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PRELIMINARY MAP OF FLUORINE PROVINCES IN THE CONTERMINOUS UNITED STATES

By

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INTRODUCTION

Fluorine, a chemical element used widely in the manufacture of steel, aluminum, fluorocarbons, and certain other organic and inorganic compounds, ceramics, glasses, and plastics, is derived from the minerals fluorspar and fluorapatite. In 1976, the United States consumed about 680,000 short tons (612,000 metric tons) of fluorine valued at about $136 million. Satisfactory substitutes do not exist for most of its uses. Largely because fluorine emitted around plants producing phosphoric acid, aluminum, and fluorine chemicals has a bad effect on the environment, increasing quantities of fluorine are being recovered or recycled each year. Some uses, however, are dissipative in that the fluorine is not presently recoverable.

Fluorspar is the commercial name for the mineral fluorite (CaF_2), which contains about 49 percent F and 51 percent Ca. It is the main source of fluorine and is an essential, strategic, and critical raw material that the United States cannot profitably produce in sufficient quantity; more than 1 million tons (900,000 metric tons) of several grades of concentrates are stockpiled for national emergencies. Mined fluorspar ore generally averages more than 25 percent CaF_2 and may be accompanied by lead, zinc, barium, or other coproducts. It takes 2.5 to 3 units of crude ore to make one unit of finished fluorspar product in the United States.

The United States annually consumes 1.2 to 1.5 million tons (1.1 to 1.4 million metric tons) of fluorspar, about 30 percent of the world's supply, but produces only a small proportion of the demand domestically. For the past five years, the United States production of beneficiated fluorspar, currently valued at approximately $100 a short ton, averaged about 166,000 short tons (150,000 metric tons) annually, equivalent to about 73,000 tons (66,000 metric tons) of fluorine. About 85 percent of the domestic fluorspar mined in 1976 was from the Illinois-Kentucky district (no. 1), and the rest was mined in Arizona, Montana, Nevada, Texas, and Utah. About 85 percent of the United States' requirements for fluorspar is imported each year. Between 1973 and 1976 the imports came from Mexico (73 percent), Spain (8 percent), Italy (4 percent), South Africa (3 percent), and others (12 percent) (U.S. Bur. Mines, 1978). By the year 2,000 the nation's need for fluorspar or equivalent from fluorapatite may reach 4 million tons to satisfy an estimated demand of nearly 2 million tons (1.8 million metric tons) of fluorine (Wood, 1976, p. 396).

Since 1968, fluorine also has been manufactured from fluosilicic acid, a byproduct of phosphoric acid derived from fluorapatite ($Ca_{10}(PO_4,CO_3)_6 F_{2-3}$), which occurs in bedded marine phosphorite, phosphatic shale, and phosphatic limestone. As an indication of how important phosphate rock has become as a source of fluorine in 1977, 11 plants in the United States produced about 64,000 tons (58,000 metric tons) of fluosilicic acid byproduct from phosphoric acid manufacture, equivalent to 50,000 tons (45,000 metric tons) of fluorine (DeFilippo, 1978). For 8 of these plants, the phosphate rock came from Florida deposits; for the other 3 plants, it came from deposits in North Carolina, Utah, and Morocco (R. J. DeFilippo, oral commun., 1979). The fluosilicic acid was used in the aluminum and chemical industries and in water fluoridation.

The accompanying fluorine province map is the first to show localities for the two main sources of fluorine It shows the geographic areas in the conterminous United States where fluorspar and fluorapatite have been found and where the best potential still exists for the discovery of extensions of these deposits and of new primary and byproduct sources of fluorine. Present and future potentially large source deposits are indicated as well as subeconomic occurrences in which fluorine may be produced as a byproduct commodity. Preliminary estimates of the resource potential in the provinces are indicated in table 1. The map was compiled largely from data in publications (Gower and Madsen, 1964; Cathcart and Gulbrandsen, 1973; Brown, 1974; Worl and others, 1974; Heyl, 1974; Van Alstine, 1976a, b; Cannon and Klasner, 1976; Sheppard and Gude, 1969; and Shawe and others, 1976; and Worl, 1974) and from records of fluorine resource specialists of the Geological Survey. Selected geologic information, which is the basis for the regional boundaries shown on the map, is from the Geologic Map of the United States (King and Beikman, 1974). The rationale of province maps and some of the unfamiliar technical terms and geologic concepts used in the atlas of metal and nonmetal provinces, of which this map is a part, are discussed and defined in a companion background report by Tooker (1979).

DISTINGUISHING MAP FEATURES

The provinces shown on the map identify areas of the conterminous United States that contain significant deposits and occurrences of fluorine in fluorspar in igneous, sedimentary, and metamorphic rocks, or in sedimentary fluorapatite in phosphate rock. The map symbols indicate the size of the deposits and whether the locality is a source of fluorspar or fluorapatite. A province represents a region containing a thinly populated collection or a cluster of deposits or occurrences that may have formed in similar geologic environments. No distinction as to economic or subeconomic value is implied in this definition. Where possible, the boundaries of fluorapatite provinces are drawn on the basis of geologic units, which often results in a province composed of detached areas containing compatible types of deposits or unevaluated occurrences. For example, in the fluorapatite provinces in Alabama, Arkansas, Texas, California, Idaho, Utah, and Wyoming, the limits of the provinces are drawn around areas where phosphate rock formations crop out intermittently. In the absence of a prominent mappable formation, the boundary may enclose discrete groups of localities.

Systematic assessment of fluorine resources may reveal greater resource possibilities than are currently recognized for some areas. The province map is designed to help narrow the search for geologically favorable concentrations of fluorine resources.

Deposits and occurrences of fluorine minerals and materials are divided into large and small sizes on the maps of the atlas series (Tooker, 1979). For fluorspar, the classification is consistent with that of Worl and others (1974). Large deposits include those whose combined production and remaining minable or potentially minable fluorspar ore, or equivalent fluorapatite exceed 2 million short tons (1.8 million tonnes); the concentrates from this quantity of ore are valued at more than $60 million. For comparison, the amount of fluorspar ore consumed in the United States in 1975 was about twice the quantity in a large deposit.

The large deposits have been subdivided into type A and type B classes as a basis for considering the status of domestic fluorine resource production. Type A deposits (large star symbol) are those fluorspar deposits known to have been in production in 1975, on the basis of U.S. Geological Survey information. None of the fluorspar deposits shown was listed in a world survey of major mines (Mining Mag., 1976), because domestic fluorspar mines did not achieve the high levels of 1975 production considered in that survey. Type A deposits (large plus symbol) include active phosphate rock producers, from some of which byproduct fluorine is recovered from the fluorapatite. Thirty-two large phosphate mines containing large byproduct fluorine resources were listed in the 1976 survey, and in 1976, 11 processing plants were recovering fluorine resource materials from some of these domestic deposits (Quan, 1978, p. 2). Type B deposits, on the other hand, are large fluorspar (large dot symbol) past, present, or potential producers. Some are inactive because they are temporarily subeconomic owing to changed economic conditions. Others contain economic or subeconomic primary or byproduct fluorine materials, perhaps not fully evaluated, that may represent a large potentially recoverable resource. No type B (fluorapatite) deposits were identified on the phosphorus map by Cathcart and Tooker (1979), and none is shown here.

Small deposits or occurrences include all the other fluorine localities shown on the map; these active or inactive localities are shown as type C. The past production and minable or potentially minable fluorspar (small dot symbol) or fluorapatite (small plus symbol) of these small deposits are less than 2 million short tons; some of the deposits have not yet been appraised.

A study of geologic features (Worl and others, 1974) of about 450 fluorite localities in the United States showed that 100 of them have had significant production. The location of some of the fluorine-rich geologic units that contain these features are shown on the map. About 90 of these productive deposits are either localized in steep veins or in nearly flat-lying manto or bedding-replacement deposits in carbonate sediments, in granitic or volcanic igneous bodies, or in metamorphic rocks (Van Alstine, 1974; Shawe and others, 1976). The major fluorspar districts are localized chiefly along and near large faults, continental rifts, and lineaments (Van Alstine, 1976b); the fluorspar may be accompanied by commercial quantities of barium, zinc, molybdenum, uranium, thorium, niobium, tin, beryllium, and rare-earth minerals. From the geochemical point of view, fluorine is widely distributed in small amounts in many kinds of rocks in the conterminous United States, but it is most abundant in alkalic and highly silicic igneous rocks. Productive fluorspar deposits along or near major fault zones occur in host rocks of various geologic ages; commonly these are old (Precambrian or Paleozoic age) rocks uplifted along regional structures, but the fluorspar mineralization might have occurred at much later geologic times. Elsewhere the host rocks are mainly of Mesozoic or Cenozoic age.

In similar fashion, the fluorine-bearing phosphate rocks are not found at any single geologic horizon (Cathcart and Gulbrandsen, 1973). Deposits in the southeastern Coastal Plains of the Atlantic Ocean and Gulf of Mexico, and those along the California coastline of the Pacific Ocean, are chiefly in young (Cenozoic) rocks, those in the northern Rocky Mountains of the eastern Cordilleran belt (and in Alaska) are in older (Paleozoic and Mesozoic) rocks, and those in Tennessee, Iowa, and Kentucky are in still older Paleozoic rocks. Deposits of fluorine-bearing phosphate rock recently were discovered in Precambrian rocks of the Upper Peninsula of Michigan (Cannon and Klasner, 1976). Fluorine resources are also found in topaz, bastnaesite, and nonsedimentary apatite; these presently are mostly unevaluated subeconomic resources. The geology and geochemistry of fluorine are discussed in detail elsewhere (Worl and others, 1973; Shawe and others, 1976), and the types of deposits that occur within provinces, shown in table 1, are differentiated on the map by Worl and others (1974).

FLUORINE PROVINCES

The map and table 1 show 39 fluorine provinces and subprovinces. Those based on fluorspar deposits are concentrated in the eastern part of the Cordilleran belt, in the Appalachian belt, and in discontinuous local clusters in the eastern part of the Central Plains. Fluorspar deposits and occurrences, in common with those of several metals (Tooker, 1978), tend to be located in rocks overlying old continent crust that contains Precambrian basement rocks. In the Cordilleran and Appalachian belts and eastern Central Plains, the deposits cluster in zones where these basement rocks have been uplifted and in places exposed; deposits of fluorite are commonly localized in favorable younger cover rocks and structures (Van Alstine, 1976b).

Fluorapatite fluorine provinces are mainly in the Coastal Plain areas of southeastern United States; near the Coastal Plain-Central Plains border in Tennessee, Kentucky, and Arkansas; in the northern Rocky Mountains of the eastern Cordilleran belt in Idaho, Utah, Montana, and Wyoming; and in the western Cordilleran belt in California. Offshore fluorapatite deposits along the southern Atlantic Ocean coast from North Carolina to Florida, and also along the Pacific Ocean coast of southern California, are considered potential subprovinces of those onshore.

The large active vein, manto, and carbonatite deposits in province 1, the large stratiform breccia deposits of provinces 6a and 20b, and the newly recognized subeconomic disseminated occurrence in province 6b, which is expected to prove large when fully evaluated, at this time are considered to represent the principal present and future domestic sources of fluorspar. Only 8 additional fluorspar deposits or districts were classed as major or important by Worl and others (1974); thus, most of the abundant type C localities shown on the fluorine map are minor producers or occurrences. The discovery of large fluorspar deposits in the last few years in Illinois, Kentucky, Tennessee, Oregon (Sheppard and Gude, 1969), and Idaho (Snyder, 1978) suggests that other important deposits are yet to be found. Although many individual fluorspar deposits in the fluorine provinces have been mapped and studied in detail in the last 35 years, others are not known well enough for the future potential of the whole province to be evaluated. Geologic investigations, therefore, should be continued as a basis for better estimates of the fluorine resource potential of fluorine from fluorspar, the classic source.

On the other hand, the map strongly suggests that the greatest future potential for domestic fluorine will be as a byproduct of phosphorus production. More than 30 active large phosphate deposits are shown, from some of which byproduct fluorine from fluorapatite is being recovered on an increasing scale. Current active exploration for phosphorus by industry undoubtedly will discover potentially large additions of fluorine and also uranium resources that may occur in these phosphatic sediments. Geologic studies are an essential requirement for the full evaluation of this very large possible source of fluorine.

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Table 1.--Location, types of deposits and resource potential estimates for fluorine provinces

Province			Geologic types of deposits[1]	Preliminary estimates of resource potential[2]		
No.	State	Area		High	Medium	Low
1	Illinois and Kentucky	Hicks Dome and environs	I, II, III, IV	X	--	--
2	Colorado, Wyoming, and New Mexico	Front Range mineral belt-Sangre de Cristo Range	I, II, V	X	--	--
3	New Mexico, Arizona, and Texas	Gila River-Caballo uplift, San Andres uplift	I, III, IV, VI	--	X	--
4	Texas	Diablo platform and Llano uplift	I, II, IV, VI	--	X	--
5	Washington	Northern border	I	--	--	X
6	Idaho and Montana	Salmon River-Butte-Little Belt uplift	I, III, IV, V, VI	X	--	--
6a	Oregon	Rome	VII	X	--	--
7	Idaho, Montana, Wyoming, Utah, Colorado, and Nevada	Phosphoria Formation outcrop region	VIII	X	--	--
8	Utah, Nevada, and California	Eastern Great Basin	I, II, III, IV, VI	--	X	--
9a	Nevada and California	Western Great Basin	I, III, IV, VI	--	--	X
9b	Nevada	Central phosphate outcrop region	VIII	--	X	--
10a	California	Cenozoic phosphatic shale basin	VIII	X	--	--
10b	do	Offshore Pacific basins	VIII		unknown	
11	Utah, Nevada, and California	Southern edge, Great Basin	I, II, III, IV, V, VI	--	--	X
12a	Arizona and California	Southwestern	I, III, V	--	--	X
12b	Arizona	Southern	I	--	--	X
13	Michigan	Phosphorite outcrops, east of Keweenaw Bay	VIII		unknown	
14	Iowa, Wisconsin, and Illinois	Maquoketa (phosphorite) Shale outcrop region	VIII	--	--	X
15	Missouri	St. Francis Mountains	I, II, VI	--	--	X
16a	Arkansas	Paleozoic phosphatic shale outcrop region	VIII	--	X	--
16b	do	Little Rock-Hot Springs	II	--	--	X
17	Ohio	Findlay arch	I, IV	--	--	X
18	Kentucky	Cincinnati arch	I, VIII	--	X	--
19a	Tennessee	Nashville Dome	I, III	--	X	--
19b	do	Central phosphatic shale outcrop region	VIII	X	--	--
20a	Tennessee, North and South Carolina	Eastern Tennessee phosphatic shale outcrop region	VIII	X	--	--
20b	do	Appalachian uplift	I, IV	X	--	--
21a	Alabama and Texas	Coastal Plain phosphorite outcrop regions	VIII	X	--	--
21b	Alabama	South edge Appalachian uplift	IV, V, VI	--	--	X
22	Virginia and Tennessee	Western Appalachian uplift	IV	--	--	X
23	Virginia, Maryland, and Pennsylvania	Appalachian uplift	I, IV, VI	--	--	X
24	Pennsylvania, New Jersey, and New York	Appalachian uplift	I, IV, VI	--	--	X
25	New York	West edge Adirondack Mountains	I, VI	--	X	--
26	New York and Vermont	East edge Adirondack Mountains	VI	--	--	X
27	New Hampshire, Vermont, Massachusetts, and Connecticut	Connecticut River Valley	I, IV, V	--	--	X
28	New Hampshire and Maine	Appalachian uplift	I, V, VI	--	--	X
29	Virginia	Central phosphatic shale outcrop region	VIII	--	--	X
30a	North Carolina, South Carolina, Georgia, and Florida	Coastal Plain phosphorite outcrop regions	VIII	X	--	--
30b	do	Offshore Atlantic region	VIII	X	--	--

[1] Index to geologic types of deposits: Source: Worl, Van Alstine, and Heyl (1974)

Fluorspar commonly associated with intrusive igneous rocks:
- I. Veins
- II. Stockworks and pipes
- III. Replacement mantos
- IV. Disseminations
- V. Pegmatites and carbonatites
- VI. Contact skarn zone

Fluorspar associated with volcanogenic sedimentary rock:
- VII. Disseminations

Fluorapatite associated with sedimentary rocks:
- VIII. Phosphatic shale, phosphorite, or phosphatic limestone

[2] A *high* estimate indicates the presence or expectation of more than one large (type A or B) deposits; a *low* estimate is based mainly on the presence of type C deposits and (or) occurrence alone.

Background information relating to this map and others in the Atlas of Metal and Nonmetal Provinces in the Conterminous United States is published as U.S. Geological Survey Circular 792 (Tooker, 1979), available free of charge from the U.S. Geological Survey, Branch of Distribution, 1200 Eads St., Arlington, VA 22202.