

Ultraviolet fluorescence of minerals--Examples from New Mexico

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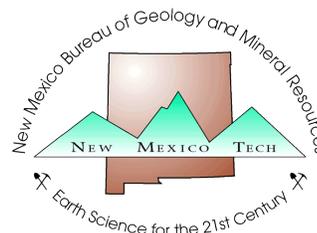
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Ultraviolet fluorescence of minerals

examples from New Mexico

by Peter J. Modreski

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Fluorescence, as the term is commonly used, refers to the emission of visible light by substances during their irradiation by ultraviolet (UV) light. Most minerals are not perceptibly fluorescent but many are, including a large number of light-colored, iron-free minerals. A few minerals, such as scheelite and autunite, are always or nearly always fluorescent because of the intrinsic presence of ions or atomic groups that absorb UV radiation and emit visible light. Most, such as fluorite, calcite, and apatite, are variably fluorescent depending on the presence of suitable impurity elements ("activators," such as Mn^{2+} , Cr^{3+} , Fe^{3+} , and Dy^{3+}) that cause fluorescence, and the absence of others ("quenchers," such as Fe^{2+} , Cu^{2+} , or Ni^{2+}) that destroy it. In some minerals a "coactivator" or "sensitizer," such as Pb^{2+} , is required to provide the necessary energy levels to absorb UV radiation. Phosphorescence is the continued emission of light from a material after the source of irradiation has been removed. Luminescence is a general term encompassing fluorescence plus light emission due to other forms of excitation, such as cathodoluminescence.

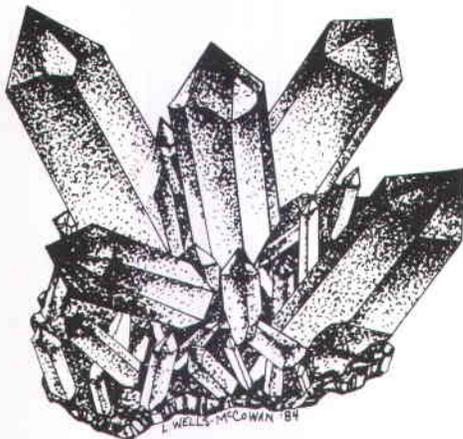
Fluorescence in minerals is observed commonly through excitation by two types of UV source: shortwave UV light, usually produced by a low-pressure mercury discharge lamp that produces a spectrum containing the Hg line at a wavelength of 254 nanometers (nm); and longwave UV light, which contains a strong component of light near 365 nm and is usually produced by a mercury lamp coated with a phosphor. Both types of lamp are used with filters that remove the bulk of the visible light unavoidably produced by the lamps. Shortwave UV is more effective than longwave in producing fluorescence in most minerals, although a few (such as fluorite and sodalite) respond best to longwave excitation. More energetic means of excitation—such as cathodoluminescence—produce luminescence in a greater variety and proportion of minerals than does UV irradiation (see McLemore and Barker, 1987). However, the easy use of UV fluorescence—with simple and relatively inexpensive equipment, with hand specimens or mineral samples requiring no advance preparation, and its use in the field with a battery-powered light—makes this an effective technique for observing features of rocks and minerals that would otherwise not be detected.

For minerals in which chemical bonding has a high ionic character (minerals that are electrical insulators) luminescence, including fluorescence, is explainable in terms of crystal field theory. Most fluorescence in such

minerals (including most silicates, oxides, carbonates, and halides) is due to transitions between quantized electronic energy states of the electrons in metal cations (such as Mn^{2+}) or in polyatomic molecular ions (such as UO_2^{2+}). In minerals that are semiconductors (such as some sulfides, typified by sphalerite), the electronic transitions are not localized on particular atoms but are a function of the total composition of the mineral and are interpreted in terms of band theory; for semiconductors, it is more difficult to attribute fluorescence to a specific metal impurity.

Fluorescence in minerals is not always assignable to a specific metal impurity; it may be due to lattice defect centers such as those involving trapped electrons and missing electrons "holes," ion vacancies, and substitution of ions of differing charge than that of the ion normally occupying a given lattice site. Most metallic or submetallic minerals (including the metallic native elements and most sulfides and sulfosalts) do not exhibit fluorescence. Identification of the activators responsible for fluorescence is sometimes simple, but it can also be a complicated process that may require optical spectroscopy, trace-element analysis, synthesis of pure and doped minerals to verify the role of particular elements, and use of electron paramagnetic resonance (epr) techniques to verify the presence of electron-hole centers and para-

Full color photographs inside . . .



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magnetic ions. For further information on the luminescence of minerals, the reader is referred to the following sources: Leverenz (1968), Sommer (1972), White (1975), Mariano (1978), Marfunin (1979), Newsome and Modreski (1981), Tarashchan (1978), and Walker (1985).

Fluorescence can be useful to the geologist and mineralogist in many ways: as a way of recognizing minerals (sometimes of economic value), which would otherwise go undetected; providing an indication of zoning or alteration in minerals; as a means of recognizing the presence of certain metals or other elements; as evidence of variation in metal content or conditions of deposition throughout a body of rock; and as a sensitive geochemical probe of the internal crystal chemistry of a mineral. The minerals illustrated here include some of the brightest, most common, and distinctive of the fluorescent minerals known to occur in New Mexico. For additional information about the occurrence and properties of fluorescent minerals, the reader can refer to several books (Gleason, 1972; Robbins, 1983), reports (Barnes, 1958; Frondel, 1958; Stephenson, 1962), and to the articles cited below.

The photographs reproduced here were taken on 35 mm Ektachrome, daylight-type slide films. Film speeds used ranged from 64 to 400 ASA; exposure times (at $f/8$ to $f/16$) ranged from 5 to 120 seconds. Specimens to be photographed were placed on a black cloth background and illuminated with either of two commonly used 110 V UV lights, a UVP, Inc., UVG-54 shortwave UV light, or a UVL-56 longwave UV light. A barrier filter (Wratten gelatin filter type 2E) was used over the camera lens to block reflected UV from entering the lens and fogging the film, either directly or through fluorescence of the camera lens elements. Intense fluorescence of vivid spectral hues is easy to record accurately on film, whereas dim fluorescence, especially of unsaturated, pastel colors, may be difficult to record accurately. There is, however, considerable opportunity to vary photographic conditions to obtain an optimum brightness and color balance in a photograph of fluorescence; film speed, type of film (daylight or tungsten), exposure time (which affects the apparent color as well as the brightness of the photographic image), type of barrier filter, and use of additional color filters can all be adjusted to obtain more accurate photographs (see Eastman Kodak Company, 1972, 1978). Aside from the problem of accurately reproducing in a photograph the colors of mineral fluorescence, it can even be difficult to describe such colors in words. Newsome and Modreski (1981) and Newsome (1982, 1985) have shown that the colors of fluorescent minerals can be quantitatively and objectively described by converting a measured spectrum into standard chromaticity coordinates.

Fluorite is possibly the classic example of a fluorescent mineral; the term is derived from the name of this mineral. Fluorite most commonly fluoresces blue-violet (Figs. 1, 2), more strongly under longwave UV than short-

wave. The fluorescence is activated by rare-earth-element (REE) impurities, of which Eu^{2+} accounts for the typical blue-violet color (Haberlandt and others, 1934; Przibram, 1935; Marfunin, 1979). High abundance of other REE in fluorite can produce other colors of fluorescence (Barabanov and Goncharov, 1967; Marfunin, 1979) such as the greenish-white fluorescence under shortwave UV noted for fluorite from the Globe pegmatite, Rio Arriba County (Modreski, 1987).

Calcite is another mineral that commonly fluoresces. Its typical fluorescence is red-orange, generally much stronger under shortwave UV than under longwave. This red fluorescence is emitted by Mn^{2+} , the activator, for which Pb^{2+} commonly acts as a coactivator (Murata and Smith, 1946; Schulman et al., 1947). Red-fluorescent manganese-activated calcite is found in a wide variety of occurrences, including metamorphic rocks, hydrothermal veins associated with ore deposits, relatively low-temperature veins and nodules in sedimentary rocks. A wide spectrum of other colors of fluorescence, including blue, pink, yellow, and white, are, less frequently, encountered in calcite; most of these calcites have not been studied sufficiently to determine the nature of the activators, although it is probable that defect centers related to trapped electrons or electron holes account for many of the very broad-band, whitish-colored types of fluorescence. Calcite from the Waldo mine, shown in Figs. 3 and 4, illustrates both the typical red fluorescence (SW) and a less common, bluish-white fluorescence of unknown origin.

Gypsum, as illustrated in Fig. 5 under longwave UV, is another example of a mineral with fluorescence of undetermined cause; the white fluorescence of this specimen from the Stevenson-Bennett mine is probably due to defect centers. Parts of this specimen also exhibit a green fluorescence, brighter under shortwave UV, and attributable to hexavalent uranium in the form of the uranyl ion, UO_2^{2+} .

Fluorescence has played an important role in discovery and study of scheelite deposits. Nearly all scheelite is fluorescent, due to intrinsic luminescence from the tungstate (WO_4^{2-}) molecular ion. The color of the fluorescence varies in a predictable way, from blue for pure tungsten scheelite (CaWO_4) through bluish-white, white, and yellowish-white to yellow for scheelite with increasing Mo content.

A fluorescence comparator card containing 12 calibrated samples of fluorescent powders in the scheelite-powellite series was produced by Ultra-violet Products, Inc., for estimation of the molybdenum content of scheelite ores. According to this comparator, the scheelites illustrated here (Figs. 6-8) contain (expressed in both weight percent Mo and mole percent powellite, CaMoO_4): less than 0.05 wt. % Mo (<0.15 mole % powellite) in the Irish Rose mine; approximately 0.7 wt. % Mo. (2 mole % powellite) in the Ortiz mine; and more than 5 wt. % Mo (>14 mole % powellite) in the Iron Mountain No. 2 mine. The fluorescence of all scheelite-powellite

containing more than this amount of molybdenum appears equally yellow, and cannot be differentiated with the visual comparator. Semiquantitative determination of the Mo content using energy-dispersive, x-ray fluorescence spectrometry (XRD-EDS) confirms these compositions, showing approximately 1-2 mole percent powellite in the white-fluorescent scheelite from the Ortiz mine (Fig. 7) and approximately equal amounts of Mo and W in the yellow-fluorescent Iron Mountain powellite-scheelite (Fig. 8). The scheelite rimming wolframite shown in Fig. 6 is very similar to that illustrated by Van Horn (1930) from Cornwall, England.

A wide variety of other ore and gangue minerals of hydrothermal ore deposits exhibit fluorescence, particularly the secondary, oxidized minerals. Fig. 9 shows the longwave fluorescence of fluorite (blue-violet) with associated cerussite (yellow) from the Blanchard mine. Willemite and calcite, from the tactite deposit at Iron Mountain, fluoresce, respectively, green and red under shortwave UV (Fig. 10), duplicating the colors of the famous willemite-in-calcite ore of Franklin, New Jersey. The distinctive colors of fluorescence in these two minerals are both produced by the same activator, Mn^{2+} , reflecting the different crystal field energy of four coordinated Mn^{2+} in willemite vs. six coordinated Mn^{2+} in calcite (White, 1975). One readily observable characteristic that helps to distinguish willemite from green-fluorescent uraniferous opal, which is found

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FIGURE 1—Fluorite; Blue Jacket mine, Caballo Mountains, Sierra Co.; 5.5 × 5 cm; banded green fluorite as open-space filling around breccia fragments, overlain by slightly amethystine quartz; 3200 K floodlamps, with blue filter. ASA 64, *f*/11, 1/8 sec.

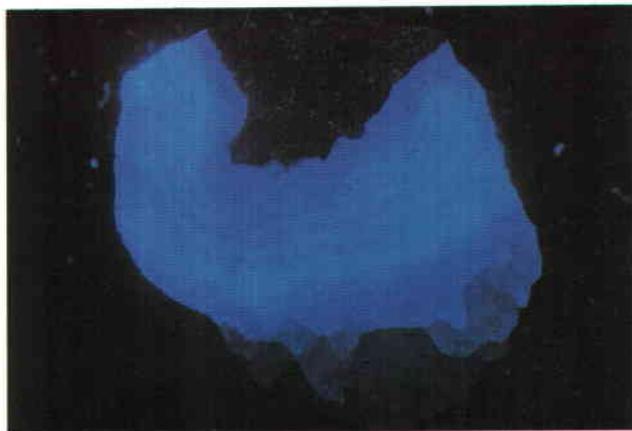


FIGURE 2—Same specimen as Fig. 1, showing blue-violet fluorescence of fluorite under longwave UV; predominate activator is probably Eu^{2+} . ASA 64, *f*/8, 1 min.



FIGURE 3—Calcite; Waldo mine, Magdalena district, Socorro Co.; 4.5 × 4 cm; typical orange-red fluorescence of calcite (shortwave UV) from interior scalenohedral growth zones of slightly grayish calcite, overgrown by colorless, steep rhombohedral terminations with blue-white fluorescence. Activator of the red fluorescence is Mn^{2+} ; cause of blue-white fluorescence is unknown, but probably related to defect centers. Blue-white areas also have strong blue-white phosphorescence. ASA 64, *f*/8, 20 sec.



FIGURE 4—Same specimen as Fig. 3, longwave UV; tips of crystals fluoresce white, and interior growth zones fluoresce weak red. ASA 64, *f*/8, 2 min.

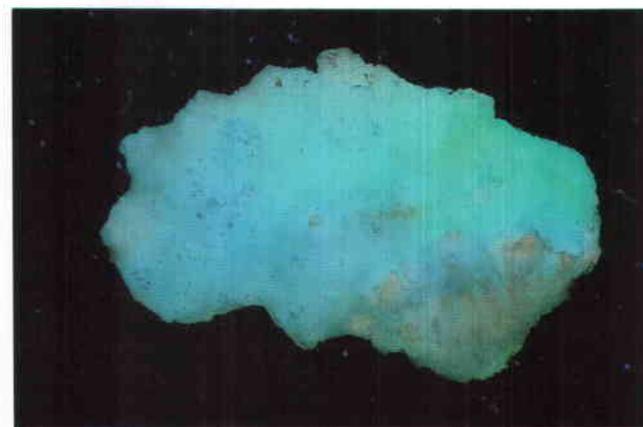


FIGURE 5—Gypsum; Stevenson-Bennett mine, Doña Ana Co.; 7 × 4 cm; crust of white, sugary gypsum; fluorescent blue-white to greenish-white (longwave UV); shortwave fluorescence (not shown) is bright green. Uranyl ion (UO_2^{2+}) activator accounts for the areas of brightest green fluorescence; the overall white fluorescence is probably due to defect centers. ASA 64, *f*/8, 45 sec.



FIGURE 6—Scheelite; Irish Rose mine, Victorio district, Luna Co.; 4.5 × 3 cm; scheelite rimming wolframite; fluorescent blue (shortwave UV); fluorescence of scheelite is intrinsic to the tungstate (WO_4^{2-}) ion. ASA 100, *f*/11, 60 sec.



FIGURE 7—Scheelite; Ortiz gold mine, Santa Fe Co.; 1.2 × 0.9 cm; bipyramidal crystal (orange in normal light); fluorescent white (shortwave UV). ASA 400, f/16, 50 sec.



FIGURE 8—Powellite; Iron Mountain No. 2 mine, Sierra Co.; 6 × 4 cm; white crystals in garnet-magnetite tactite; fluorescent yellow (shortwave UV); this specimen contains about 50 mole percent CaMoO_4 . ASA 64, f/8, 20 sec.

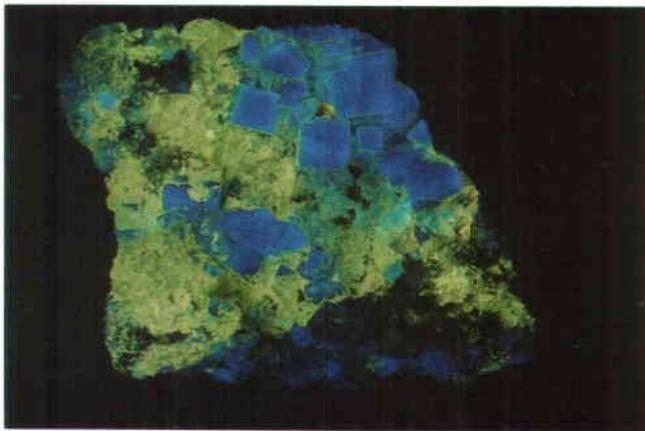


FIGURE 9—Fluorite with cerussite; Blanchard mine, Hansonburg district, Socorro Co.; 6 × 6 cm; fluorite cubes fluoresce blue-violet, and a late coating of fine-grained, powdery, white cerussite fluoresces yellow (longwave UV). Activator in fluorite is Eu^{2+} ; in cerussite, unknown. ASA 100, f/8, 45 sec.

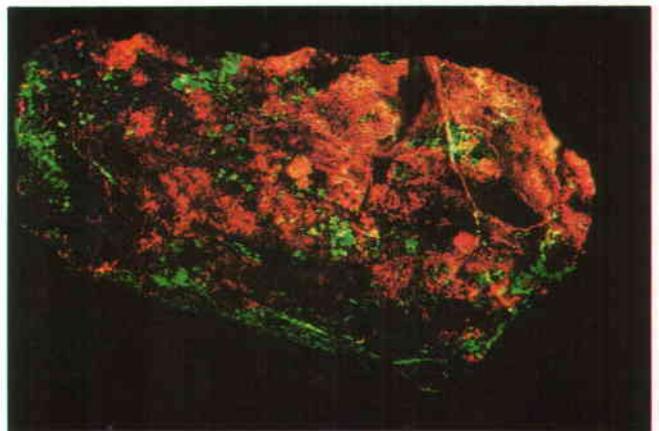


FIGURE 10—Willemite with calcite; Iron Mountain, Sierra Co.; 8 × 4 cm; willemite fluoresces green, calcite fluoresces red (shortwave UV); activator in both minerals is Mn^{2+} . ASA 100, f/8, 30 sec.

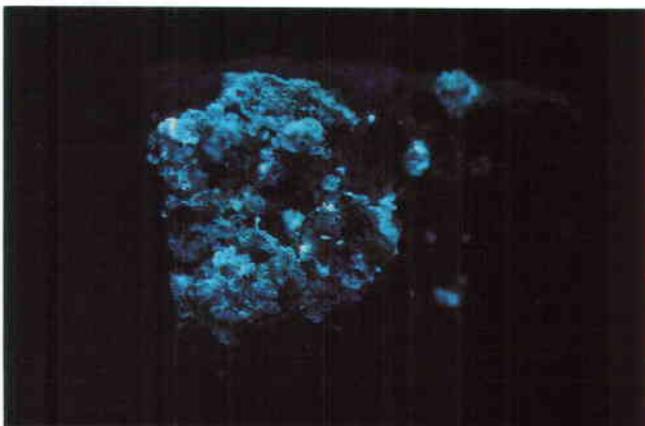


FIGURE 11—Hydrozincite; Blanchard mine, Socorro Co.; 4 × 3 cm; late encrustation on gypsum; fluorescent blue (shortwave UV); activator is unknown. ASA 100, f/8, 30 sec.



FIGURE 12—Smithsonite; Empire mine, Hanover district, Grant Co.; 11 × 6.5 cm; yellow "turkey-fat" cadmium-bearing smithsonite; fluorescent deep red (shortwave UV); longwave fluorescence (not shown) is dull orange. ASA 100, f/8, 45 sec.



FIGURE 13—Andersonite; Ambrosia Lake, McKinley Co.; 5 × 4 cm; greenish-yellow crust on sandstone; fluorescent bluish-green (shortwave UV); intrinsic fluorescence due to UO_2^{2+} . ASA 64, f/8, 5 sec.

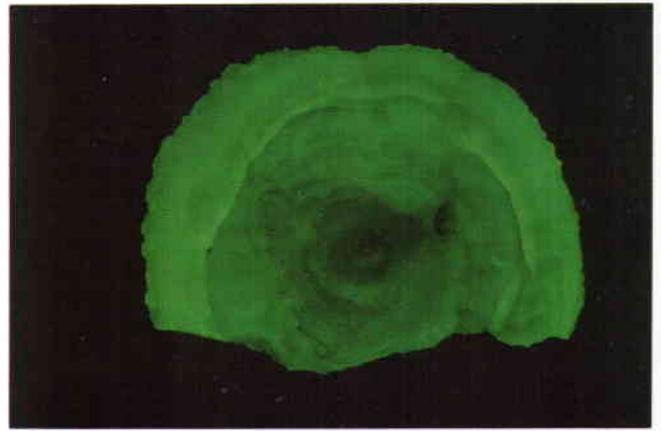


FIGURE 14—Chalcedony; Apache Creek area, Catron Co.; 5 cm diameter; pale pink "chalcedony rose" nodule; fluorescent green (shortwave UV); activator is UO_2^{2+} . ASA 64, f/8, 45 sec.



FIGURE 15—Calcite with opal; Kelly mine, Magdalena district, Socorro Co.; 7 × 5 cm; white botryoidal/arborescent calcite intergrown with a small amount of opal; fluorescent green (shortwave UV); activator is UO_2^{2+} in the opal. ASA 64, f/8, 10 sec.

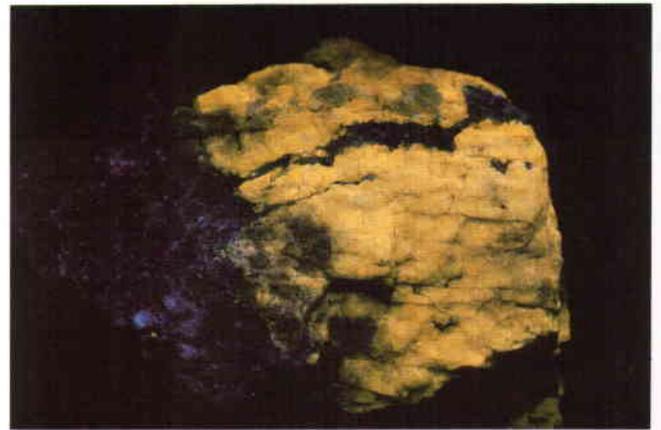


FIGURE 16—Apatite; Harding pegmatite, Taos Co.; 5.5 × 4.5 cm; portion of a blocky, gray-white to bluish-gray crystal; fluorescent yellow (shortwave UV); predominant activator is Mn^{2+} . ASA 400, f/8, 5 sec.

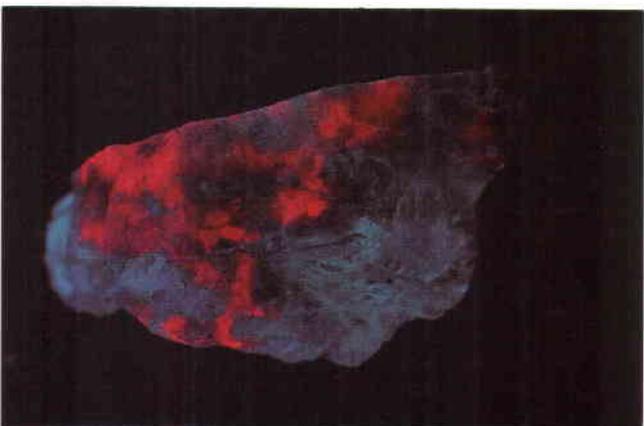


FIGURE 17—Eucryptite; Harding pegmatite, Taos Co.; 5 × 3 cm; white, anhedral eucryptite, intergrown with spodumene and quartz; fluorescent red (shortwave UV); activator uncertain. ASA 100, f/8, 30 sec.

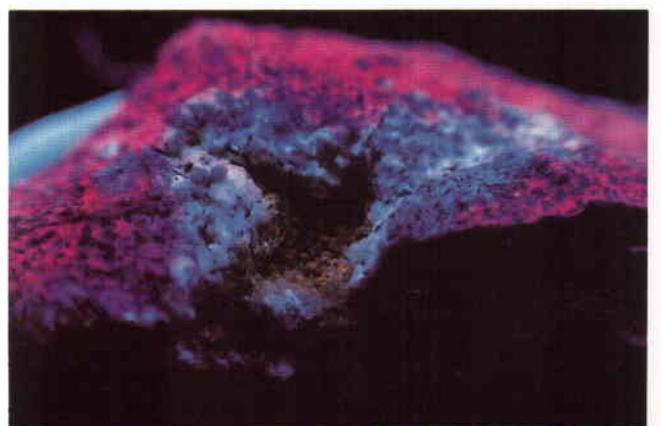


FIGURE 18—Alkali feldspar (orthoclase and/or sanidine) in phonolite around gas cavity; Point of Rocks Mesa, Colfax Co.; 4 × 2 cm. Pinkish-red fluorescence of the feldspar (shortwave UV) gives way to bluish-white fluorescence immediately around the miarolitic cavity, within which crystals are coated with a thin film of an asphaltic or hydrocarbon material, which fluoresces orange. Probable activator in the red-fluorescing feldspar is Fe^{3+} ; activator of the blue-fluorescing feldspar may be Eu^{2+} . ASA 400, f/8, 1 min.

on fracture surfaces in many rocks, is the common phosphorescence of willemite; opal is almost never phosphorescent.

Hydrozincite, $Zn_5(CO_3)_2(OH)_6$, commonly found in small amounts in oxidized zinc ores, often fluoresces bright blue under shortwave UV (Fig. 11); the cause of this fluorescence appears never to have been studied. Smithsonite is not normally fluorescent, but yellow "turkey-fat" smithsonite from the Empire mine (Fig. 12) has a strong, deep red fluorescence under shortwave UV (weaker orange long-wave), as was first pointed out by Graeme and Graeme (1985). The surface layer of the red-fluorescent smithsonite shown in Fig. 12 contains approximately 0.6 wt. % Cd (by XRF-EDS); smithsonite of a similar yellow color and red fluorescence occurs at Mapimi, Mexico, and elsewhere.

Many, but not all, of the hexavalent uranium minerals are fluorescent, due to the uranyl (UO_2^{2+}) ion; color of the fluorescence ranges from yellow-green to blue-green. Gorobets et al. (1977) and deNeufville et al. (1981) pointed out that in uranium minerals that fluoresce yellow-green (including autunite, novacekite, uranospinitite, and zippeite) the uranyl ion occupies a site with tetragonal (point group D_{4h}) symmetry, whereas in those that fluoresce bluish-green (including andersonite (Fig. 13), liebigite, bayleyite, and schroekingite) the uranyl site has D_{2h} or D_{3h} symmetry. Some other uranyl minerals (carnotite, uranophane, and torbernite) and minerals containing unoxidized tetravalent uranium do not fluoresce. Uranium, in the form of the uranyl ion associated with 4–6 water molecules (Gorobets et al., 1977), also occurs in other minerals, particularly in the cryptocrystalline forms of quartz and in opal; it accounts for the green fluorescence often seen in agate, chalcedony (Fig. 14), and opal. Calcite and aragonite have often been described as exhibiting a green fluorescence, but in all of the samples I have examined (including calcite and aragonite from New Mexico, Arizona, California, Colorado, Washington, and Mexico), the fluorescence is localized in thin layers of opal on the surface of the carbonate or intergrown with it.

This is the case with white, botryoidal, green-fluorescent calcite from the Kelly mine shown in Fig. 15. Green-fluorescing calcite from the Tres Hermanas Mountains, Luna County (not shown), similarly contains opal. The carbonate mineral shown in Fig. 15 is verified as calcite by x-ray diffraction, although it is possible that it originally crystallized as aragonite, which subsequently inverted to the more stable calcite polymorph. Green-fluorescent uranyl ion in minerals can be recognized readily by the distinctive bands in its spectrum due to vibrational quantum levels in the uranyl molecular ion (Gorobets et al., 1977; Newsome and Modreski, 1981), as recorded by a spectrophotometer or seen with a hand spectroscopy. Fifty to several hundred parts per million (ppm) of uranium as UO_2^{2+} is sufficient to cause a bright fluorescence in agate or opal (deNeufville et al., 1981; Zielinski,

1980), and as little as 2–6 ppm is reported to produce fluorescence detectable in the laboratory (Gorobets and Pormnov, 1973). Adamite, $Zn_2AsO_4(OH)$, from Mapimi, Mexico, containing 270 ppm U also has a bright green fluorescence and shows the characteristic spectrum of the uranyl ion (Newsome and Modreski, 1981; Modreski and Newsome, 1984).

Apatite is a common fluorescent mineral; the fluorescence can be due either to Mn^{2+} (yellow fluorescence) or to various combinations of REE, including Eu^{2+} , Ce^{3+} , Sm^{3+} , and Dy^{3+} , producing blue, white, or pink fluorescence (Knutson et al., 1985; Leckebusch, 1979; Portnov and Gorobets, 1969; Marfunin, 1979). Yellow-fluorescent apatite, shown in Fig. 16 from the Harding pegmatite, is typical of many pegmatitic apatites. Apatite from the Copper Flat porphyry copper deposit, Sierra County, fluoresces pinkish-white under shortwave UV (Modreski, 1987).

Aside from the apatite mentioned above, the Harding pegmatite is noted for red-fluorescent eucryptite (Fig. 17). Some spodumene from the Harding pegmatite fluoresces white or blue-white; whether this is due to the spodumene itself or to an alteration mineral is not clear. A newly recognized mineral (London, 1986) from the Harding pegmatite is the margarite-group mica bityite, $(Ca,Na,K)LiAl_2(AlBeSi)_2O_{10}(OH)_2$. Bityite occurs as grayish-white platy crystals in the hanging-wall-contact zone of the pegmatite and may be recognized by its consistent weak, grayish-white fluorescence under shortwave UV (not shown).

Many of the light-colored silicate minerals in low-iron igneous rocks (particularly granites, syenites, and granite pegmatites) can fluoresce. Albite and the potassium feldspars typically fluoresce in shades of red, which may range from barely perceptible to moderately bright. Red fluorescence in feldspar has been ascribed predominantly to Fe^{3+} (Mariano, 1978; Marfunin, 1979; White et al., 1986), although REE, Pb^{2+} , and many other metals may also play a role (Marfunin, 1979). Yellow to orange to red fluorescence of sodalite and related feldspathoids is due to the S_2^- molecular ion (Marfunin, 1979). Fig. 18 shows red-fluorescent alkali feldspar from the phonolite sill at Point of Rocks Mesa grading into blue-fluorescent (due to Eu^{2+} ?) feldspar around a gas cavity that also contains an orange-fluorescent hydrocarbon coating. Numerous fluorescent minerals are present in the phonolite at Point of Rocks; some individual hand specimens show fluorescent feldspar (violet-red), zircon (yellow), villaumite (yellow-orange) and opal (green) in shortwave UV, and sodalite (orange) and villaumite (orange-red) under longwave UV (not shown); still other fluorescent minerals occur at Point of Rocks (Modreski, 1987).

Much remains to be learned about the fluorescence of minerals. Activators in many minerals are still understood poorly or not at all. The distribution of fluorescent minerals and variation of their fluorescence within or around a given deposit has been system-

atically studied in only a very few cases. Rarely has enough work been done to permit correlations between fluorescence, mineral chemistry, associated minerals, paragenetic position, and the physical and chemical parameters of the crystallization environment. The combination of fluorescence observations with microprobe and trace-element analyses, fluid inclusion and isotopic data, and cathodoluminescence and other techniques holds promise for much new insight into the mechanisms and conditions of mineral deposition.

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85-126—Lithologic descriptions of selected Middle and Upper Jurassic rocks from Gallup to Laguna in northwest New Mexico, by S. M. Condon, 1985, 68 pp.

86-283—Analytical results for 38 hot spring samples collected in the western United States, by W. H. Ficklin, C. L. Smith, and J. R. Motooka, 1986, 3 pp.

Special maps for sale

The New Mexico Bureau of Mines and Mineral Resources now offers for sale maps of mining districts and mineral deposits in the western states. Separate maps, compiled and published by Charles A. Mardirosian, consulting geologist, cover the states of Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. They are printed in three colors at a scale of 1:1,000,000 (Alaska, scale 1:2,500,000) and show counties, major towns, topography, coal fields, and mining districts. The districts and deposits are tabulated by county along with the principal commodity and a geologic description and/or reference number. Reference citations are grouped in a separate table for easier use. In addition to the state maps, a composite map of eleven western states (excluding Alaska) at a scale of 1:2,000,000 is available.

Previously sold at \$30.00 or more, these maps are now being offered for \$10.00 each. They are an invaluable reference tool for geologists, mining engineers, and mineral collectors. An illustrated brochure is available free upon request. Orders can be addressed to NMBMMR, Publications Office, Socorro, NM 87801. Telephone inquiries will be answered at (505)835-5410.

Grand Junction Geological Society trip

The Grand Junction Geological Society, in cooperation with the Museum of Western Colorado, will sponsor a field trip to world-famous dinosaur quarries and museums, September 18-20, 1987. The trip will begin and end in Grand Junction, Colorado, with overnight stops in Price and Vernal, Utah. For information and registration forms contact Bill Chenoweth, 707 Brassie Drive, Grand Junction, CO 81506.

Responses to geologic questionnaire

Responses to the questionnaire concerning geologic projects in New Mexico will be published in the next issue of *New Mexico Geology* (v. 9, no. 3) instead of this issue. The form, which was published in *New Mexico Geology*, v. 8, no. 4 (November 1986), must be sent in before May 30, 1987, in order to be included with the many listings already received.

MINING REGISTRATIONS

(November 6, 1986, through February 11, 1987)

Bureau of Mine Inspection Energy & Minerals Dept. 2825-E Broadbent Pkwy. NE Albuquerque, NM 87107

Date and operation	Operators and owners	Location
11-6-86 gold, silver, silicon	Operator—Antelope, Picom Corp., P.O. Box 120, Winston, NM 87943; Gen. Mgr.—James Grainger, Chloride, NM. Property owner—St. Cloud Mining Co., Winston, NM.	Sierra County; sec. 26, T9S, R9W; private land; directions to mine: 0.5 mi north of the Great Republic mine.
11-6-86 metal	Operator—Cat. Mountain, Falcon Mining Corp., (Greg Richards), P.O. Box 5575, Hobbs, NM 88241; Gen. Mgr.—Greg Richards, same address, phone: 392-1515; Gen. Supt.—Ron Richards, P.O. Box 80261, Midland, TX 79709, phone: (915) 697-5255; Official—Russell Richards, same address as Gen. Supt. Property owner—Mozelle Johnston, P.O. Box 362, Socorro, NM 87801, phone: 835-1365.	Sierra County; sec. 10, T16S, R7W; federal land; directions to mine: 2 mi east of Hillsboro inside sharp bend in NM-90 at milepost 101.
12-3-86 silver	Operator—Hopeful Claims, James L. Reed, owner, P.O. Box 836, Bayard, NM 88023-0836; Gen. Mgr.—James L. Reed. Property owner—James L. Reed, same address as above.	Grant County, sec. 18, T18S, R16W; federal land; directions to mine: west of Tyrone (P.D.) 5 mi on NM-180 West—Goat Canyon.
1-22-87 silver and gold	Operator—Carlisle Mine, Royal Minerals, Inc., P.O. Box W, Duncan, AZ 85534; Person in charge—Douglas Hanson, Mesquite Ave., Duncan, AZ 85534, phone: (602) 359-2835; Other official—Michael Best. Property owner—Douglas Hanson, President	Grant County, sec. 1, T17S, R21W; private land; directions to mine: 15 mi from Duncan, AZ, on Carlisle Rd.
1-22-87 silver and gold	Operator—East Camp, Royal Minerals, Inc., P.O. Box W, Duncan, AZ 85534; Person in charge—Douglas Hanson, Mesquite Ave., Duncan, AZ 85534, phone: (602) 359-2835; Other official—Michael Best. Property owner—Douglas Hanson, President	Grant County; secs. 5-9, T16, 17S, R21W; private land; directions to mine: 20 mi from Duncan, AZ, on Carlisle Rd.
1-27-87 Placer mill	Operator—Rattlesnake Mill Site, Black Range Exploration, Inc., P.O. Box 183, Hillsboro, NM 88042; Gen. Mgr.—Sonny Hale, same address; Supt.—Rex L. Evatt, III, same address. Property owner—Black Range Exploration, same address.	Sierra County; sec. 10, T16S, R7W; private land; directions to mill: Warm Springs Road.

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