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A Mineral Survey for Piezo-Electric Materials

By W. L. BOND

BECAUSE of the increasing interest in piezoelectric materials in many branches of science an exhaustive study of the minerals was undertaken with the object of finding all the materials that could possibly be of use for piezo-electric elements. Much help was derived from existing data.¹

Considerations of symmetry show us that for a crystal to be piezo-electrically active it must belong to a crystal class that has no center of symmetry (the Pentagonalicositetredral class of the cubic system, however, although it has no center of symmetry cannot be piezo active).² This makes twenty classes of possible piezo activity and twelve classes that could not possibly be active. About 90% of the crystals found in nature fall in those classes having centers of symmetry.

Although the mineralogical data are incomplete in their assignment of minerals to definite classes in the seven systems, the existing data give a start in the choosing of minerals likely to have useful piezo-electric properties.

All available data were gone through to obtain the following list of minerals classified by crystal structures. As many of the non-centric ones as were obtainable in the United States were tested by the method of Geibe and Scheibe³ (resonance in a thermionic oscillator circuit). Whenever the authorities differed on the classification of a mineral it was so examined if obtainable.

In the mineral list, each mineral is numbered according to the number of the class in Groth's *Physikalische Kristallographie*, as follows: (*) indicating classes of possible activity:

*1 Assymmetric } Triclinic system
2 Pinacoidal }

¹ Dana—A System of Mineralogy, Ford—Dana's Textbook of Mineralogy; Groth—*Chemische Kristallographie*; Landölt Börnstein—*Tabellen*; International Critical Tables; *Zeitschrift für Kristallographie*.

² W. Voigt, *Kristal physik*.

³ *Zeits f Physik* 33, pg. 761 (1925).

*3 Sphenoidal	}	Monoclinic system
4 Domatic		
5 Prismatic		
*6 Bisphenoidal	}	Orthorhombic system
*7 Pyramidal		
8 Bipyramidal		
*9 Bisphenoidal	}	Tetragonal system
*10 Pyramidal		
*11 Scalenohedral		
*12 Trapezohedral		
13 Bipyramidal		
*14 Ditetragonal Pyramidal		
15 Ditetragonal Bipyramidal		
*16 Pyramidal	}	Rhombohedral system
17 Rhombohedral		
*18 Trapezohedral		
*19 Bipyramidal		
*20 Ditrigrical pyramidal		
21 Ditrigrical Scalenohedral		
*22 Ditrigrical Bipyramidal		
*23 Pyramidal	}	Hexagonal system
*24 Trapezohedral		
25 Bipyramidal		
*26 Dihexagonal Pyramidal		
27 Dihexagonal Bipyramidal		
*28 Tetrahedral-Pentagonal-Dodecahedral	}	Cubic system
29 Pentagonal Icositetrahedral		
30 Dyakis-Dodecahedral		
*31 Hexakis-tetrahedral		
32 Hexakis Octahedral		

In addition to the above classification, the following list of minerals is annotated with the following symbols:

- A = active by test
- I = inactive by test
- R = unavailable or rare
- M = mineral occurs only massive, amorphous or in other unsuitable form
- S = crystal always very small
- H = mineral is always non-homogeneous
- U = unstable
- C = electrically conducting
- ? = class not absolutely certain

CLASSIFIED LIST OF MINERALS

Actinolite	5	Allanite	5	Amosite	M
Adelite	5	Allemontite	21	Ampangabeite	8?UI
Aegirite	5?I	Allophane	M	Amphibole	5?HI
Aenigmatite	2	Almandite	32	Analcime	32
Aeschynite	8	Altaite	32	Ancylite	8
Alabandite	*31I	Aluminite	M	Andalusite	8
Alamosite	5	Alunite	21	Andesine	2
Albite	2	Alunogen	M	Andorite	8
Algondonite	H	Amblygonite	2	Andradite	32
Allactite	5?SI	Amesite	5	Anemousite	2

Anglesite	8	Bismite	21?I	Chillagite	10?
Anhydrite	8	Bismuthinite	8	Chloanthite	30
Ankerite	17	Bismutite	M	Chlorastrolite	H
Annabergite	5	Blödite	5	Chlorite	5
Annerodite	8	Blomstrandine	8?MI	Chloritoid	5
Anomite	5	Boleite	15?I	Chlormanganokalite	21
Anorthite	2	Boracite	*7A	Chloropal	M
Anorthoclase	2	Borax	5	Chloraphoenicite	I
Anthophyllite	8	Borickite	M	Chlorospinel	32
Antigorite	5?H	Bornite	*11I	Chondrodite	5
Antlerite	M	Boulangerite	8	Chromite	32
Apatite	25I	Bournonite	8	Chrysoberyll	8
Aphrosiderite	?I	Braunite	15	Chrysolite	8
Aphthitalite	21	Breithauptite	*20I	Cinnabar	*18I
Apophyllite	15	Britholite	27?S	Claudetite	5
Aragonite	8	Brochantite	8	Clausthalite	M
Ardeninite	8	Bromyrite	32	Cleveite	32
Ardunite	M	Brookite	8	Clinochlor	5
Arfvedsonite	5	Brucite	21	Clinoclasite	5
Argentite	32	Brushite	5	Clinohedrite	*4A
Argentojarosite	I	Bunsenite	32	Clinohumite	5
Argyrodite	32	Bytownite	2	Clinozoisite	5
Arrhenite	H			Cobaltite	*28C
Arseniosiderite	8	Cabrerite	5	Cohenite	M
Arsonolite	32	Cacoxnite	M	Colemanite	5
Arsenophyrite	8	Calamine	*7A	Collinsite	I
Ascharite	M	Calaverite	5	Collophanite	M
Astrakanite	5	Calciothorite	M	Coloradoite	M
Astrophyllite	8?I	Calcite	21	Columbite	8
Atacamite	8	Caledonite	8	Connellite	25
Auerlite	15	Calomel	15	Cookeite	M
Augite	5I	Campylite	25	Cordylite	21
Aurichalcite	M	Cancrinite	27	Cornetite	?I
Automolite	32	Canfieldite	32	Corundum	21
Aventurine	2	Cannizzarite	?I	Corynite	28I
Axinite	2	Carnallite	8	Cotunnite	8
		Carnotite	I	Covellite	*18?I
Babingtonite	2	Carpholite	5	Crestmoreite	M
Baddeleyite	5	Caryocrite	21	Cristobalite	M
Baldaufite	?R	Cassiterite	15	Crocidolite	M
Barkevikite	5	Castorite	5	Crocoite	5
Barite	8	Caswellite	I	Cronstedtite	*16A
Barytocalcite	5	Catapleite	5	Crookesite	M
Bastnäsite	I	Celestite	8	Cryolite	5
Baumhauerite	5	Celsian	5	Cryolithionite	32
Bauxite	M	Cenosite	8?I	Cuprite	32
Beaverite	?S	Cerargyrite	32	Cuproscheelite	I
Bechilite	M	Cerite	8	Cyanite	2
Beckelite	32?S	Cerrusite	8	Cyrtolite	I
Bementite	8?I	Cervantite	8?		
Benitoite	*22I	Chabazite	21?I	Dahlite	M
Beraunite	I	Chalcanthite	2	Danburite	8
Bertrandite	*7I	Chalcedony	8?M	Datolite	5
Beryl	27	Chalcocite	8	Dawsonite	M
Beryllonite	8	Chalcolamprite	32	Dechenite	8
Berzelianite	MR	Chalcopyllite	21?I	Delessite	?SI
Berzelite	32?I	Chalcopyrite	*11C	Dellafosite	I
Betafite	32	Chalcosiderite	2	Delorenzite	8
Bindheimite	M	Chalcostibite	8	Delvauxite	M
Binnite	32?I	Chamosite	M	Demantoid	32
Biotite	5	Chiastolite	8	Deschloizite	8
Bischofite	5	Childrenite	8?I	Desmine	5

Deweylite	M	Freyalite	M	Heulandite	5
Diamond	31?I	Frieselite	8	Hielmite	8?I
Diaphorite	8	Fritzscheite	15	Hieratite	32
Diaspore	8	Fuchsite	I	Hillebrandite	M
Diopside	5			Hiordahlite	2
Diopase	17	Gadolinite	5	Hisingerite	M
Dixenite	?SI	Gageite	I	Hodgkinsonite	5?I
Dolemite	17	Gahnite	32	Hoferite	M
Domeykite	8	Galena	32	Hokutolite	H
Douglasite	5	Ganomalite	I	Holmquistite	5?HI
Dufrenite	8	Garnet	32	Hopeite	8
Dufrenaysite	5	Gastaldite	5	Howlite	M
Dumortierite	8	Gay-Lussite	5	Huebnerite	5
Dysanalyte	32	Gedrite	8	Humite	8
Dyscrasite	8	Gehlenite	15	Hussakite	*13
		Germantite	32	Hutchinsonite	8
Edingtonite	*6A	Gersdorffite	30	Hyalophane	5
Eleonorite	?R	Geyselite	M	Hydroboracite	5
Ellsworthite	MR	Gilsonite	M	Hydromagnesite	5
Elpidite	8	Gismondite	5	Hydrozincite	M
Embolite	32	Glaserite	21	Hypersthene	8
Emerald	27	Glauberite	5		
Emmonsite	?SI	Glaucodot	8	Ilmenite	17
Emplectite	8	Glaucosite	M	Ilminerutile	15
Enargite	8	Glaucophane	5	Ilsemannite	M
Enstatite	8	Gmelinite	17	Ilvaite	8
Eosphorite	8?HI	Goethite	8	Inesite	2
Epidiasmine	8?SI	Goslarite	*6I	Iodembolite	32?I
Epididymite	8	Graphite	21	Iodobromite	32
Epidote	5	Greenockite	*20IS	Iodyrite	*26?I
Epistilbite	*4?A	Griffithite	M	Iolite	8
Epistolite	5	Grossularite	32		
Epsomite	*6A	Guanajuatite	8?	Jadeite	5
Erikite	8	Gummite	M	Jamesonite	5?SI
Erythrite	5	Gymnite	M	Jarosite	21
Erythrosiderite	8	Gypsum	5	Jeffersonite	5?I
Euclase	5			Jenkinsite	M
Euchroite	8?I	Hackmanite	I	Jeze kite	5?
Eucolite	21	Haidingerite	?S	Johnstrupite	5
Eucairite	M	Halite	32	Jordanite	5
Eudialyte	21	Halloysite	M	Joseite	M
Eudidylite	5	Hambergite	8		
Eulytite	*31I	Hancockite	5?S	Kainite	5
Euxenite	8	Hanksite	27	Kalinite	30
		Hardystonite	M	Kaolinite	5
Fairfieldite	2	Harmotone	5	Kasolite	I
Fassaite	5	Hatchettolite	32?I	Kelihauite	5
Faujasite	32	Hauerite	*28I	Kentrolite	8
Fayalite	8	Hausmannite	*11I	Kermesite	5?SI
Ferberite	5	Hauynite	*31I	Kieserite	5
Fergusonite	*10I	Hedenbergite	5	Klaprotholite	8
Ferrierite	I	Hedyphane	M	Klebsbergite	?S
Florensite	21	Heintzite	5	Knopite	32?I
Fluocerite	27	Hellandite	5	Kobaltmanganerz	M
Fluorite	32	Heloite	*28?R	Koenenite	21
Forsterite	8	Helvite	*31I	Koppite	32
Forshagite	M	Hematite	21	Kornerupine	8
Fouquerite	I	Hercynite	32	Krennerite	8
Fowlerite	2	Herderite	8	Kroehnkite	5
Francolite	25	Herregrundite	5	Kunzite	2
Franklinite	32	Hessite	32		
Freibergite	*31C	Hetaerolite	M		

Labradorite	2	Melanite	32	Noselite	*31I
Langbanite	17	Melanocerite	21	Nowmeite	M
Langbeinite	*28A	Melanophlogite	?SI		
Langite	8	Melanterite	5	Ochrolite	I
Lanthanite	8	Melilite	15	Octahedrite	15
Lapis-lazuli	H	Meliphanite	*9?A	Okenite	M
Laumontite	5	Mellite	15	Oligoclase	2
Laurionite	8	Mendozite	30	Olivenite	8
Laurite	*28	Menilite	M	Olivine	8
Lautarite	5	Merwinite	I	Omphacite	M
Lavenite	5	Mesolite	5	Onofrite	31
Lawsonite	8	Metacinnabarite	*31I	Opal	M
Lazulite	5	Meta Torbernite	I	Orpiment	8
Lazurite	5	Metavoltine	?SI	Orthoclase	2
Leadhillite	5	Miargyrite	5	Osmiridium	21
Lehnerite	I	Microcline	2	Otavite	21
Lehrbachite	M	Microlite	32	Ottrelite	2?I
Leonite	5	Micropertchite	?HS		
Lepidolite	5	Microsommitte	?SI	Pachnolite	5
Lepidomelane	H	Miersite	*31R	Pandermite	5
Leucite	*31?I	Milarite	27*	Paragonite	5
Leucophanite	*6A	Millerite	*20I	Parahoeppite	2
Leucophoenicite	5?I	Mimetene	25	Paralaurionite	5
Libethenite	8	Mimetite	25, 231	Paratakamite	21?
Limonite	M	Minium	?S	Paravavxite	I
Linarite	5	Mirabilite	5	Pargasite	5
Linnaeite	32?	Mizzonite	13	Parisite	21
Licroconite	5?I	Molybdenite	27	Patronite	M
Liskeardite	M	Molybdite	8	Pearceite	5
Lithiophilite	8	Monazite	5	Pectolite	5
Loewite	15	Monticellite	8	Penninite	5
Loellingite	8	Montmorillonite	M	Pentlandite	32
Loparite	I	Montroydit	8	Percylite	32?I
Lorandite	5	Morensomite	6	Periclase	32
Loranskite	8?	Morganite	27	Peristerite	2
Ludlamite	5?I	Mosandrite	5	Perovskite	8?
Ludwigite	M	Mossite	15	Perthite	?H, S
		Mottramite	M	Petalite	5
Magnesite	21	Muellerite	M	Petzite	32?
Magnetite	32	Muscovite	5	Pharmacolite	5
Magnetoplumbite	I	Muthmannite	*7R	Pharmacosiderite	*31I
Malachite	5			Phenacite	17
Malacon	I	Nadorite	8?I	Phillipsite	5
Mallardite	MI	Nagyagite	8	Phlogopite	5
Manganhedenbergite	5?I	Natrolite	8	Phosgenite	15
Manganite	8	Natron	5	Phosphoferrite	M
Manganophyllite	I	Naumannite	32	Phosphophyllite	5
Manganosite	32	Nemalite	M	Phosphosiderite	I
Manganotantalite	8?	Neotantalite	32	Phosphuranylite	M
Marcasite	8	Neotocite	M	Pickeringite	M
Margarite	5?RI	Nephelite	*23I	Picotite	32
Margarosanite	2	Nephrite	M	Picromerite	5
Margasite	5	Neptunite	5	Piedmontite	5
Marialite	13	Nesquehonite	8?I	Pinakiolite	I
Marignacite	32	Nicolite	*20I	Pinguite	M
Marmolite	M	Nickolsonite	8	Pinite	M
Marshite	*31I	Nickelbluete	5	Pinnoite	*10I
Martite	32?I	Nickeleisen	32	Pirssonite	*7
Mascagnite	8	Niter	8	Pisolite	M
Matlockite	15?I	Nocerite	21?SI	Pitchblende	32
Maucherite	15?I	Northrupite	32	Plagionite	5?I
Meionite	15I			Plattnerite	15

Pleonast	32	Romeite	32?I	Stilpnosiderite	M
Plumbojarosite	21	Roscoelite	?S	Stolzite	13
Polianite	15	Rosenbushite	5	Strengite	8
Pollucite	?I	Rowlandite	M	Stromeyerite	8
Polybasite	5	Ruby	21	Strontianite	8
Polycrase	8	Rumpfitte	M	Struvite	*7A
Polydymite	32?	Rutherfordine	5	Sulfoborite	8?R
Polyhalite	5?I	Rutile	15	Sulfur	8 or 7
Polymignite	8			Sulvanite	M
Powellite	13C	Safflorite	8	Sussexite	M
Prehnite	*7I	Sal-ammoniac	*28	Svanbergite	21
Priorite	8?I	Salite	5	Sychnodymite	32
Prismatine	8	Samarskite	8	Sylvanite	5
Probertite	M	Sanidine	5	Sylvite	*28I
Prochlorite	5?I	Sapphirine	5	Symplesite	?SI
Proustite	*20C	Sarcolite	*10?I	Syndaliphite	5?
Pseudobrookite	8?S	Sartorite	5?S	Synganite	5
Pseudomalichite	M	Sassolite	2		
Psilomelane	M	Scheelite	13I	Tachyaphaltite	15
Psittacinite	M	Schefferite	5	Tachyhydrite	21M
Ptilolite	?S	Schirmerite	M	Talc	5
Pucherite	8	Schizolite	2	Tantalite	8
Pumpellyite	I	Schorlomite	32	Tapiolite	15
Pyroargyrite	*20I	Schreibersite	M	Tarbuttite	2
Pyrite	30	Schrockingerite	8	Tasmanite	?S
Pyroaurite	21	Schrotterite	M	Teallite	8?S, I
Pyrochlore	32	Schwartzengergite	?S	Tengerite	M
Pyrochroite	*20?I	Schwetznite	*31	Tennantite	*31I
Pyrolusite	8?HI	Scolecite	*4A	Tenorite	8
Pyromorphite	25	Scorodite	8	Tephroite	8
Pyrope	32?	Semseyite	5?I	Tetradymite	21
Phyrophanite	17	Senarmontite	32	Tetrahdrite	*31C
Pyrophyllite	8	Sepiolite	M	Thalenite	5
Pyropissite	M	Serpentine	5	Thaumasite	M
Pyrosmallite	I	Serpierite	8?S	Thenardite	8
Pyrostilpnite	5	Shortite	*7A	Thermonatrite	8
Pyroxene	5	Siderite	21	Thomsenolite	5
Pyroxmangite	2	Sillimanite	8	Thomsonite	8
Pyrrhotite	*20?C	Sipylite	*10I	Thorianite	32
		Skemmatite	H	Thorite	15
Quartz	*18A	Skutterudite	30	Thortveitite	8?I
Quenselite	I	Smaltite	*38I	Thuringite	M
Quercyite	M	Smithsonite	21	Tiemannite	*31A
Quisqweite	M	Sodalite	*31?I	Tiger-eye	M
		Sodaniter	21	Tilasite	5?I
Ralstonite	32	Spencerite	5	Titanite	5?I
Rammelsbergite	8	Spessartite	32	Titanmagneteisen	32
Raspite	5	Sphalerite	*31A	Topaz	8
Realgar	5	Spinel	32	Topazolite	32
Rhabdophanite	M	Spodumene	5	Torbernite	15
Rhodochrosite	21	Spurrite	5?I	Tourmaline	*20A
Rhodolite	I	Staffelite	M	Trechmannite	17
Rhodonite	2	Stannite	*11I	Tremolite	5
Rhomite	2	Staurolite	8	Tridymite	32?I
Richterite	I	Steenstrupine	21	Trimerite	2
Richardite	M	Stephanite	*7RI	Triphylite	5
Riebeckite	5	Sternbergite	8	Triplite	5
Rinkite	5	Stibiconite	M	Triploidite	5
Rinneit	21	Stibiotantalite	*7A	Tritomite	21?
Ripidolite	5	Stibnite	8?I	Troegerite	5?
Risorite	32?I	Stichtite	I	Troilite	M
Riversideite	M	Stilbite	5?	Trona	5

Troostite	17	Variscite	8?S	Wollastonite	5
Tscheffkinite	M, H	Vauxite	I	Wulfenite	*10
Tschemmigite	30	Vermiculite	I	Wurtzite	*20A
Tungstenite	M	Vesuvianite	15		
Tungstite	8	Villiamite	32?I	Xanthoconite	21
Turgite	I	Vivianite	5	Xanthophyllite	5?I
Turquoise	2	Volborthite	I	Xanthoxenite	5?S
Tychite	32	Voltaite	32?I	Xenotime	15
Tyrolite	M	Vonsenite	8?I		
Tysonite	27				
Ulexite	M	Wad	M	Yttrialite	M
Ullmannite	30	Wagnerite	5	Yttrocerite	M
Uralite	?HI	Walpurgite	2	Yttrofluorite	32
Uraninite	32	Warwickite	I	Yttrokrasite	8
Uranocricite	8?	Wavellite	I	Yttrotantalite	8
Uranophone	M	Wernerite	*10I		
Uranopilite	M	Whewellite	5	Zeratite	M
Uranosphaerite	M	Whitneyite	MI	Zaophyllite	I
Uranospinitite	8?	Wiikite	I	Zeunerite	15
Uranothallite	8	Wilkeite	I	Zincite	*19?I
Uranothorite	M	Willemite	17	Zinkenite	8
Uranotile	2	Wilsonite	I	Zinwaldite	5
Utahite	?S	Witherite	8	Zircon	15
Uvanite	8?S	Wittichenite	8	Zirkelite	32
Uvarogite	32	Woehlerite	5	Zoisite	8
Valentinite	8	Wolfchite	8	Zorgite	M
Vanadinite	25I	Wolframite	5	Zunyite	*31AS

Of the 830 minerals listed 70 belong to classes that allow piezo-activity but only 17 are found to be active by the Giebe and Scheibe test. (Our test of Iodyrite was negative but Greenwood and Tomboulian⁴ found it to be active; on the other hand, we found Scolecite to be active while they report it inactive.) It may be that others of the remaining 56 classes have such small piezo-electric constants as to be undetectable. Others may be incorrectly classified as to symmetry.

Of these active materials, quartz is the most important. Because of its excellent mechanical properties (stability, etc.) as well as for its relative cheapness it seems destined to remain one of the most important piezo materials.

Tourmaline is also important because of the high magnitude of its elastic moduli in certain directions; however, it cannot be obtained in large pieces of satisfactory homogeneity.

Sphalerite is very difficult to handle because of its many cleavage planes, and appears to give little promise of becoming practically useful. Its activity is quite marked.

Homogeneous crystals of calamine appear to be very rare, so that workable crystals large enough for ordinary piezo-electric application are unobtainable. Most of the material occurs massive.

⁴ On Piezo Electricity—Greenwood and Tomboulian—Zeits. f. Krist. Jan. 1932.

Epsomite gives a marked response but the crystals are generally small and they do not weather well. There is some possibility, however, that they can be made artificially.

Boracite gives a marked response, but boracite alters slowly. Its impermanence may bar it for some uses.

Stibiotantalite occurs only in thin scales, and the necessary cuts must be made in the most wasteful way. Twinning is prevalent and the composition varies widely.

Scolecite occurs only as small crystals a few millimeters in diameter and a centimeter or so in length, uniformly twinned.

Iodyrite has been found to be active by other investigators. It is electrically conductive, very soft and not very common.

Struvite is soft, unstable, and occurs only in small crystals.

Zunyite occurs only in minute crystals.

Langbeinite slowly changes its crystal structure. It may be made artificially so may be of some use if it can be kept from alteration.

Leucophanite and Meliphanite are related minerals. Neither seems to occur in good (i.e., homogeneous and untwinned) crystals of usable size.

Wurtzite does not appear very active but *good* crystals were not obtainable.

Tiemannite crystals were also unobtainable, but fragments of massive tiemannite responded. Crystals might respond more energetically if they were obtainable, but minerals that are too difficult to get would not be of practical use.

Epistilbite occurs only in small specimens, uniformly twinned.

The mineral clinohedrite is strongly active but crystals are very rare.

Cronstedtite and Edingtonite are very weakly active. Crystals of these are very rare.