvanite
1154. Svabite
1155. Svanbergite
1156. Sychnodymite
1157. Stewartite
1158. Stibiocolumbite
1159. Stichtite
1160. Stoffertite
1161. Stokesite
1162. Strigovite
1163. Stromeyrite
1164. Strontianocalcite
1165. Strüverite
1166. Stutzite
1167. Succinite (amber)
1168. Sobralite
1169. Soda-glauconite
1170. Soddite
1171. Spencerite
1172. Arsenopyrite, nickeliferous
1173. Spodiophyllite

1174. Spodiosite
1175. Stasite
1176. Staszicite
1177. Steenstrupine
1178. Stellerite
1179. Senaite
1180. Serendibite
1181. Serpierite
1182. Shanyavskite
1183. Shattuckite
1184. Selensulfur
1185. Sheridanite
1186. Siegenite
1187. Silicomagnesiofluorite
1188. Schreibersite
1189. Simonellite
1190. Sincosite
1191. Sphenomanganite
1192. Mârcasite, arsenical
1193. Sitaparite
1194. Smaragdite
1195. Schafarzikite
1196. Scheererite
1197. Schertelite
1198. Schizolite
1199. Tetrahedrite, cobaltiferous
1200. Cumengite
1201. Cuprite
1202. Cuproadamite
1203. Cuprogoslarite
1204. Cupromagnesite
1205. Cuproplumbite
1206. Cuproscheelite
1207. Cuprozincite
1208. Curite
1209. Rubidium-microcline
1210. Dahllite
1211. Danaite
1212. Dannemorite
1213. Daviesite
1214. Davyne
1215. Dechenite
1216. Delessite
1217. Delorenzite
1218. Delvauxite
1219. Dewindtite
1220. Diabantite
1221. Diallage
1222. Dietrichite
1223. Dihydrite
1224. Diopside-jadeite
1225. Dioptase
1226. Dixenite
1227. Dolomite, zinciferous
1228. Doughtyite
1229. Douglasite
1230. Tinzenite
1231. Dravite
1232. Dundasite
1233. Durdenite
1234. Dysanalite
1235. Dysluite
1236. Dysodile
1237.
1238. Echellite
1239. Ectropite
1240. Elaterite
1241. Elpidite
1242. Weibyite
1243. Elbaite
1244. Emmonsite
1245. Endeiolite
1246. Endlichite
1247. Scacchite
1248. Epidesmine
1249. Epistolite
1250. Eguéite
1251. Erikite
1252. Erythrosiderite
1253. Sanguinite
1254.
1255. Eucolite
1256. Eucolite-titanite
1257. Eucryptite
1258. Eudidymite
1259. Ferberite
1260. Ferganite
1261. Fermorite
1262. Ferrazite
1263. Ferronatrite
1264. Ferroanthophyllite
1265.
1266. Ferrocalcite
1267. Ferrocobaltite
1268. Ferrogoslarite
1269. Ferrocolumbite
1270. Fichelite
1271. Fiedlerit.
1272. Finnemanite
1272. Finnemanite
1273.
1274. Flagstaffite
1275. Flajolotite
1276. Clinoptilolite
1277. Siderite, magnesian
1278. Fowlerite
1279. Francolite
1280. Fluormanganapatite
1281. Fredricite
1282. Frieseite
1283. Fuchsite
1284. Fuggerite
1285. Furnacite
1286. Garnierite
1287. Belonesite
1288. Gedrite
1289. Geocerite
1290. Georgeixite
1291. Germanite
1292. Georgiadesite
1293. Gerhardtite
1294. Geyerite
1295. Holmquistite
1296. Gilespite
1297. Orvillite
1298. Gilpinite
1299. Gilsonite
1300. Glaucochroite
1301. Glauconite
1302. Globosite
1303. Gonnardite
1304. Grahamite
1305. Grandidierite
1306. Greenalite
1307. Greenovite
1308. Griffithite
1309. Griphite
1310. Grothite
1311. Grünerite
1312. Guadalcazarite
1313. Gummite
1314. Gyrolite
1315. Hackmanite
1316. Hannayite
1317. Harstigite
1318. Hartite
1319. Hatchettite
1320. Hastingsite
1321. Zinc
1322. Hematostibiite
1323. Henwoodite
1324. Hessonite
1325. Hetaerolite
1326. Heteromorphite
1327. Szaibelyite
1328. Hjelmite
1329. Hieratite
1330. Higginsite
1331. Sandbergite
1332. Heterosite
1333. Histrixite
1334. Catoptrite
1335. Högbomite
1336. Hörnesite
1337. Illsemannite
1338. Homilite
1339. Horsfordite
1340. Huanatajayite
1341. Hügelite
1342. Humboltine
1343. Hulsite
1344. Huntilite
1345. Hydroclinohumite
1346. Kischetimite
1347. Chloroxiphite
1348. Hydrophilite
1349. Hydrothomsonite
1350.
1351. Ice
1352. Iddingsite
1353. Idrialite
1354. Ilmenorutile
1355. Impsonite
1356. Ambatoarinite
1357. Irvingite
1358. Ishikawite
1359. Ivaarite
1360. Jalpaite
1361. Jefferisite
1362. Jeffersonite
1363. Jet
1364. Johannite
1365. Josephinite
1366. Jurupaite
1367. Kaersutite
1368. Kalicinite
1369. Diabolite
1370. Kamarezite
1371. Kämmererite
1372. Kamacite
1373. Kasolite
1374. Kayserite
1375. Keelyite

1376. Kehoite
1377. Kertschenite
1378. Könenite
1379. Kongsbergite
1380. Tilkerodite
1381. Koppite
1382. Kotschubeite
1383. Kreittonite
1384. Kremersite
1385. Knopite
1386. Kreuzbergite
1387. Magnetite, magnesian
1388. Kurskite
1389. Lagonite
1390. Lampadite
1391. Lambertite
1392. Laubanite
1393. Lautarite
1394. Laavenite
1395. Lavrovite
1396. Lawrencite
1397. Leifite
1398.
1399. Leuchtenbergite
1400. Leucopetrite
1401. Leverrierite
1402. Lewisite
1403. Liebethenite
1404. Lignite
1405. Liskeardite
1406. Lucinite
1407. Luckite
1408. Lubeckite
1409. Hacklite
1410. Larderellite
1411. Mackintoshite
1412. Lassallite
1413. Kochite
1414. Magnesioludwigite
1415. Malacon
1416. Siderite, calciferous
1417. Malinowskite
1418. Pyrrhotite, nickeliferous
1419. Manganapatite
1420. Manganbrucite
1421. Manganese-chalcanthite
1422. Manganchlorite
1423. Manganfayalite
1424. Manganhedenbergite
1425. Manganmagnetite
1426. Manganocalcite
1427. Manganocolumbite
1428. Manganophyllite
1429. Kempite
1430. Vanadic ochre
1431. Manganostibite
1432. Manganotantalite
1433. Manganpectolite
1434. Mangan-vesuvianite
1435. Mansjöite
1436. Marmatite
1437. Marshite
1438. Marsjatskite
1439. Martite
1440. Maskelynite
1441. Mauzeliite
1442. Mazapilite
1443. Melanovanadite
1444. Mellite
1445. Melnikovite
1446. Mendelyeevite
1447. Merwinite
1448. Mesitite
1449. Messelite
1450. Metastibnite
1451. Metavoltaite
1452. Millosevichite
1453. Miloschite
1454. Minasite
1455. Galena, argentiferous
1456. Moissanite
1457. Molybdomenite
1458. Molybdosodalite
1459. Molysite
1460.
1461. Montebrasite
1462. Morencite
1463. Morinite
1464. Mosandrite
1465. Mossite
1466. Mottramite
1467. Müllerite
1468. Mullanite
1469. Naegite
1470. Napalite
1471.
1472. Narsasukite
1473. Natroalunite
1474. Natrodavyne
1475. Natrojarosite
1476. Nemalite
1477. Neotantalite
1478. Neotocite
1479. Motlocite
1480. Newberyite
1481. Nicholsonite
1482. Nichel-skutterudite
1483. Prolectite
1484. Nitrobarite
1485. Nocerite
1486. Lechatelierite
1487. Nordmarkite
1488. Offrétite
1489. Siderotil
1490. Ramsayite
1491. Orientite
1492. Oruetite
1493. Osmiridium
1494. Otavite
1495. Oxammite
1496. Ozocerite
1497. Owyheeite
1498. Pageite
1499. Palladium
1500. Palmerite
1501. Palmierite
1502. Tourmaline, magnesian
1503. Paracoquimbite
1504. Paraurichalcite
1505. Paralaurionite
1506. Paraluminite
1507. Paramelaconite
1508. Parasepiolite
1509. Paravivianite
1510. Paravauxite
1511. Paredrite
1512. Pargasite
1513. Paternoite
1514. Patronite
1515. Parsonsite
1516. Peckhamite
1517. Phillipite
1518. Rubidium-orthoclase
1519. Pholidolite
1520. Phosphoferrite
1521. Phosphophyllite
1522.
1523. Picite
1524. Pickeringite
1525. Picotite
1526. Picroepidote
1527. Picromerite
1528. Picropharmacolite
1529. Picrotitanite
1530. Pigeonite
1531. Pintadoite
1532. Pistomesite
1533. Pilbarite
1534. Natroncatapleite
1535. Planchéite
1536. Planerite
1537. Planoferrite
1538. Avaite
1539. Plazolite
1540. Plessite
1541. Plumbocalcite
1542. Plumbojarosite
1543. Plumosite
1544. Pöchite
1545. Podolite
1546. Polysphaerite
1547. Cerium sulfate
1548. Porpezite
1549. Posepnyte
1550. Prizbramite
1551. Priceite
1552. Priorite
1553. Rutherfordine
1554. Silver, cupriferous
1555. Ellsworthite
1556. Rumpfite
1557. Chinkolobwite
1558. Pucherite
1559. Pyroaurite
1560. Pyrobelonite
1561. Pyrophanite
1562. Errite
1563. Pyrrharsenite
1564.
1565. Picrotephroite
1566. Pseudowavellite
1567.
1568. Quisqueite
1569. Rathite
1570. Redingtonite
1571. Rhodolite
1572. Rhomboclase
1573. Rhönite
1574. Richellite
1575. Brandisite
1576. Riversideite
1577. Romeite
1578. Rosasite
1579. Roschérite

1580. Rosenbuschite
1581. Rothoffite
1582. Rowlandite
1583.
1584. Tengerite
1585. Joaquinite
1586. Corkite
1587. Parisite
1588. Ruby, oriental
1589. Emerald, oriental
1590. Amethyst, oriental
1591. Chlorospinel
1592. Hyalosiderite
1593. Pseudomesolite
1594. Soda-sarcolite, an hypothet. mol
1595. Zebedassite
1596. Xonotlite
1597. Destinezite
1598. Mariposite
1599.
1600. Yttrocrasite
1601. Heterogenite
1602. Wattevellite
1603. Volchonskoite
1604. Uranochalcite
1605. Pleonaste
1606. Iron - copper - chalcanthite
1607. Heubachite
1608. Wodanite
1609. Barytbiotite
1610. Löllingite, cobaltiferous
1611. Trerorite
1612. Plumboferrite
1613. Vauxite
1614. Cornetite
1615. Rhodocrosite,calciferous
1616. cobaltiferous
1617. Sarcopside
1618. Magnesiochromite
1619. Schorlite
1620. Schroeckingerite
1621. Rhodocrosite, magnesio
1622. Stevensite
1623. Monimolite, calciferous
1624. Tarapacaite
1625. Tamarugite
1626. Titanolivine
1627. Silver, auriferous
1628. Hydrotroilite
1629. Gel-cerargyrite
1630. Hydrocuprite
1631. Gel-variscite
1632. Spheromangite

BLANK NUMBERS

The following numbers had been assigned to minerals which were later, for one reason or another, stricken from the chart. They *do not now* appear upon the chart, and appear in the Numerical Index followed by a blank.

271, 309, 433, 534, 958, 1041, 1055, 1088, 1237, 1254, 1265, 1273, 1350, 1398, 1460, 1471, 1522, 1564, 1567, 1583, 1599.

THE CHEMICAL RELATIONSHIPS IN THE MINERAL KINGDOM