Bulletin 244

DEPARTMENT OF COMMERCE
HERBERT HOOVER, Secretary
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FLUORSPAR

ITS MINING, MILLING, AND UTILIZATION

WITH A CHAPTER ON CRYOLITE

BY

RAYMOND B. LADOO

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PREFACE

The importance of fluorspar in the industrial development of this country, particularly in the open-hearth steel industry, has only begun to be realized fully. The World War showed that fluorspar was an essential mineral and was not as abundant as had been supposed. Strong demand for fluorspar caused a vigorous search for new deposits, but this search had little success.

Although considerable information has been published on various phases of the fluorspar industry, no attempt had been made to correlate this scattered material and to study the industry as a whole. Mr. Ladoo visited nearly all the important fluorspar mines and mills in the United States and obtained as much information as possible regarding foreign deposits, production, and methods. In the study of foreign deposits the Bureau of Foreign and Domestic Commerce gave much assistance. Questionnaires regarding fluorspar resources and production were sent to United States consuls in various parts of the world, and the replies received aided materially in widening the knowledge of the world's reserves of fluorspar.

The field work for this report was done in 1921, 1922, and early in 1923. Conditions in the industry have altered a little since that time through the development of a few new domestic and foreign deposits and through some changes in utilization, but such changes do not alter materially the conclusions reached. The original manuscript, prepared by Mr. Ladoo in 1923, has been rearranged somewhat. Names of companies have been changed to correspond with present ownerships, but descriptions of mines and mills apply to the time the examinations were made.

Work in the United States was greatly facilitated by the hearty cooperation of the producers and consumers. Particular credit is due to the officials and staff of the Fairview Fluorspar & Lead Co., especially to J. M. Blayney, president, and W. C. Bohn, general manager; to the Rosiclare Lead & Fluorspar Mining Co.; and to the Kentucky Fluorspar Co. Their interest, advice, and cooperation made possible a careful and detailed examination of many deposits, particularly in the West, which probably could not have been studied otherwise. The Fairview and Kentucky mines and equipment are now the property of the Franklin Fluorspar Co. The advice and assistance of C. S. Nunn, of Marion, Ky., are also gratefully acknowledged. Many other companies and individuals helped by supplying information or by giving free access to their mines, mills, and deposits. All those who rendered service can not be enumerated individually, but their aid is hereby acknowledged.

FRANK L. HESS,
Chief Engineer, Minerals and Metals Division.

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FLUORSPAR: ITS MINING, MILLING, AND UTILIZATION

By Raymond B. Ladoo

INTRODUCTION

In recent years the fluorspar industry has become of great importance because of the largely increased production of steel by the basic open-hearth process. Fluorspar is employed as a flux in this process, which takes 80 to 85 per cent of the total domestic production of fluorspar and most of the imports. Use of the basic open-hearth process seems to be increasing much more rapidly than that of the other processes. Production of steel by the Bessemer process reached its highest point in 1906 when the annual production was 12,275,830 tons; in the same year the total open-hearth production (of which about 90 per cent was basic) was 10,980,413 tons. In 1923 the annual production of basic open-hearth steel reached its maximum of 34,665,021 tons (nearly 97 per cent of the total open hearth), but that of Bessemer had dropped to 8,484,088 tons. This rapid increase in the production of steel, largely caused by the World War, tremendously increased the demand for fluorspar. This demand in turn led to a great advance in prices (at times the increase was as much as 600 per cent for prompt delivery), to exceedingly active mining, and to vigorous search for new deposits.

Meantime the demand for fluorspar for most other purposes had steadily increased, and in 1921 the domestic fluorspar industry entered the postwar period of depression with depleted reserves, permanently increased costs, more difficult mining conditions, and greater fear of competition from low-priced imported fluorspar.

During the last few years demand has continued to increase but domestic producers have found conditions difficult because high expenses have held over from the war period and sales prices continue low. No information is available to show that imports can adequately take care of the domestic demand. The known Canadian deposits are small or are high in objectionable impurities, and costs are said to be high. In England fluorspar has been obtained in the past largely as a by-product from other mining operations, or from the reworking of old tailings dumps. Prices have been very low, but the quality of the product has been generally inferior to that of domestic fluorspar. It seems probable that British and continental demand will require an increasing proportion of the British output.

The fluorspar industry differs from many others in that the largest producers have the highest costs of production. The smaller producers, who in general have lower costs, are at present entirely unable to supply the total domestic demand. Thus in order to bring out, both now and in future, an output that will adequately supply domestic needs, prices must eventually stand at a level which will render profitable the present operation of the larger mines and also allow a surplus sufficient to provide for necessary prospecting and development of the deeper levels of the larger mines and the working of smaller and less accessible deposits.

Low-priced fluorspar, both imported and domestic, may for a time seem of advantage to consumers, but eventually it will be detrimental to them. In the deeper mines less accessible ore will be left, which can never be recovered, or recovered only at very high cost, if the mines are abandoned. At the smaller mines, where cheap production has followed unsystematic removal of surface material, workings have been allowed to cave. Some of these mines have been worked a second time, of course at greatly increased costs, and the workings have again caved. Inevitably much ore has been permanently lost by these methods, and a third mining, if possible at all, must be at a still higher cost and by systematic work on a large scale. Higher prices are necessary to justify the investment of the capital needed to mine these deposits efficiently and to provide the fluorspar that the industries of this country will need.

In the basic open-hearth process the proportion of fluorspar needed is small, averaging only 7 to 8 pounds per ton of steel. Fluorspar at $20 per ton means on an average only 7 to 8 cents per ton of steel, and an increase of $5 per ton of fluorspar means an increase of only 1¾ to 2 cents per ton of steel. The cost of fluorspar is an almost negligible item in the cost of the finished steel.

HISTORY

The first commercial production of fluorspar in the United States seems to have been in 1837 from a topaz vein near Trumbull, Conn. It sold at $60 per ton and was used with magnetic iron pyrite in the smelting of copper ores. Fluorspar had been known in the Illinois-Kentucky field for many years before shipments began. Mining for lead and zinc was begun in 1835 near the site of the old Columbia mines in Crittenden County, Ky., by a company headed by President Andrew Jackson. In 1842 lead mining started at Rosiclare, Ill. Fluorspar undoubtedly was obtained as a by-product from much of this early mining, but it seems to have had little or no market value, for the first shipments recorded were in 1871 from the Royal mines in western Kentucky. The mineral was ground at the mines in the first fluorspar-grinding mill in this country, and was used by glass works in Baltimore.

The regular collection of statistics on the production of fluorspar in the United States began about 1883 when an output of 4,000 short tons, valued at $20,000, was recorded. Production slowly increased to 12,400 tons valued at $84,000 in 1893, dropped back to 4,000 tons valued at $24,000 in 1895, and jumped to 15,900 tons valued at $96,650 in 1899. Since then production increased steadily except for a few minor setbacks, until it reached a maximum of 263,817, tons valued at $5,465,481, in 1918. From 1898 to 1904 the annual production in Kentucky exceeded that in Illinois, but in 1905 the rank of the two States was reversed and remained so until 1921, when Kentucky again led; Illinois retained first rank in 1922 and 1923, but Kentucky led in 1924.

Shipments of fluorspar in Colorado began in the early seventies, when a small tonnage was used in the Central City district as a flux in smelting gold and silver ores. Shipments from the Jamestown district began about 1873 or 1874, and from Wagon Wheel Gap in 1913. First reported shipments from other States are as follows: Arizona, 1902; Nevada, 1919; New Hampshire, 1911; New Mexico, 1909; Tennessee, 1902; Utah, 1918; Washington, 1918. Although a small production—48 tons—was reported from Texas in 1924, none was shipped and none produced in 1925.

In England fluorspar was mined at Weardale as early as 1847 for use as a blast-furnace flux.

The earliest recorded use of fluorspar was in metallurgy; Agricola in 1529 noted its use as a flux. It is stated that in early methods of smelting, fluorspar was considered an indispensable fluxing material. With the improvements in metallurgical methods and equipment in the early part of the ninteeenth century, the relatively scarce and expensive fluorspar was largely supplanted by limestone except for the smelting of highly refractory ores.

In the United States, although the earliest use seems to have been for smelting, the most important early uses, in point of tonnage consumed, seem to have been in the manufacture of glass, particularly opalescent glass, enamels, and hydrofluoric acid. This situation seems to have continued until about 1898, when the value of fluorspar as a flux and cleansing agent in the basic open-hearth process for steel began to be realized. In a few years this new use consumed more fluorspar than the older uses, until in recent years 80 to 85 per cent of the domestic production has been used by the steel industry.

During the World War an unprecedented demand for fluorspar caused the opening of many small, inaccessible deposits, particularly in the West; but even at the very high prices then prevailing most of the ventures were unprofitable and many soon ended. Thus the industry, with one or two exceptions, settled back to its former dependence on the Illinois-Kentucky field.

PRODUCTION, CONSUMPTION, AND RESERVES

WORLD PRODUCTION

No accurate statistics are available for compiling an estimate of the world production of fluorspar. For example, Mexico is known to produce fluorspar for use as a flux in the smelting of gold, silver, lead, copper, and other ores in that country, but no records of such production are kept. Japan, China, Korea, and Manchuria produce fluorspar, probably in small quantities, for use in Japan and China, but no statistics are available. The following table, however, from "Mineral Resources of the United States" covers nearly all of the world production.

Fluorspar produced in principal countries, 1913, 1915, and 1917–1925, in metric tons

Country	1913	1915	1917	1918	1919	1920	1921	1922	1923	1924	1925
Australia:											
New South Wales	-------	424	1,326	2,315	2,046	1,213	-------	-------	-------	478	(1)
Queensland	-------	-------	72	-------	-------	613	545	-------	-------	1,894	(1)
Victoria	-------	-------	-------	102	319	13	199	-------	-------	-------	(1)
Canada	-------	-------	3,855	6,679	4,593	10,192	5,007	4,085	126	69	3,525
France	7,524	(1)	(1)	(1)	4,894	8,997	5,776	9,251	12,913	(1)	(1)
Germany:											
Bavaria	(1)	1,500	6,470	6,011	6,396	6,272	7,210	13,221	10,543	21,663	(1)
Prussia	16,977	7,874	7,856	9,387	10,444	7,339	11,989	8,630	10,810	13,078	(1)
Saxony	3,260	3,045	1,410	2,332	2,906	2,918	4,763	5,493	3,215	4,616	(1)
Great Britain	54,524	33,655	65,915	54,357	37,452	55,561	23,508	33,343	49,818	50,286	(1)
Italy	-------	-------	800	876	900	810	1,600	1,395	3,362	6,831	7,700
Japan	-------	-------	-------	-------	-------	(1)	(1)	36	(1)	(1)	(1)
Norway	-------	180	-------	155	560	-------	-------	-------	-------	-------	-------
Spain	351	370	250	350	280	416	176	392	-------	4,474	(1)
Union of South Africa	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	10,975	10,192	(1)
United States	104,853	124,230	198,519	239,333	125,454	169,441	31,715	128,453	109,939	113,378	103,118

1 Figures not available.

This table shows that the United States is by far the largest producer, making more than 75 per cent of the total recorded production in 1918. England was second with about 17 per cent and Germany third with about 2½ per cent. In 1922, for which complete statistics are now available, the United States was producing about 63 per cent, England about 16 per cent, and Germany 13 per cent.

CONSUMPTION

Although the United States is by far the largest producer, it is a still larger consumer, for in 1925 the imports were 48,700 tons and the exports 1,055 tons. The total indicated consumption in recent years in the United States is shown by the following table:

Fluorspar made available for consumption in the United States, 1919–1925, in short tons

Year	Shipments from mines	Imports for consumption	Exports	Available for consumption
1919	138, 290	6, 943	(1)	145, 233
1920	186, 778	24, 612	[2] 2, 764	208, 626
1921	34, 960	6, 229	-------	41, 189
1922	141, 596	33, 108	[2] 2, 296	172, 408
1923	121, 188	42, 226	[2] 1, 144	162, 270
1924	124, 979	51, 043	617	175, 405
1925	113, 669	48, 700	1, 055	161, 314

[1] Not available.
[2] Reported by producers; none recorded by Bureau of Foreign and Domestic Commerce.

A more detailed statement of consumption by the different industries is given under "Utilization."

The following table gives the amount of fluorspar imported into the United States, by country of origin.

Fluorspar imported into the United States, 1923–1925, by countries

[General imports]

Country	1923			1924			1925		
	Short tons	Value		Short tons	Value		Short tons	Value	
		Total	Average		Total	Average		Total	Average
Africa:									
British South	10, 380	$157, 625	$15. 19	10, 585	$134, 959	$12. 75	7, 906	$108, 647	$13. 74
Portuguese	-------	-------	-------	540	13, 018	24. 11	-------	-------	-------
Belgium	35	712	20. 34	6	75	12. 50	78	1, 624	20. 82
Canada	(1)	5	-------	213	3, 216	15. 10	-------	-------	-------
China	90	1, 183	13. 14	506	5, 089	10. 06	559	5, 816	10. 40
Czechoslovakia	-------	-------	-------	-------	-------	-------	27	591	21. 89
France	-------	-------	-------	232	2, 782	11. 99	2, 537	20, 887	8. 23
Germany	8, 580	67, 595	7. 88	6, 834	69, 357	10. 15	11, 680	103, 845	8. 89
Italy	268	2, 471	9. 22	1, 585	14, 804	9. 34	4, 278	32, 208	7. 53
Netherlands	11	180	16. 36	1, 177	13, 951	11. 85	-------	-------	-------
United Kingdom:									
England	22, 862	202, 548	8. 86	29, 089	296, 662	10. 20	21, 635	195, 229	9. 02
Scotland	-------	-------	-------	276	1, 729	6. 26			
	42, 226	432, 319	10. 24	51, 043	555, 642	10. 89	48, 700	468, 847	9. 63

[1] Quantity not recorded.

England seems to be the second largest consumer, although definite statistics are not available. Apparently the British consumption of fluorspar, largely in the iron and steel industries, has ranged from about 30,000 tons to 50,000 tons per annum in recent years.

The German consumption of fluorspar in the past seems to have been between 10,000 and 15,000 tons yearly, but is reported to be increasing. The iron and metal smelting industries account for 79 to 84 per cent of the consumption, chemical industry 5 per cent, glass industry 10 to 15 per cent, enamel industry 5 per cent, and the optical industry 5 per cent.

In recent years Canada has consumed 12,000 to 15,000 tons a year, mostly in the steel industries in Ontario and at Sydney, Nova Scotia. Most of the Canadian fluorite mined is used in Canada and in addition 8,000 to 13,000 tons annually have been imported from the United States and England.

Before the World War, Russia imported considerable quantities of fluorspar from England, probably for metallurgical uses. No data on consumption in Russia are available.

Mexico for many years has used small quantities of fluorspar from local deposits for smelting refractory ores, as a flux in the steel industry, and for the manufacture of hydrofluoric acid.

Japan uses fluorspar in the steel industry and in making glass and enamels. In 1920 the steel industry used 230 metric tons, and it is said that the total imports (no domestic production) probably did not exceed 300 tons. Fluorspar analyzing as low as 50 per cent CaF_2 is obtained from Korea and used in making steel.

In Australia the steel works at New Castle, New South Wales, have used in recent years about 2,000 tons annually, obtained from local sources. A small quantity is used by enameling works at Sydney.

In South Africa consumption has been small, but some fluorspar is used in steel and other metallurgical industries, in the chemical industry, and in glass and enamel.

Probably all countries that have any industrial development consume some fluorspar for chemical, smelting, and ceramic uses, but only in countries which are large manufacturers of iron and steel can a large consumption be expected.

PRODUCTION IN THE UNITED STATES

Except for a few years during and subsequent to the World War, the Illinois-Kentucky district has produced more than 90 per cent of the fluorspar mined in this country. The following table shows the production by States:

Domestic fluorspar shipped from mines in the United States, 1918–1925

State	Gravel			Lump		
	Short tons	Value	Average price	Short tons	Value	Average price
1918						
Arizona	------	------	------	364	$5,537	$15.21
Colorado	32,680	$287,620	$8.80	5,795	129,160	22.29
Illinois	122,721	2,565,394	20.90	9,518 (Illinois and Kentucky)	260,948	27.42
Kentucky	79,411	1,856,739	23.38			
New Mexico, Other States [1]	[2] 1,309	[2] 25,507	19.49	[2] 3,267	[2] 61,373	18.79
	[2] 236,121	[2] 4,735,260	20.05	[2] 18,944	[2] 457,018	24.12
1919						
Illinois	81,026	1,962,934	24.23	4,246 (Illinois and Kentucky)	133,993	31.56
Kentucky	29,470	770,381	26.14			
Colorado, New Mexico, Other States [1]	[2] 12,088	[2] 184,044	15.23	[2] 1,087	[2] 27,998	25.76
	[2] 122,584	[2] 2,917,359	23.80	[2] 5,333	[2] 161,991	30.38

[1] 1918: New Hampshire, Utah, and Washington. 1919: Arizona, Nevada, New Hampshire, and Utah. 1922: New Hampshire and Utah.

[2] Some lump spar included with gravel.

Domestic fluorspar shipped from mines in the United States, 1918–1925—Continued

State	Gravel			Lump		
	Short tons	Value	Average price	Short tons	Value	Average price
1920						
Illinois	103,486	$2,396,322	$23.16	8,332	$381,171	$36.27
Kentucky	39,997	1,029,195	25.73	2,178		
Nevada	530			----------		
New Hampshire	[2] 202	[2] 13,332	17.61	(2)	[2] 8,608	20.30
Utah	----------			268		
Arizona	25			156		
Colorado	10,076	157,768	14.96	2,776	195,000	22.52
New Mexico	470			5,883		
	[2] 154,786	[2] 3,596,617	23.24	[2] 19,593	[2] 584,779	29.85
1921						
Colorado	3,143	39,907	12.70	----------	----------	----------
Illinois	8,208	146,746	17.88	1,099		
Kentucky	11,714	185,451	15.83	1,689	80,838	21.39
New Mexico	1,650	21,450	13.00	991		
New Hampshire	[2] 567	[2] 13,721	24.20	(2)	(2)	----------
	25,282	[2] 407,275	16.11	[2] 3,779	[2] 80,838	21.39
1922						
Colorado	2,309	20,169	8.73	----------	----------	----------
Illinois	76,537	1,243,151	16.24	1,722		
Kentucky	45,680	774,086	16.95	2,629	96,033	18.57
New Mexico	1,008	12,320	12.22	820		
Other States [1]	[2] 690	[2] 15,353	22.25	[2] 78	[2] 1,404	18.00
	[2] 126,224	[2] 2,065,079	16.36	[2] 5,249	[2] 97,437	18.56
1923						
Colorado	3,957	36,631	9.26	2,087	23,079	11.06
Illinois	52,249	1,013,927	19.41	5,659		
Kentucky	39,394	756,701	19.21	2,432	232,846	26.37
New Mexico	3,540	38,161	10.78	738		
New Hampshire	----------	----------	----------	142	6,356	19.26
Utah	----------	----------	----------	188		
	99,140	1,845,420	18.61	11,246	262,281	23.32
1924						
Colorado	11,986	130,791	10.91	315	4,620	14.67
Illinois	54,541	1,042,089	19.11	2,766		
Kentucky	41,809	789,352	18.88	932	108,090	22.68
New Mexico	1,620	19,318	11.92	883		
Utah	----------	----------	----------	184		
	109,956	1,981,550	18.02	5,080	112,710	22.19
1925						
Colorado	10,560	137,343	13.01	1,216	16,364	13.46
Illinois	46,195	783,451	16.96	3,366		
Kentucky	39,153	669,672	17.10	1,176	115,814	21.13
New Mexico	1,487	20,817	14.00	939		
	97,395	1,611,283	16.54	6,697	132,178	19.74

State	Ground			Total		
	Short tons	Value	Average price	Short tons	Value	Average price
1918						
Arizona	----------	----------	----------	364	$5,537	$15.21
Colorado	----------	----------	----------	38,475	416,780	10.83
Illinois	8,752	$273,203	$31.22	132,798	2,887,099	21.74
Kentucky				87,604	2,069,185	23.62
New Mexico	----------	----------	----------	3,437	64,348	18.72
Other States [1]	----------	----------	----------	1,139	22,532	19.78
	8,752	273,203	31.22	263,817	5,465,481	20.72
1919						
Illinois	10,373	446,224	43.02	92,729	2,430,361	26.21
Kentucky				32,386	883,171	27.27
Colorado	----------	----------	----------	9,687	150,739	15.56
New Mexico	----------	----------	----------	2,346	37,643	16.05
Other States [1]	----------	----------	----------	1,142	23,660	20.72
	10,373	446,224	43.02	138,290	3,525,574	25.49

[1] 1918: New Hampshire, Utah, and Washington. 1919: Arizona, Nevada, New Hampshire, and Utah. 1922: New Hampshire and Utah.

[2] Some lump spar included with gravel.

Domestic fluorspar shipped from mines in the United States, 1918–1925—Contd.

State	Ground			Total		
	Short tons	Value	Average price	Short tons	Value	Average price
1920						
Illinois	8,481			120,299	$3,096,767	$25.74
Kentucky	3,916	$537,151	$43.32	46,091	1,246,942	27.05
Nevada	2			532		
New Hampshire	----	----	----	202		
Utah	----	----	----	268	22,070	18.66
Arizona	----	----	----	181		
Colorado	----	----	----	12,852	251,308	19.55
New Mexico	----	----	----	6,353	101,460	15.97
	12,399	537,151	43.32	186,778	4,718,547	25.26
1921						
Colorado	----	----	----	3,143	39,907	12.70
Illinois	3,170			12,477	315,767	25.31
Kentucky	1,863	235,981	40.00	15,266	294,513	19.29
New Mexico	866			3,507	60,186	17.16
New Hampshire	----	----	----	567	13,721	24.20
	5,899	235,981	40.00	34,960	724,094	20.71
1922						
Colorado	----	----	----	2,309	20,169	8.73
Illinois	5,596			83,855	1,493,188	17.81
Kentucky	4,175	368,649	36.42	52,484	970,059	18.48
New Mexico	352			2,180	30,992	14.22
Other States [1]	----	----	----	768	16,757	21.82
	10,123	368,649	36.42	141,596	2,531,165	17.88
1923						
Colorado	----	----	----	6,044	59,710	9.88
Illinois	7,137			65,045	1,443,490	22.19
Kentucky	3,615	398,118	36.86	45,441	945,402	20.81
New Mexico	50			4,328	50,861	11.75
New Hampshire	----	----	----	142	6,356	19.26
Utah	----	----	----	188		
	10,802	398,118	36.86	121,188	2,505,819	20.68
1924						
Colorado	----	----	----	12,301	135,411	11.01
Illinois	4,760			62,067	1,288,310	20.76
Kentucky	5,106	356,871	35.89	47,847	988,940	20.67
New Mexico	77			2,580	38,470	13.92
Utah	----	----	----	184		
	9,943	356,871	35.89	124,979	2,451,131	19.61
1925						
Colorado	----	----	----	11,776	153,707	13.05
Illinois	4,867			54,428	1,024,516	18.82
Kentucky	4,497	308,881	32.25	44,826	833,794	18.60
New Mexico	213			2,639	40,325	15.28
	79,57	308,881	32.25	113,669	2,052,342	18.06

[1] 1918: New Hampshire, Utah, and Washington. 1919: Arizona, Nevada, New Hampshire, and Utah. 1922: New Hampshire and Utah.

Figure 1 shows the relation between the production and consumption of fluorspar and the production of basic open-hearth steel.

RESERVES

No data are available for accurate estimation of fluorspar reserves in the United States or in the world, because very few fluorspar companies have ever attempted to estimate their reserves fully. Most companies do not even block out or develop any large tonnage in advance of mining. A few of the largest companies do adequate development work and block out ore several years in advance of mining, but no example can be cited of a company fully exploring its property by drilling or other prospecting.

Upon the basis of past and present production and of such reports as are available, the largest fluorspar reserves in the world, named in

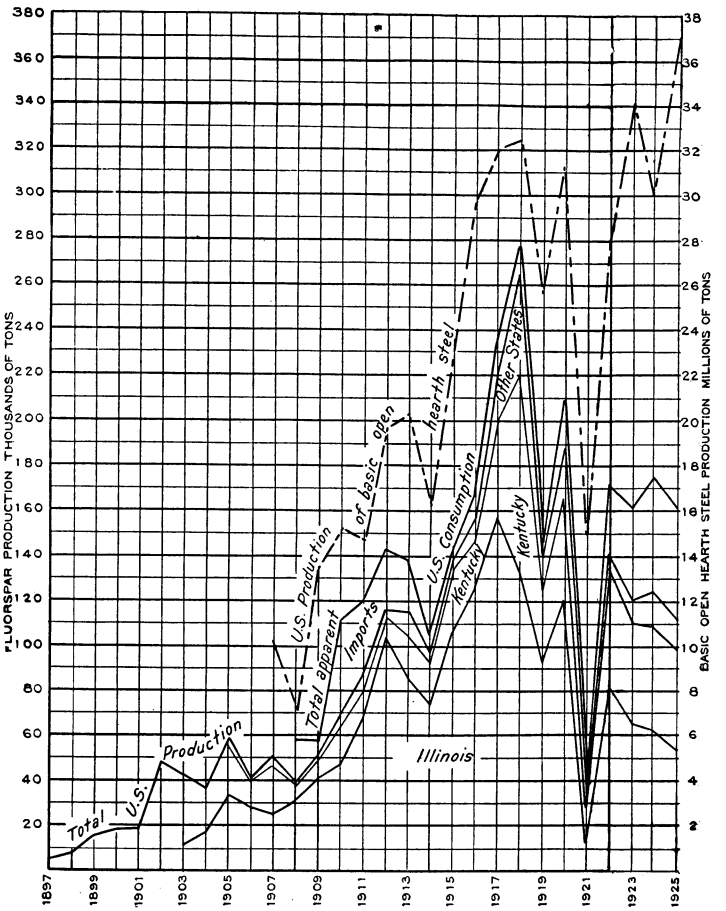

FIGURE 1.—Production and consumption of fluorspar and basic open-hearth steel

order of present importance, are in the United States, England, and Germany. Countries having reserves of moderate known importance are Italy, France, Canada, and South Africa (Transvaal). In other countries fluorspar deposits are either known to be small or at great distances from transportation and markets, or adequate information is not available.

UNITED STATES

The Rosiclare vein in southern Illinois has supplied a very large proportion of the total past production of the United States. The known productive areas of this vein have been adequately explored to a depth of 350 feet, in places as deep as 620 feet. Most workable ore above the 350-foot level has been extracted and ample evidence shows that the ore bodies are getting shorter and narrower, with longer "pinches" between separate bodies; therefore this vein probably can not be depended upon to supply the bulk of the domestic fluorspar production for many more years.

Although there are some other deposits in Illinois, such as the Daisy mine and the new Argo mine near Rosiclare, which probably will be important producers for several years to come, production from present known deposits in Illinois will no doubt decline appreciably within a comparatively few years.

The western Kentucky deposits have not been as thoroughly prospected, and the best of the present known veins have not been worked or even explored to any great depth. It is probably safe to assume, however, that most of the easily found deposits have been discovered and that much of the easily accessible surface ore has been removed. Future mining must go deeper and the larger deposits be worked more systematically if they are to supply any large proportion of the domestic production.

The present known deposits in Kentucky may, perhaps, be relied upon to yield important quantities of fluorspar for some time to come, and the Kentucky field will probably outlive the Illinois field. Nevertheless, when the latter reserves are exhausted and Kentucky is called upon to supply the bulk of the domestic fluorspar requirements, the reserves can not be expected to last many years unless consumption decreases or new deposits are found.

The only known deposit which is at all comparable with the Rosiclare, Daisy, Blue Diggings, or Tabb veins of the Illinois-Kentucky district is that at Wagon Wheel Gap, Colo. This deposit can probably be relied upon to supply western markets for a considerable period. No other districts in the United States are important enough from present indications of known deposits to be considered as possessing important reserves.

The fluorspar consumption of the United States will probably continue to increase. Even at the present rate of consumption the known domestic fluorspar reserves will not last many years. It is unwise to hazard a guess as to the extent of such reserves, but within 20 years or perhaps much sooner domestic deposits may be unable to supply our needs, unless large new deposits are discovered, consumption decreases, or imports fill a larger proportion of our demands.

The World War showed that fluorspar is a necessary mineral, and domestic producers should be encouraged to develop as large reserves as possible and to work narrow veins even at great depths. Although this country may be able to import considerable fluorspar temporarily, we do not know that our domestic needs could be supplied for any length of time from foreign deposits.

FOREIGN COUNTRIES

More information is available on the fluorspar resources of Great Britain than of any other foreign country, but no definite estimates of total reserves have been made. Moreover, reports are conflicting, for some observers state that reserves are very large and will last many years, while others have expressed almost opposite views. It is evident, however, that most of the old mine dumps which have supplied so much of the British production in the past are now practically exhausted, that future production must come largely from actual mining operations, and that British fluorspar consumption is apparently increasing.

Germany is now a fairly important producer, but little is known of her reserves. In the past, however, German fluorspar consumption has required nearly all of the domestic production. It is probably safe to assume that when normal conditions are restored Germany will not have any large exportable surplus of fluorspar.

Italy, France, Canada, and South Africa (Transvaal) have fluorspar deposits which will probably continue to supply moderate amounts for some time to come. For example, Italy reports that one deposit contains about 200,000 tons of sure ore and 200,000 tons more of probable ore. In comparison with the annual consumption of fluorspar throughout the world these resources are insignificant, but the deposit is important, for the fluorspar is of high grade.

Important fluorspar deposits may be developed in a number of other countries—Mexico, for example—but no dependence can be placed upon such possibilities.

CONCLUSIONS

Present knowledge of the world's fluorspar resources indicates that few districts can produce any very large tonnage. Some of these districts probably have already passed their period of maximum production. Consumption is increasing and new deposits are not being developed rapidly enough to maintain production at its present rate.

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Our resources should be carefully conserved by working narrow and low-grade veins in depth, by minimizing losses in milling, and by the most efficient utilization of fluorspar for all purposes. To carry out the first two suggestions the market price of fluorspar must be high enough to give the producers a profit commensurate with the risk involved.

MINERALOGY

COMPOSITION

Fluorspar or fluorite is calcium fluoride (CaF_2) and consists theoretically of 51.1 per cent of calcium (Ca) and 48.9 per cent fluorine (F). A large body of fluorspar analyzing more than 99 per cent CaF_2 is rarely found, and by far the largest proportion of the mineral shipped contains only 80 to 85 per cent of calcium fluoride. Most commercial fluorspar contains silica or calcite, or both, and usually some iron oxide and alumina. Other more or less common associated minerals are barite, galena, and sphalerite. The following table illustrates the variations in composition of fluorspar:

Analyses of fluorspar

	1	2	3	4	5	6	7	8
Fluorspar (CaF_2)	87.64	76.61	88.94	82.16	88.92	78.52	98.5	99.49
Silica (SiO_2)	4.15	2.74	8.35	10.64	3.07	10.33	.1	.07
Calcite ($CaCO_3$)	6.41	9.11	1.34	2.26	1.23	.50	.5	.18
Alumina (Al_2O_3)	1.58	3.07	1.20	4.27	1.96			
Iron oxide (Fe_2O_3)								
Barite ($BaSO_4$)		8.13			4.16	9.70		
Total	99.78	99.66	99.83	100.33	99.34	99.05	99.1	99.74

1. Rosiclare district, Ill., washed gravel spar, average shipments, 1912, analyses by Colorado Fuel & Iron Co.
2. Noyes mine, Madoc, Ontario, Canada. Average of 16 carload shipments. Analysis by Algoma Steel Corporation.
3. Deming district, N. Mex. Car shipment. Analysis by Colorado Fuel & Iron Co.
4. Jamestown district, Colo. Car shipment. Analysis by Colorado Fuel & Iron Co.
5. Wagon Wheel Gap, Colo. Analysis quoted by Aurand, H. A., Fluorspar Deposits of Colorado: Colorado Geol. Survey Bull. 18, 1920, p. 78.
6. Tonuco, N. Mex., gravel spar. Analysis by L. A. Stewart, Fairview Fluorspar & Lead Co.
7. High Lost mine, Matlock Bath, Derbyshire, England, selected lump spar. Trans. Inst. Min. Eng. (England), 1908, vol. 35, p. 513.
8. North Gate, Colo., picked specimen. Analysis by L. A. Stewart, Fairview Fluorspar & Lead Co.

Most of the fluorspar shipped, particularly the grade used as a flux for steel, has been concentrated. Thus the analyses given for marketed products represent adjustment of grade by mechanical means to meet specifications.

GENERAL DESCRIPTION AND NOMENCLATURE

Fluorspar is a moderately hard, glassy mineral, transparent or translucent, crystallizing in the isometric system, usually in cubes. The crystals have good octahedral cleavage and perfect octahedra may be easily cleaved out. The mineral commonly occurs in crystalline masses and often in well-formed crystals; less often in granular form. It has a wide range of color. In large deposits white and gray fluorspar are probably the most common. In narrower veins, and often in well-crystallized deposits in siliceous rocks, green and purple fluorspars are common, particularly near the surface. Other colors seen more or less frequently are blue, yellow, orange, red, pink, brown, and black. The causes of this variation in color are not known.

Hardness: 4. Specific gravity: 3.01 to 3.25. Melting point: 1,270 to 1,387° C. About 900° C. is also given, but probably represents impure material. Index of refraction: 1.434. Color: White, gray, green, purple, blue, yellow, red, pink, brown, black, and colorless. Streak: Usually white, but pinkish in all purple varieties. Luster: Vitreous, dull, or earthy when the mineral is granular; rarely submetallic. Cleavage: Octahedral, good. Fracture: Conchoidal to splintery. Transparency: Transparent or translucent to nearly opaque. Tenacity: Brittle. Most fluorspar decrepitates or flies apart when heated.

Fluorspar from some localities shows phosphorescence, especially after moderate heating; that is, it emits a characteristic glow in the dark after the exciting cause or agent has been removed. Some specimens also show fluorescence, which resembles phosphorescence except that the glow continues only during exposure to the exciting cause; this cause may be sunlight, electrical discharges, or Röntgen rays.

The term fluorite, which is now probably in widest use in works on mineralogy, seems to suggest the pure mineral, but in commercial practice the name fluorspar is used almost exclusively. The fluorspar of commerce always contains impurities, such as silica and calcite. In England it is called fluorspar or fluor, or sometimes, locally, Derbyshire spar, or blue John (local variety). In the United States the earliest references were to "fluate of lime."

In some places the term "spar" is often used, especially by miners, to denote fluorspar, and it is used in this report where there is no danger of confusion. But, as "spar" is also applied to denote barite (heavy spar), feldspar, calc-spar (calcite), gypsum, and even quartz, the term should be used carefully.

Color alone is not ordinarily a good indication of the purity of fluorspar, but experience often shows that in particular districts color may be used as a guide. Thus, in the mills using ore from the Rosiclare vein in Illinois, acid grade, as well as glass and enameling grades of fluorspar, is made by sorting from a picking belt. For acid grade only the transparent, white, or very light tints of gray, blue, and green are picked. For glass and enamel slightly darker shades are picked, but the material must be clear and nearly transparent; dark brown and deep purple fluorspar is rejected. Near North Gate, Colo., however, a specimen of deep-green ore was selected which analyzed 99.49 per cent CaF_2 and therefore was of excellent grade for acid.

STRUCTURE

Fluorspar differs in structure. In commercial deposits it occurs most commonly as a coarsely crystalline vein filling, which may be homogeneous and of uniform color, or may show bands of different colors. The structure that ranks next in importance is distinct crystals, either individuals or aggregates of intergrown and twinned crystals. Crystals are usually found partly filling cavities or along sides of underground watercourses, but occasionally they are found in residual clay that has formed by the weathering of the rocks that originally held the crystals. Less commonly, fluorspar has a bedded structure. The best examples of this structure are the bedded deposits near Cave in Rock, Ill. The structure of some deposits closely resembles that of a loosely coherent sandstone. In the Jamestown (Colo.) district most of the fluorspar occurs as a medium to coarsely granular aggregate that resembles porous sandstone. At Beatty, Nev., the typical ore is much finer in texture and ranges from loosely coherent to pulverulent.

At Wagon Wheel Gap much of the ore is white, hard, and has a structure closely resembling that of a very fine-grained white marble or perhaps a hard, white, finely crystalline barite.

In the western Kentucky district much of the residual ore formed by weathering is a loose to partly coherent coarse gravel, in places very pure (as at the Yandell and Liberty Bond and Watson mines) and in places mixed with clay. It is locally known as "gravel" fluorspar.

A columnar or even an almost fibrous structure is sometimes observed. A cavernous or porous structure is common in the Madoc (Ontario) district and is occasionally found elsewhere, as in western Kentucky.

ASSOCIATED MINERALS

The nature and the relative proportions of the minerals associated with fluorspar are of importance. The mode of association is equally important, for upon this depends the ease of separation or even the possibility of separation at a profit.

Calcite or calcium carbonate is perhaps the most common gangue material in the large commercial deposits, particularly that in the Illinois-Kentucky field. It occurs both in the crystalline form and as limestone of various degrees of purity. Its specific gravity (2.7) is somewhat lower than that of fluorspar (3.0 to 3.25); and it is rarely intimately intergrown with the fluorspar. Therefore it usually can be separated easily by mechanical means, and, as for most uses it is not considered a deleterious impurity, its presence ordinarily is not a serious matter.

Quartz or silica is present in most deposits and in some is abundant. It occurs in massive fluorspar as small grains, as massive vein quartz, and in intergrown aggregates of quartz and fluorspar; in residual deposits of gravel fluorspar it occurs as sand. In the Great Eagle mine near Lordsburg, N. Mex., these intergrown aggregates form the larger part of the deposit. Specimens are common that show at one end pure quartz which imperceptibly changes to pure fluorspar at the other end. At Tonuco, N. Mex., are found great masses of concentrically banded quartz nodules or bowlders, which toward the outside grade into fluorspar. Such bowlders appear to be very pure fluorspar, but when broken are found to be nearly solid quartz.

The specific gravity of quartz is only 2.65, and when it occurs as free sand in a deposit of residual fluorspar gravel it is easily removed by log washers, jigs, or tables; but when it exists in finely intergrown aggregates it can not be separated and a pure fluorspar product obtained. As fluorspar concentrates containing more than 6 per cent silica are severely penalized, the presence of a large amount of quartz in massive fluorspar may seriously affect the value of a deposit.

Barytes or barite is a relatively common associate of fluorspar in some localities. It occurs as distinct crystals, as crystalline masses, and as small grains so mingled with fluorspar that it can be detected only by analysis. Its specific gravity is 4.3 to 4.6, 1 to 1½ points more than that of fluorspar, but in spite of this difference mechanical methods of separation have thus far failed to yield satisfactory products. Barytes is considered an injurious impurity for most uses (more than 1 per cent is prohibited by some steel companies) and its presence in a deposit is very unfavorable.

Galena, or lead sulphide, is often associated with fluorspar, at some places in considerable quantities. The Rosiclare vein, Illinois, was first worked for lead. Galena in quantity in a finished fluorspar product would be objectionable, but as its specific gravity is high (7.4 to 7.6) it may be easily removed by jigging and tabling and afterward sold as a valuable by-product. Most of the galena in the Rosiclare district carries about 7 ounces of silver per ton.

Sphalerite, or zinc sulphide, is found in some fluorspar veins in the Illinois-Kentucky district. It is an objectionable impurity in fluorspar concentrates and, as its specific gravity is only 3.9 to 4.1, separation is difficult. To make a clean or satisfactory separation by jigging or tabling has been impossible, but the development of successful flotation or electrostatic methods seems probable.

Wall rock, such as shale, sandstone, limestone, quartzite, or granite, or surface materials, such as sand and clay, usually contaminate the fluorspar as mined, but at most deposits they are easily removed by hand sorting or by milling.

Other associated minerals, such as pyrite, chalcopyrite, and celestite, are sometimes found, but usually they are easily separable or occur only locally and in unimportant quantities.

GEOLOGICAL OCCURRENCE

The element fluorine has been estimated to constitute about 0.1 per cent of the earth's crust. Although it is widely distributed in minute quantities, deposits containing a large proportion of the element are distinctly uncommon. Cryolite, a sodium-aluminum fluoride having the formula Na_3AlF_6, contains 54.4 per cent of fluorine and fluorspar 48.9 per cent. Fluorspar and cryolite are the only minerals that contain a large proportion of fluorine. But there is only one large deposit of cryolite known, in Greenland, and the mineral can not be considered as a substitute for fluorspar in large amounts. Thus fluorspar is the only fluorine mineral of great commercial importance, and large deposits of fluorspar are relatively uncommon.

Fluorspar is formed under a great variety of geological conditions. These have been summarized by Wilson [1] and Clark.[2] The former, in summarizing the theories suggested to explain the origin of fluorspar deposits of the Madoc (Ontario) type, separates the theories into four classes, as follows:

1. The vein material has been concentrated from the adjacent sedimentary rocks and redeposited in fissures through the agency of the ordinary groundwater circulation.
2. The vein material has been derived from the adjacent sedimentary rocks through the solvent action of ascending heated waters.
3. The lime contained in the fluorspar has been derived from the limestone wall rock but the fluorine and other elements composing the vein material have been brought up in solution from a magmatic source.
4. Both the vein material and the solutions from which the vein material has been deposited are of magmatic origin.

It is, of course, probable that all important deposits of fluorspar were not formed in the same way and by the same agencies, but certain general conclusions seem to be applicable to most commercial deposits.

[1] Wilson, M. E., Fluorspar deposits of Madoc district, Ontario: Canada Dept. of Mines, Geol. Survey Summary Rept., 1920, part D, pp. 47–48.

[2] Clark, F. W., Data of geochemistry: U. S. Geol. Survey Bull. 695, 1920, pp. 331–332.

First, virtually all important deposits are in or near fault fissures. They may exist as fillings of the fissures, as replacements of the walls, as replacements of favorable sedimentary beds in or near zones of faulting, as fillings of solution cavities near faults, and as residual deposits left by the weathering of deposits formed in one of the other ways mentioned.

Second, limestone beds or calcite veins are the most favorable places for the formation of large deposits. Most deposits in igneous rocks are small, narrow, and nonpersistent. In sedimentary beds comprising limestones, shales, and sandstones, as in the Illinois-Kentucky district, the widest and best parts of the deposits are nearly always in the limestones or in highly calcareous shales and sandstones, or in those parts of the fissures where the original filling was calcite. Where the fissures cut sandstones or other highly siliceous rocks they show a strong tendency to become narrow and of poor grade. A notable exception to this generalization is the deposit at Wagon Wheel Gap, Colo. This deposit, which is by far the largest and most persistent of those known to be in igneous rocks, occurs in Tertiary volcanic rocks, rhyolite tuff, and some quartz latite and andesite. There, however, as in other fluorspar deposits in igneous rocks such as that near North Gate, Colo., there are known sources of lime near by. At Wagon Wheel Gap the vein, if projected, would pass through a deposit of travertine around a hot mineral spring a short distance away. At North Gate the vein is in granite gneiss separated by a fault from a group of sedimentary beds containing limestone.

Third, some evidence of igneous activity is to be seen at or near most of the important fluorspar deposits. This evidence may be intrusive dikes, as in the Illinois-Kentucky field, or hot mineral springs, as at Wagon Wheel Gap, Colo., and at the Great Eagle mine near Lordsburg, N. Mex., or it may be the corrosion and etching of fluorspar surfaces as by hot solutions or vapors (observed in the Illinois-Kentucky district). In the Madoc district, Ontario, these evidences of igneous activity seem to be lacking, but Wilson[3] suggests that solutions of magmatic origin may have risen along faults.

From the foregoing evidence it seems probable that most commercial fluorspar deposits were formed as given under 3 or 4 in Wilson's summary, and some perhaps by a combination of the two. Unwarranted assumptions have been based on these theories.

Thus it has often been said of the Illinois-Kentucky district that if the fluorspar is of deep-seated or magmatic origin, the deposits may be expected to continue to great depth or at least to the base of the limestone formations. But this deduction is not necessarily valid and developments on the deeper levels in both Illinois and

[3] Wilson, M. E., work cited, p. 52.

Kentucky seem to disprove it. Although it is true that those vents, chimneys, or channels which served as feeders might be expected to be mineralized to some depth, it does not follow and is not even probable that the mineralization of the whole vein system continues to the same depth. It seems more likely that a few vents or chimneys served as feeders. Solutions or vapors rising through these channels might not spread much until they encountered some obstacle, such as impervious strata (perhaps removed later by erosion), when under the increased pressure they would spread laterally through fissures or would actively replace limestone or calcite along joints or planes of weakness. According to this theory, the largest and thickest bodies of fluorspar would be nearest the surface and the deposits would become shorter and possibly narrower farther down until at great depth only the chimneys or feeders would be mineralized. Deep workings in the Illinois-Kentucky district, as described more fully on later pages, seem to show this condition, although it is admitted that enough deep mining has not been done to prove or disprove it. In the Derbyshire district, England, where conditions seem to resemble closely those of the southern Illinois-western Kentucky district, the fluorspar deposits become shorter and narrower with increasing depth and the vein matter changes to calcite and barite. This change may, however, be due to fundamental differences in rock structure and in mode of occurrence.

Proper determination of the origin of a deposit and correct interpretation of theories of origin are of greatest importance commercially. On them depend intelligent estimation of ore reserves which, in turn, has an important bearing on the method of mining to be followed, the extent and type of development, the nature and size of mining plant and equipment, the size of the mill, and the justifiable investment of capital. If the ore body in its full length and thickness may be expected to continue far down, "pinches" and the changing of vein matter from fluorspar to calcite may be considered as only local variations and more extensive development may be expected to reveal ore in workable quantities; but if there is no good reason to believe that the ore body will persist to great depth, the unfavorable conditions noted above should be fairly good evidence that extensive exploration of barren ground by deep levels would be a waste of time and money. Under certain conditions it is evident that too much reliance has been placed on the persistence of fluorspar deposits with depth.

PROSPECTING AND DEVELOPMENT

The most important deposits of fluorspar in the United States lie in fault fissures that cut nearly horizontal sedimentary rocks. The system of faults is very complex. Because of deep weathering and recent sedimentation the exact position and nature of the faults can be determined only by careful and detailed prospecting. This is particularly true in the western Kentucky district. On account of various factors mentioned elsewhere in this report, the conduct of prospecting and mining in Kentucky has until recently been irregular, spasmodic, and unsystematic. As the more easily found ore is removed, production must decline and finally stop, or costs (and therefore prices) must greatly increase, or regular and systematic prospecting must be undertaken.

Accurate maps must be prepared bearing all present reliable data. Careful records of all future prospecting should be kept and the information made available so that needless reprospecting may be avoided. It seems possible that all of the producers in a district could pool their information and jointly pay the cost of compiling and keeping up the records. In any event, the larger companies should adopt some definite system and follow it. Any improvement over the present methods should more than justify the added cost.

GENERAL CONSIDERATIONS

Prospecting may be extremely simple in regions where vegetation is scanty and little or no surface soil covers the rocks, as is generally true in fluorspar districts of the far West. But in the Illinois-Kentucky district, particularly in Kentucky, vegetation usually is heavy and solid rock is covered with residual and transported material to a depth of 100 feet in many places, and nearly 200 feet in some places. Of course, some important veins in Illinois outcrop (or did), but most of the solid veins in Kentucky are deeply buried, consequently prospecting is often difficult and uncertain.

Although the southern Illinois and western Kentucky districts are separated only by the Ohio River, the common modes of occurrence in the two fields differ greatly. In Illinois the largest veins outcropped in solid rock, and at only a few relatively unimportant deposits is the outcrop of the vein represented by disintegrated "gravel" in clay or other unconsolidated material. In Kentucky a few solid veins outcrop, but most deposits either show no visible fluorspar at the surface or it exists as "float" or "gravel" mixed with clay. (See fig. 2.)

The country is rolling, but the hills are only high or steep enough to make possible the use of tunnels for either prospecting or mining at a few places.

As prospecting in the far West is usually simple and as the bulk of the Illinois production comes from a few veins that are well known and well defined, prospecting in western Kentucky is given more attention in this report. There the production has always come and probably must continue to come from many small scattered deposits and a few larger deposits along fairly well-defined veins. In fact, much of the mining is on such a small scale that it is more like prospecting than real mining.

In seeking new deposits or the extensions of known deposits a prospector must remember that virtually all the fluorspar in western Kentucky occurs as fillings in, or replacements along, faults. Each of these faults usually maintains a nearly constant direction and dips at high angles. Although not all the faults are mineralized, evidence of faulting should be sought first. Often the main faults are not mineralized, but the productive deposits may be on minor faults close to the main fault and intersecting it at a sharp angle, as for example the deposits along the Columbia fault. In other places

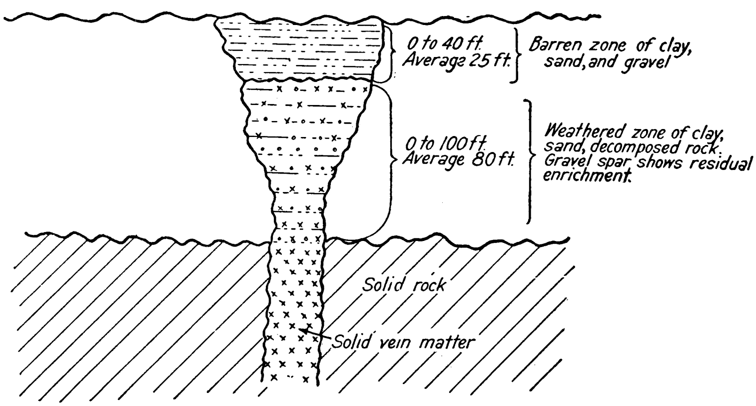

FIGURE 2.—Cross section showing general conditions in fluorspar deposits of western Kentucky

along a major fault may be a series of shorter parallel faults, the whole constituting a fault zone. An example is the Tabb fault. In such a series mineralization may continue some distance along one fault, then end to reappear and continue in another parallel fault. Occasionally two or more parallel faults may be mineralized in the same area. For these reasons the absence of fluorspar in any one part of a fault zone does not necessarily mean that the whole zone is barren.

The evidences of faulting are as follows:

1. The presence of two different formations near together and at about the same elevation; for example, a sandstone and a limestone at the same level and close together, or a flint or a sandy soil meeting a clay soil along a nearly straight line.

2. A series of sink holes in a nearly straight line, an arrangement caused by the solution of underlying limestone along a fault or joint plane. This evidence is not always conclusive and needs further proof.

3. Bold outcrops of quartzite in long ridges. During the faulting of a sandstone bed the rock pressure may be great enough to change the sandstone to quartzite along the fault. This quartzite resists weathering more than the remainder of the sandstone. If the quartzite is sheeted and slickensided the evidence is still more conclusive.

4. Slickensided, grooved, or polished surfaces on rock contacts or walls of fractures.

5. Along the line of contact the faulted beds in places are bent sharply upward or downward, but this indication is not always conclusive.

Limestone formations are most likely to contain important deposits of fluorspar. In a limestone the calcium fluoride may not only fill fissures but it may replace the calcium carbonate of the walls, thus making the veins wider. Furthermore, if the walls are limestone the impurities in the spar are mainly calcareous rather than siliceous, and this is an important advantage in milling and marketing. Where limestone forms one wall and sandstone or shale the other, conditions are still favorable, but not so good. Where both walls are sandstone or shale the faults are usually not productive, at least in the sandstone or shale layers, although the underlying (or overlying) limestone beds may be mineralized.

In many fluorspar deposits in New Mexico, Arizona, Colorado, and other far western States and in New Hampshire the wall rocks on both sides are granite, granite gneiss, or some other igneous and highly siliceous rock. With but one or two exceptions these deposits are small, irregular, and nonpersistent in depth or length; the fluorspar is high in silica, which is often intimately intergrown with it. All available evidence seems to show that, in general, important deposits of high-grade fluorspar are not to be expected in highly siliceous rocks, either igneous or sedimentary.

In the Illinois-Kentucky district other minor indications that are usually favorable are the presence of the common mineral associates of fluorspar, galena (lead sulphide), sphalerite (zinc sulphide), and barite. However, although barite may indicate the possible existence of fluorspar it is not a favorable indication of quality. Barite is an undesirable impurity and is difficult to separate by mechanical means. Sphalerite is in somewhat the same class as barite, but a method for the commercial separation of sphalerite from fluorspar will probably be developed.

Authorities differ as to the significance of vein calcite in fluorspar deposits. When found at the surface, vein calcite is usually considered a favorable indication, but when a fluorspar vein changes to calcite at depth, experience has generally shown (especially in Illinois) that the fluorspar has been "bottomed" and that deeper working is useless. Ulrich and Smith [4] believed that the calcite and fluorspar were deposited together and that the presence of one usually implies the presence or possible presence of the other; in other words, that a change from fluorspar to calcite in depth has only local significance and that deeper working may reveal additional fluorspar. Since their report was written, however, many more deposits have been opened and deeper levels explored, yielding abundant evidence against their theories. For example, this work has shown the unmistakable replacement of calcite by fluorspar in many places. Currier and Butts [5] find that the calcite was deposited first and later replaced in part by fluorspar. This replacment seems to be greatest near the present surface and to decrease in depth. Therefore calcite near the surface, if other indications are favorable, may be good evidence of the possible presence of fluorspar near by, but a wide deposit of calcite at a depth of several hundred feet may be a neutral or even a negative indication.

PRESENT METHODS IN THE ILLINOIS-KENTUCKY DISTRICT

Prospecting for fluorspar in the Illinois-Kentucky district has been done in a number of ways, as follows: (1) Test pits and shafts, (2) surface trenches, (3) tunnels (unusual), (4) crosscuts and drifts from shafts or pits, (5) core drilling, both underground and from the surface, (6) churn drilling, and (7) auger or post-hole drilling.

TEST PITS AND SHAFTS

Test pits and shafts have probably been used more than any other method of prospecting and they have found most of the ore deposits now worked. The disadvantages are: (1) As most of the veins are nearly vertical, a test pit or small shaft may miss ore that is only a few feet from it; (2) to sink shafts or pits is slow and expensive. The chief advantage is that any ore found may be followed down and its nature and extent accurately estimated. Moreover, a shaft in ore will pay at least a part of its cost. Development shafts in ore are also generally used as working shafts for a considerable time.

SURFACE TRENCHES

Trenching at right angles to the supposed strike of the vein is sometimes used. However, much of the ore, especially in Kentucky, is not so close to the surface that trenches of moderate depth will cut it. In places where the general position of the fault zone is

[4] Ulrich, E. O., and Smith, W. S. Tangier, The lead, zinc, and fluorspar deposits of western Kentucky: U. S. Geol. Survey Prof. Paper 36, 1905, p. 150.

[5] Currier, L. W., and Butts, Charles, The geology of Hardin County: Illinois State Geol. Survey Bull. 41, 1920, pp. 257–282.

fairly well known, trenching in surface soil may reveal soil differences (for example, a change from a sandy to a clayey soil) that will enable the general position of the fault to be determined more closely. Then a shaft sunk on the contact will show the presence or absence of ore.

TUNNELS

For some unknown reason prospecting by tunnels is little used even where the conditions are favorable. It is true that much of the surface in the mineralized areas is too flat for tunneling, but shafts or pits have been used where tunnels would have been cheaper and more advantageous.

CROSSCUTS AND DRIFTS FROM UNDERGROUND

Crosscuts underground have, like tunnels, been used too little. In places as many as six shafts have been sunk close together, some of them only 10 feet apart, where one shaft and one or more crosscuts or drifts would have obtained more information at a less expense of time, money, and energy. This has been particularly true of the western Kentucky district, where the surface in places has been so cut up with numerous pits and shafts that later mining is seriously handicapped.

At present, when the fluorspar in a drift of a going mine terminates in a pinch, there is usually little hesitancy in drifting through the pinch, possibly for considerable distances, in the hope of again finding spar. Sometimes crosscuts also are driven in the hope that the spar may be found in a parallel, diverging, or branching vein; usually, however, too little attention is given to this possibility and the use of such exploratory crosscuts is by no means general. Often in the past, and sometimes even now, when an operator met a tight pinch in a vein he assumed that the ore body had ended and did not have the courage or means to continue unprofitable drifting in waste rock. Now that the variable nature of the veins is better understood drifting through pinches is common. In some of the larger Illinois mines drifts through pinches several hundred feet long have found good ore beyond.

An experienced operator said he had concluded that in the Kentucky field it usually did not pay to drive through a pinch for a distance much greater than half the known length of the ore body. If an ore body 500 feet long terminated in a pinch it usually would not pay to drive in waste rock along the pinch for more than 250 feet. This generalization, of course, is not a hard and fast rule and may be modified by conditions.

CORE DRILLING

Core drilling from the surface and from underground stations has been used to some extent in both Illinois and Kentucky, but the results have usually been unsatisfactory. Vertical holes, of course, are of little value where the dip of the vein is vertical or nearly so. Angle holes or horizontal holes from underground points should theoretically be of considerable value. In practice the common occurrence of small, worthless stringers of fluorspar in the wall rock, far from larger ore bodies, may make drill cores very deceptive. The drill may follow such a narrow stringer and the cores may indicate a commercial ore body, but when the supposed deposit is explored by shafts or crosscuts nothing is found. Several such instances in the Kentucky field can be cited. One company lost many thousands of dollars in shaft sinking and surface developments that found little or no ore, although core-drill prospecting had given attractive results.

Another possible reason for the failure of core drilling may be the fact that the courses of the drill holes were not surveyed properly. It is well known that deep core-drill holes deviate in both dip and direction, often greatly from the courses on which they were started. The end of many a drill hole is a considerable distance away from its calculated position. It is possible that some deposits indicated by drilling but not found by later development actually exist some distance from the place indicated. That this may be true occasionally is suggested by the fact that often the drill holes are not cut by the underground workings.

Means are now available for accurately surveying core-drill holes, and future prospecting by core drilling in this district should take advantage of them. Methods of bore-hole surveying are described by A. F. Taggart.[6]

CHURN DRILLING

Churn drilling has been used successfully in prospecting, but it is not particularly well adapted for finding fluorspar. In Illinois, churn-drill holes have been used to determine the actual position of a fault that has been prospected later by means of shafts. To locate a fault two drill holes are put down, so far apart that they certainly are on opposite sides of the fault line and at about a right angle to the strike. Accurate records are kept of the formations and the exact elevation of each contact, then other holes are drilled between and in line with the other two, until two holes close together are shown, by differences in level of the same formations, to be on oppo-

[6] Peele, Robert, Mining Engineers' Handbook. New York, 1918, pp. 369–374.

site sides of the fault. In this way not only may the exact position of the fault be determined, but its approximate throw and perhaps its dip may be estimated, and much useless shaft sinking may be saved.

AUGER AND POST-HOLE DRILLING

Where the zone of surface weathering is deep, as it usually is in the western Kentucky district, and where the soil is relatively free from large pebbles and rocks, a less common condition, the earth auger or post-hole drill may be used to advantage. The fluorspar in this weathered zone is usually a loosely coherent gravel that an auger picks up easily. Extensions of several smaller veins in Kentucky are said to have been found in this way. Often several holes are started and abandoned later because of rock obstructions before one hole deep enough is completed. In spite of this disadvantage the method, where applicable, may be the cheapest and quickest available.

SUGGESTED IMPROVEMENTS IN PROSPECTING METHODS

To find new veins or continuations of known veins is constantly becoming more difficult and expensive. All areas known to be mineralized have been carefully searched many years for surface indications and probably all the easily discoverable deposits are now known. In addition, much prospecting, most of it very unsystematic, has been done in areas where no visible outcrops of fluorspar could be found.

At present, if the opening up of new ore is to equal production, prospecting must be done more efficiently and systematically. It should be possible to block out an area and prospect it so thoroughly that little doubt can exist as to the presence or absence of important deposits of fluorspar. Present methods are too slow and expensive for such prospecting; they must be improved or new methods devised.

For finding veins or faults where no outcrops exist and the soil covering the solid rock is thick, trenching at right angles to the supposed strike seems to offer the greatest possibilities. Instead of trenching by hand a form of drag-line scraper specially designed for this purpose might be used. Such a device might have a rather narrow scraper and be driven by a portable gasoline engine. In unconsolidated material relatively free from large bowlders the scraper should cut long, deep trenches much more rapidly and cheaply than they can be dug by hand.

Where the sinking of prospect shafts is necessary or desirable the following equipment is suggested: On a heavy motor truck or trailer could be mounted a small gasoline engine, a small geared hoist, and a belt-driven air compressor large enough to run one drill of the jack-hammer type. The hoist and compresser should be so placed, on opposite sides of the engine, that either could be run independently. With this portable outfit prospect shafts could be sunk through soil or solid rock much more rapidly and probably more cheaply than by present methods. Possibly, too, the same engine and hoist could be used to run a drag-line scraper.

MAPS AND RECORDS

In all prospecting, whether successful or unsuccessful, accurate maps and records should be kept which should show: The exact location of the drift, shaft, trench, or bore hole, its direction, its depth or length, the elevation of the collar of the opening, the material passed through, and the position of contacts, the date of work, and the names of the men in charge. Many small-scale operators, particularly some of the smaller ones, have not appreciated the need for such records, assuming that if they found and mined the spar no records were necessary; if they found no spar the records were useless. This, of course, is not true, for only through the gradual accumulation of data on formations and the presence or absence of favorable indications can future prospecting and development be done intelligently. Information obtained from a prospect deemed unfavorable may, when added to similar data from another prospect, give information of great value.

For example, in an area of branching and step faulting, as in western Kentucky, differences in elevations of the same bed in nearby prospects may indicate a fault between, and this fault may be mineralized.

A company in Illinois that keeps good records has devised a graphic method of keeping data on churn-drill holes. In addition to the regular records, it makes on thin cardboard a chart for each hole, showing, to scale, the depth of the hole and the exact boundaries between the different formations encountered. Then drill cuttings that represent the materials of each different formation are glued to the chart in their proper places. In this way a controversy as to the proper identification of a formation or its similarity to material found in other holes may be settled at any time.

DEVELOPMENT

Few fluorspar mines in the United States maintain an adequate policy for the systematic development of fluorspar reserves in advance of mining. In the southern Illinois district several of the larger companies develop their property systematically; their policy is to keep each of the principal shafts much deeper than its lowest working level, often a hundred feet deeper. Provision for lateral development is, in a way, partly made through the shrinkage-stope method of mining commonly used. One large shrinkage stope provides many working places and blocks out a large tonnage of ore. In addition, drifts are usually driven in advance of working stopes, commonly at least 100 feet and often much more.

In Illinois few shafts are used and lateral development is most important, in contrast to the Kentucky practice of using many small shafts. In Illinois it is often necessary to drive long development drifts through pillars of waste in pinches to reach known blocks of ore beyond. Such work is expensive, but has the merit of exploring thoroughly and sometimes finding ore in a block of ground that otherwise might never have been touched.

In the western Kentucky district very few mines have been developed systematically. Much mining has been on contract under short-term leases. The small operators have not had the incentive or the capital to do any development, but have mined out small patches of easily accessible ore from small temporary shafts. The need of adequate development is appreciated by the larger Kentucky operators and more attention will probably be given it in future.

At Wagon Wheel Gap, Colo., where the deposit is opened by adit tunnels, development is kept far ahead of mining by the extension of tunnels, the driving of new tunnels at low levels, and the connecting of tunnels by raises.

MINING METHODS

Although the methods used in mining fluorspar differ greatly in different mines and in different districts, all mines may be divided into three main groups, as follows: (1) Open-cut mines; (2) mines opened by drifts or tunnels; and (3) mines opened by shafts. Of these three groups the third is by far the largest and most important.

OPEN-CUT MINES

In the western Kentucky field and at a few of the smaller mines in southern Illinois and elsewhere the fluorspar veins outcrop or lie so close to the surface that open-cut mining is possible. These mines are nearly always very small and the fluorspar is removed entirely by hand labor.

In western Kentucky and at a few mines in southern Illinois surface deposits of soft residual gravel or lump spar mixed with clay and sand are worked by open pits, usually to depths of not more than 30 feet. The fluorspar is removed by pick and shovel and trammed in small cars or wheelbarrows to a log washer close by. Usually the spar is so soft that no drilling or blasting is necessary.

Although many shallow deposits may be mined economically by open cuts, use of open cuts is inadvisable if the vein continues in depth and later mining must be underground. This is particularly true where the vein and its walls are disintegrated and soft at the surface. At many deposits in western Kentucky the surface has been so cut up by open-pit mining that subsequent underground mining has been greatly hampered and much ore lost by "mud runs" and by streams of water entering the workings from the open cuts above.

When an outcrop of residual fluorspar is discovered, prospecting should be done to prove the downward continuation of the deposit. If the ore proves to be of minable width in the solid rock below, a shaft should be sunk, preferably in the footwall, and mining started at such a depth that a strong pillar of solid-vein material can be left to support the surface. After all of the deep-lying ore has been removed the surface ore may be taken; in other words, the surface ore should be mined last. This policy is now followed by the larger companies in the Illinois field.

DRIFT MINES

Many fluorspar deposits that are in a region of rugged topography and dip at a high angle (as at Wagon Wheel Gap, Colo.), and many more or less horizontal bedded deposits that lie above the general level of the surrounding country (for example, the deposits near Cave in Rock, Ill., and at the Nakaye mine, N. Mex.) can be opened by drifts or tunnels instead of shafts. Where conditions warrant, drifts and tunnels are preferable, because no hoisting and often no pumping is required. Where the veins dip at a high angle the methods of mining need not differ greatly from those used in shaft mines and require little comment here. The description of the mining method at Wagon Wheel Gap, Colo., will be interesting in this connection.

There are only a few bedded fluorspar deposits, and the only ones in the United States that have been worked at all systematically are near Cave in Rock, Ill. Those parts of the beds that contain fluorspar of minable thickness, usually more than 24 inches, are opened by drifts and the spar is extracted by a modified room-and-pillar method, such as is sometimes used in coal mining. The methods used at Spar Mountain mine illustrate this.

SHAFT MINES

Shaft mines differ greatly in size, productive capacity, methods of working, efficiency of operation, and many other respects. They range in size from small pits 30 to 40 feet deep, worked on contract by two or three men who use a hand windlass for a hoist, to the very large mines, several hundred feet deep, which employ hundreds of men and have extensive mechanical equipment. Some of the larger mines employ definite systems of mining, but unfortunately these mines are far in the minority. There are only a few really large mines (chiefly in southern Illinois), and there are a great number of small mines (chiefly in western Kentucky). At a few of these smaller mines some semblance of a definite system is attempted, but usually the ore most easily extracted near the surface has been removed as cheaply and rapidly as possible with little regard to future mining.

At those deposits which are worked by leasing to contractors for brief periods short sections of the vein, often 150 feet along the vein, mining is without system. Such mines are commonly opened by small (often 4 by 4 feet or even smaller) single-compartment cribbed shafts sunk on the vein. As soon as the shaft reaches the base of the barren surface material very narrow drifts, untimbered if possible, are run from the shaft along the vein.

If developments in this drifting are favorable, it is customary to sink the shaft 20 to 40 feet deeper and again run drifts in each direction, usually to the boundaries of the leased section. Then removal of the mineral by overhand stoping begins. Only such timber is used as is absolutely necessary to hold the ground during mining and to provide standing room to keep the miners up to the back of the stope. If all of the mineral above this level is extracted before the termination of the lease, the shaft may again be deepened 20 to 40 feet and another slice mined out.

In such mining very little dead work is done to follow the vein through pinches; often all of the easily accessible ore is extracted, or the workings cave before the termination of the lease and the mine is abandoned. In a relatively short time the workings are wholly inaccessible, and more systematic mining later is greatly hampered. Sometimes such deposits are mined again by similar inefficient unsystematic methods and the workings once more left to cave. Much ore is lost and deposits have been reported as worked out when only the part near the surface has been explored. Adequate maps are rarely made of the old workings, and subsequent mining is difficult and expensive.

In such mines ore is usually transferred with wheelbarrows or with ore buckets on small trucks that run on narrow-gauge tracks. Hoisting is nearly always by buckets, which are lifted by a hand-power windlass, small gasoline engine, or horse whim. At the surface the ore is either washed in log washers or roughly hand picked (if hard ore) and hauled to a custom mill.

OTHER SYSTEMS

The square-set system of mining is used to some extent in the surface sections of the residual gravel fluorspar deposits in the western Kentucky district. At the Yandell mine the following system was in use in 1922.

The deposit, in blocks 150 feet in length along the vein, was being worked by contractors. In the middle of each block a small cribbed shaft was sunk about 50 feet; from its bottom drifts were run in each direction to the end of the block. These drifts were timbered by a modified square-set system. Regular four-piece drift sets separated by plank dividers were used. Where the vein was wide, long caps reaching to the footwall were used as shown in Figure 3.

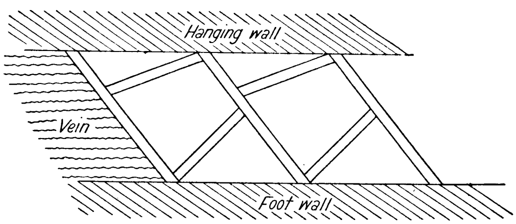

FIGURE 3.—Modified square-set system used in Yandell mine, western Kentucky

At each end of the block, raises timbered with the same modified square-set system were put up to the top of the ore. Then the ore was stoped by successive vertical slices parallel to the raises, retreating from each end of the block toward the shaft, and the openings made were all supported by square-sets. Stoping was continued until all the ore in the block above the 50-foot level was withdrawn.

If a second horizontal slice was necessary—that is, if solid rock was not reached at 50 feet—the shaft was deepened 20 or 30 feet and a second lift taken in the same way, the timber mat from the workings above being caught up as it was encountered. Only a 20 or 30 foot slice can be taken on the second lift because of the weight of the ground. Successive layers were removed in this way until solid rock was reached.

If the ore was so wide that single caps would not reach from wall to wall a different method was used. Formerly only part of the vein was taken in the first mining, and the workings and shaft were allowed to cave. Later, a new shaft was sunk and another strip adjacent and parallel to the first strip mined out in the same way.

In some places the vein was so wide that it was necessary to remove the ore in three or more such parallel strips. This method was so slow, inefficient, and wasteful that another method was devised.

Wide places in the vein (some of them as much as 40 feet wide) were mined thus: A shaft was sunk to a depth of 50 feet in the center of the block, and drifts were run down the middle of the vein in each direction to the ends of the block. From the ends of these drifts crosscuts were driven to the foot and hanging walls, and from the ends of the crosscuts raises were put up to the top of the vein. The ore was then stoped out of the vertical slice over the crosscuts back to the drift, then other crosscuts were driven to the walls next to those just mined out and the process was repeated until all of the ore was mined back to the shaft, as Figure 4 shows.

In all this work the ground was supported by square sets like those described.

When all of the " soft ore " down to the solid rock has been removed it is planned to leave a horizontal pillar of solid vein filling

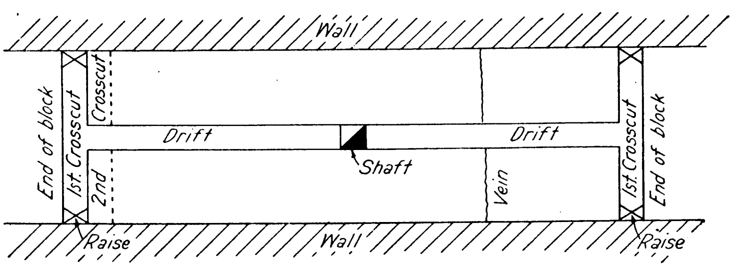

FIGURE 4.—Plan showing method of working wide vein

(locally called an arch) 5 to 15 feet or more thick to support the surface and walls. The thickness of this pillar will depend on the width of the vein, the strength of the ore and walls, and the nature of the overburden. Below this pillar it is planned to remove the ore by one of the regular methods of " hard-ore " mining common in the district.

Square-set timbering is also used to some extend in places in some of the hard-ore mines where the walls are broken and difficult to hold.

Shrinkage stoping is the standard method of mining hard ore in the three large mines on the Rosiclare vein in Illinois, at the Franklin mine in Kentucky, and at a few other mines in the Illinois-Kentucky district. This method, as it is applied at the mines of the Fairview Fluorspar & Lead Co. (now Franklin Fluorspar Co.), near Rosiclare, Ill., is described in detail later.

Overhand stoping on stulls is similar to the shrinkage-stoping method, except that no ore is allowed to accumulate in the stopes, and stulls are set between the walls to provide a footing for the miners close to the working face above. This method, as applied at the Mary Belle mine, is described later.

Underhand stoping into raises has been used at a few Kentucky mines. In this method the ore may be blocked out, as in shrinkage stoping or in overhand stoping on stulls, into blocks or stopes of convenient length, and at the center of each block a raise is put through connecting the adjacent levels. Then, beginning at the upper level, the ore around the raise is drilled, broken into the raise, and drawn off through chutes at the bottom of the raise. As the ore is removed stulls may be set in the open stopes to hold the walls. This method is illustrated in the sketch, Figure 5.

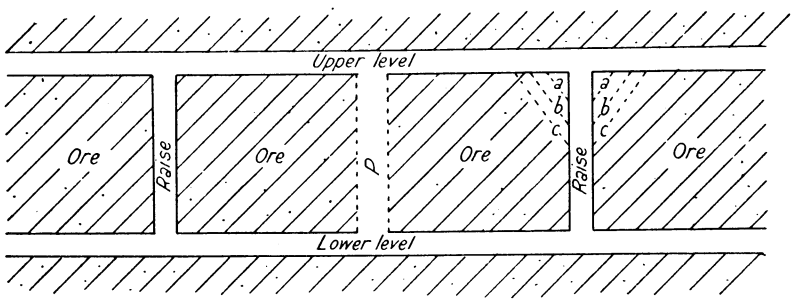

FIGURE 5.—Elevation showing underhand stoping into raise: *a–a*, *b–b*, *c–c*, Successive slices of ore broken into raise; *p*, pillar to be left on lines of stulls to be set to hold walls

MISCELLANEOUS MINING PRACTICE AND EQUIPMENT

Shafts.—Almost without exception vertical shafts are used in fluorspar mines in the United States. At small mines, worked by contractors or small leasing companies, the proper location of shafts has received little attention; the shafts almost invariably are sunk on the vein regardless of the nature of the ground. They are cut as small as possible consistent with ease and speed in sinking (many are 4 by 4 feet or smaller), and are lightly timbered. Such shafts are too small for efficient work, they are not strong enough to stand much earth or rock pressure, and many of them cave before the sections of the deposits they serve are mined out.

Shafts sunk on the vein have other serious disadvantages. Much ore must be left standing in pillars to protect the shaft, or there is the constant danger of its collapsing. Even if pillars are left there is still some danger of movement if the vein is wide and large open stopes are left.

The sinking of small, single-compartment shafts in the vein is, of course, permissible for exploration or development. If the vein proves to be narrow and nonpersistent in depth, to use the small prospect shafts for extracting the small tonnage recoverable may be economical. Often, however, development work is not carried deep enough to determine conclusively the downward extent of the vein. There is little excuse, except lack of ready capital, and this should not be allowed to govern, for the mining of a wide vein through numerous small, temporary, ill-equipped shafts scattered irregularly along it is not good engineering practice.

The best practice, and that which is now followed by all of the large companies, is to sink a main vertical shaft or shafts in the footwall and so far from it that no settling of the vein or hanging wall will affect the shaft. If the vein has an appreciable dip, the shaft may perhaps be sunk only a few feet from the footwall side of

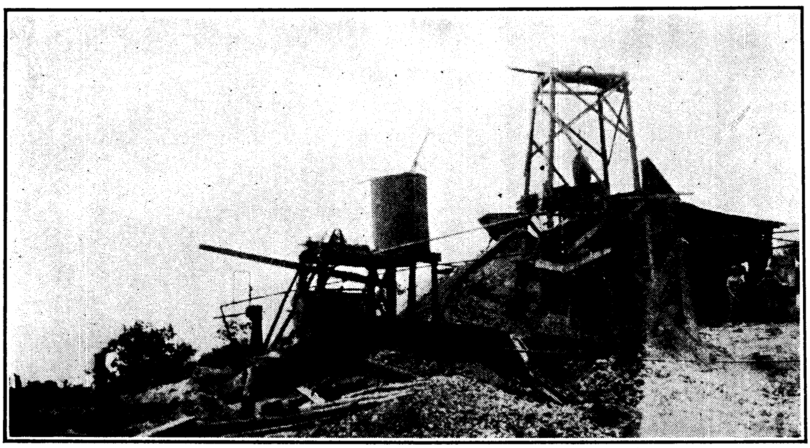

FIGURE 6.—Typical small contractor's headframe and log washer, Yandell mine, near Mexico, Ky.

the vein at the surface. If the vein is almost vertical the distance should be 50 to 100 feet or even more, depending upon the strength and character of the footwall rock.

At the larger mines in Illinois it is now standard practice to sink well-timbered, 3-compartment shafts that measure 5 by 14 feet to 6 by 20 feet in the clear. Of the 3 compartments 2 are for hoisting and 1 for pipes and ladders. At several mines that part of some of the shafts that is above solid rock is concreted. In many sections through solid rock timber is unnecessary except for skip guides and ladderways.

Headframes.—At fluorspar mines headframes range from light, low timber structures suitable only for prospecting to those built of heavy timber and structural steel. Figures 6 and 7 show these two extremes. At a few mines the headframes have been so light and poorly constructed that hoisting accidents seemed inevitable. Both safety and efficiency demand that headframes shall be well built.

Levels.—In the largest mines levels are spaced at about 100-foot intervals vertically. In some of the smaller mines 50-foot intervals are used, and at others no regular system is followed. At most mines the 50-foot interval is too small, unless the ground is hard to hold, and working drifts are kept open for long periods with difficulty. If 50-foot intervals are used instead of 100-foot the cost of drifting, timbering, and tracklaying is doubled.

Haulage.—Hand haulage is common in the smaller mines, but in the largest mines mules are used. In one mine mules spot cars beneath ore chutes and make short hauls, and a gasoline locomotive is used for the long hauls. Usually gasoline locomotives are not to be recommended for underground use because of the danger from poi-

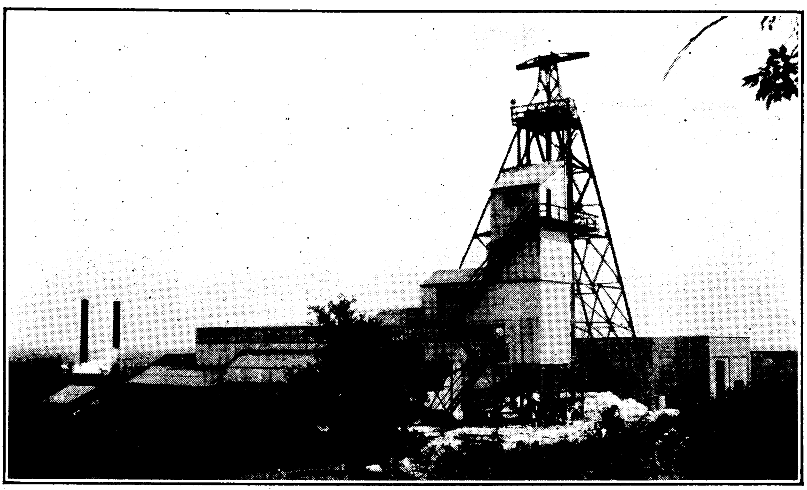

FIGURE 7.—Headframe and mill, Hillside Fluor Spar Mines, near Rosiclare, Ill.

sonous gases in the exhaust. In the mines of the Rosiclare Lead & Fluorspar Mining Co. three storage-battery locomotives do most of the underground hauling; each can haul 8 to 10 steel cars holding 1 ton each down a 1 per cent grade.

The ore is usually hauled to the shaft in steel or wooden cars, bottom or side dump, holding about 1 ton each. In the large mines in Illinois the ore is dumped from the cars over grizzlies with bars spaced about 8 inches apart into large storage bins beneath the shaft station, from which it is drawn off into skips and hoisted to the surface. At the smaller Illinois mines, and almost without exception at mines in western Kentucky, there are no ore storage bins underground. The ore is dumped from the cars into buckets that are hoisted to the surface. Where a regular production, even if of moderate size, is to be maintained the use of underground storage bins and skips is strongly recommended.

Ventilation.—Ventilation in fluorspar mines is usually not important. No poisonous or explosive gases are found, and the natural ventilation is usually good. In a few of the larger mines a small portable fan may be used in the driving of drifts on the deeper levels a considerable distance in advance of stoping.

Lighting.—In virtually all fluorspar mines in the United States the miners use open-flame carbide lamps. In the largest mines electric lights are used in the shaft stations, pump rooms, and main haulage ways. In the smaller mines no lighting is provided other than that from the miners' lamps.

Pumping.—Pumping is an important problem at nearly all of the shaft mines of the Illinois-Kentucky district. In the largest mines on the Rosiclare vein in Illinois, pumping is one of the largest single items of expense. The vein is near the Ohio River and not only must ordinary underground water be handled but also seepage from the river, and occasionally during floods river water enters the shafts from the top. As depth increases drainage becomes more difficult and more expensive.

Hoisting equipment.—Hoisting equipment of almost every type may be found in fluorspar mining. In the prospecting stages hoisting may be by hand windlass or horse whim. In the Kentucky field many small mines have small hoists belted to oil engines that use gasoline, kerosene, or crude oil for fuel. The oil engine seems to have nearly displaced the old donkey-engine type of steam hoist. At the largest mines large double-drum, steam-driven hoists or, at a few places, electric hoists are used.

Surface plant and equipment.—At the smaller mines the surface equipment is small, usually consisting only of the hoist and perhaps an air compressor, but at the larger mines it is extensive. A few mines have large well-equipped shops, where all small repairs and many large repairs are made, and mine cars, skips, and similar equipment used about the mine are built. These mines also have carpenter shops where all mine timber is sawed and framed. All drill sharpening is done by automatic drill sharpeners.

MILLING

TYPES OF ORE AND NATURE OF IMPURITIES

The methods of concentrating or milling fluorspar depend upon the nature and amount of the associated impurities and upon the type of the ore. The impurities or associated minerals may be roughly divided into: (1) Those which have no harmful effect in the common methods of utilization and may thus be classed as diluents; and (2) impurities which are really injurious in the processes in which fluorspar is used, and which therefore must be entirely eliminated or reduced to a very low percentage. Opinions differ as to the effect of some impurities, as noted in a discussion of this subject under "Utilization," but the following classification is accurate enough for milling purposes.

1. **Harmless impurities or diluents.**—Calcite or any from of calcium carbonate; silica in any form; silicates and alumina-silicates, such as feldspar, which do not contain large amounts of the metals; wall rocks, such as granite, slate, shale, and so on; clay and sand.

2. **Injurious impurities.**—Barite; galena; sphalerite; pyrite; all other sulphides and sulphates; all other lead and zinc minerals; all iron compounds (in glass and enamel grade spar).

Although the so-called harmless impurities act merely as diluents they are not tolerated in large quantities in merchantable fluorspar; thus the lowest marketable grade of fluorspar is ordinarily the gravel grade, which contains at least 80 per cent calcium fluoride and not over 6 per cent silica. The remainder is generally calcium carbonate. The problem of milling therefore resolves itself into elimination of all injurious impurities and raising the grade of the ore to meet the lowest specifications at least.

Successful concentration of fluorspar depends as much upon its type and physical nature as upon the impurities. In general there are three principal types of ore: (1) Residual and (or) disintegrated ore mixed with sand and clay; (2) massive crystalline ores, in which the fluorspar is easily separable from the gangue minerals; and (3) hard mixed ores in which the fluorspar is intimately associated with other vein minerals or with fragments of wall rocks (breccias).

Ores of the first type are most easily concentrated. Such ores, containing as low as 25 per cent fluorspar, may often be easily and cheaply concentrated to a high-grade product.

Massive crystalline ores may sometimes be so mined and prepared by simple hand sorting that mechanical concentration is unnecessary. If concentration is necessary, simple jigging is ordinarily ample. In the Illinois-Kentucky district, where the chief impurity is calcite, it is usually considered that the poorest grade of ore of this type which can be milled profitably at present prices must contain at least 50 per cent calcium fluoride. If the gangue was mostly silica, ores of as low grade as 50 per cent could hardly be treated economically.

When fluorspar is intimately associated with gangue minerals, particularly silica and the silicates—barite, sphalerite, and so on—commercial separation is often impossible by present known methods.

TYPES OF CONCENTRATING MILLS

FOR DISINTEGRATED OR RESIDUAL ORES

Disintegrated or residual ores mixed only with sand or clay usually need very simple treatment. Sometimes residual ores occur in large lumps, as near Cave in Rock, Ill.; more often the crystalline fluorspar of such deposits has disintegrated mechanically, forming a fluorspar gravel mixed with sand and clay. If the lumps have not disintegrated, which is rather unusual, the clay at the surface may have been removed by natural drainage so that simple hand sorting yields a commercial product.

Residual gravel fluorspar must be purified by washing. This may be done by washing in single or double log washers, washing in log washers followed by sorting on a picking belt, or log washing and jigging.

The ordinary log washer commonly used in fluorspar milling usually consists of an octagonal wooden log 12 to 18 feet long and about 12 inches in diameter, to which iron blades are attached. The log is set in a wooden trough about 2 feet deep by 2 feet wide and the whole machine inclined at an angle of 1° to 3° from the horizontal. The blades are set at an angle and distributed around the log in a spiral, with each blade 1 to 4 inches ahead of the blade next to it.

The log is usually revolved at 12 to 14 revolutions per minute, but on cleaner ores speeds as high as 40 revolutions per minute are sometimes used. The ore is fed in at the lower end, usually by hand, and a 1½ to 2 inch stream of water enters at the upper end of the trough. The action of the blades thoroughly disintegrates the ore and slowly carries it to the upper or discharge end of the washer. The water aids in the disintegration and at the lower end carries off the clay and fine sand in suspension. At the upper or discharge end there is usually placed a small inclined section of screen with about one-fourth-inch holes, upon which the ore drops, allowing a certain amount of drainage. From this screen waste is also sometimes picked. Figure 8 shows a typical single-log washer.

When the ore is particularly dirty or difficult to disintegrate a double-log washer or two single logs connected in tandem may be used. A double-log washer consists of a trough about double the usual width in which two logs are set side by side. Figure 9 shows a double-log washer.

A single-log washer requires about 1½ to 2 horsepower and a double-log 3 to 4 horsepower. Small steam engines were formerly used exclusively to drive log washers, but now small gasoline or kerosene engines are more common. A 5-horsepower engine provides a reserve of power and is large enough to do some additional work about the mine. Fohs[7] states that at 14 revolutions per minute the 16-foot washer handles about 20 tons in 10 hours (probably crude-ore basis). For soft ores of which the solid part is practically pure fluorspar, at mines where water is plentiful, simple log washing is a very cheap and efficient method of milling. However, it has the disadvantage that fine grains of fluorspar are lost in the overflow or in the undersize from the lip screen at the discharge end. Attempts are sometimes made to save these fines by passing the overflow through settling tanks or even crude classifiers. In this way a low-grade concentrate is made which is mixed in small proportions with the clean, washed product.

If the residual ore is in fairly large lumps mixed with waste rock, clay, sand, and gravel, it may first be passed through a log washer

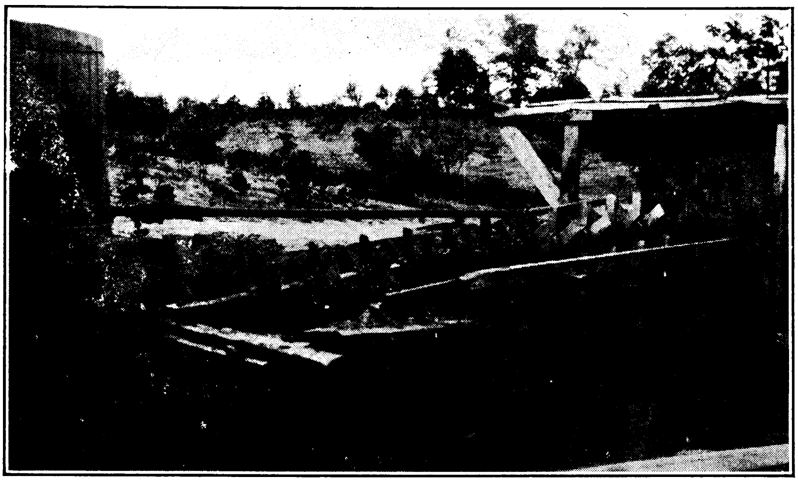

FIGURE 8.—Typical single-log washer, on La Rue vein near Marion, Ky.

to remove the clay and sand, then over a picking belt, where the coarse waste may be removed.

When the impurities are too fine to be removed from a picking belt and too coarse to be eliminated in the log washer, the log-washer product is sometimes sized by screening and passed over a jig. The one example of this method noted was apparently unsuccessful, for it had been abandoned and simple log washing resumed. The reason for lack of success was apparent, however, for only one jig was used and the jig feed was not properly sized.

The trough, or gravity washer, was formerly used in the western Kentucky district but is now practically abandoned. It consisted of an inclined wooden trough about 1 foot wide, 8 to 10 inches deep, and 25 to 75 feet long, set at 10° to 12° from the horizontal.

[7] Fohs, F. Julius, Fluorspar Deposits of Kentucky: Kentucky Geol. Survey. Bull. 9, 1907, p. 113.

At the upper end was an inclined-bottom feed bin, from which the ore was sluiced down the trough with a 1½ to 2 inch stream of water. Walk ways along the sides of the trough allowed men to assist the passage of the ore when necessary by prodding or pushing with a hoe or bar. This method was cheap, but not as successful as the log washer, especially for dirty ores; moreover, the loss in fines was greater.

FOR HARD OR MIXED ORES

The log washer is not successful for hard ores or those mixed with calcite, quartz, galena, sphalerite, and so on. For such ores a much more complicated and expensive method is usually necessary.

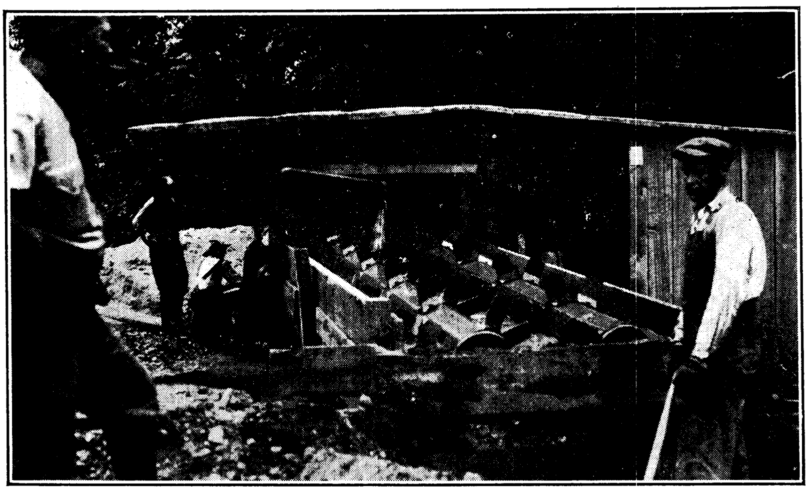

FIGURE 9.—Typical double-log washer, Nancy Hanks mine, west of Marion, Ky.

Very occasionally the crude ore is so pure that hand sorting yields a marketable product, but such work on a large scale has never been possible. In some of the larger deposits part of the ore could be recovered by simple hand sorting, but as the remainder must be milled a picking belt is used as part of the milling equipment and no attempt is made to select the ore underground. At the Nakaye mine in New Mexico (see p. 126), where the impurities are chiefly calcite and limestone, the larger lumps of ore and waste are separated by hand sorting and the fines are shoveled over a screen with one-half-inch openings. The screen undersize is wasted and the oversize is hand sorted. This method could not be expected to be successful, because fluorspar has a better cleavage and is more brittle than calcite or limestone, therefore the fines would contain more fluorspar than the coarse. That this is actually true is shown by the fact that the fines wasted analyzed 83.52 per cent

CaF_2, 4.56 per cent SiO_2, and 15.70 per cent $CaCO_3$, while the sorted screen oversize saved analyzed 70.81 per cent CaF_2, 0.78 per cent SiO_2, and 28.09 per cent $CaCO_3$.

In general the method of milling hard ores used in the larger mills of the Illinois-Kentucky district embodies the following principles: The mine-run ore is fed into a revolving screen or washing trommel with a water spray to clean off the larger lumps of ore. The coarse ore drops on a picking belt from which is picked waste and No. 1 and No. 2 grades of lump ore. The ore remaining on the belt goes to one or more crushers, below which the undersize from the washing trommel joins it. This crushed ore is then fed through a series of sizing trommels, of which the coarsest has usually not larger than five-eighths-inch holes and the finest from three-sixteenths-inch to one-sixteenth-inch holes. The oversize from the coarsest screen is returned to crushing rolls for regrinding, and the undersize from the finest screen is usually sent, after partial dewatering, to concentrating tables. Other screen products are used as jig feeds. Several types of jigs are used, but the five-cell jig of the Harz type is most common.

MILL OF FRANKLIN FLUORSPAR CO.

Figure 10 is a flow sheet of a concentrating mill of the Franklin Fluorspar Co. at Marion, Ky. This mill was formerly the property of the Kentucky Fluorspar Co.

TREATMENT OF ORES CONTAINING GALENA

When ores containing galena are milled, a lead product is usually obtained from the first cell of all jigs. In the coarser sizes this product may not be pure enough for shipment; it is then recrushed and re-treated on the same jigs or on a separate lead jig. The product from the second cell of all jigs may be a lead middling product, which is recrushed and rejigged with the impure lead concentrates from the first cell.

In fluorspar jigging no attempt is usually made to treat separately the products of the screen and the hutch. The screen and hutch discharges both empty into the same launder. The products of the third, fourth, and fifth cells (and of the first and second cells when the ore contains no lead) constitute the finished gravel-grade fluorspar and are sent to the gravel-spar stock bins. The product from the first cell of the lead jig is a finished lead concentrate; from the second cell come lead middlings which are reground and rejigged; the other products of the lead jig are recrushed in fine rolls passed through classifiers and sent to concentrating tables. From the tables are obtained finished lead and fluorspar products, tailings, middlings which are recrushed

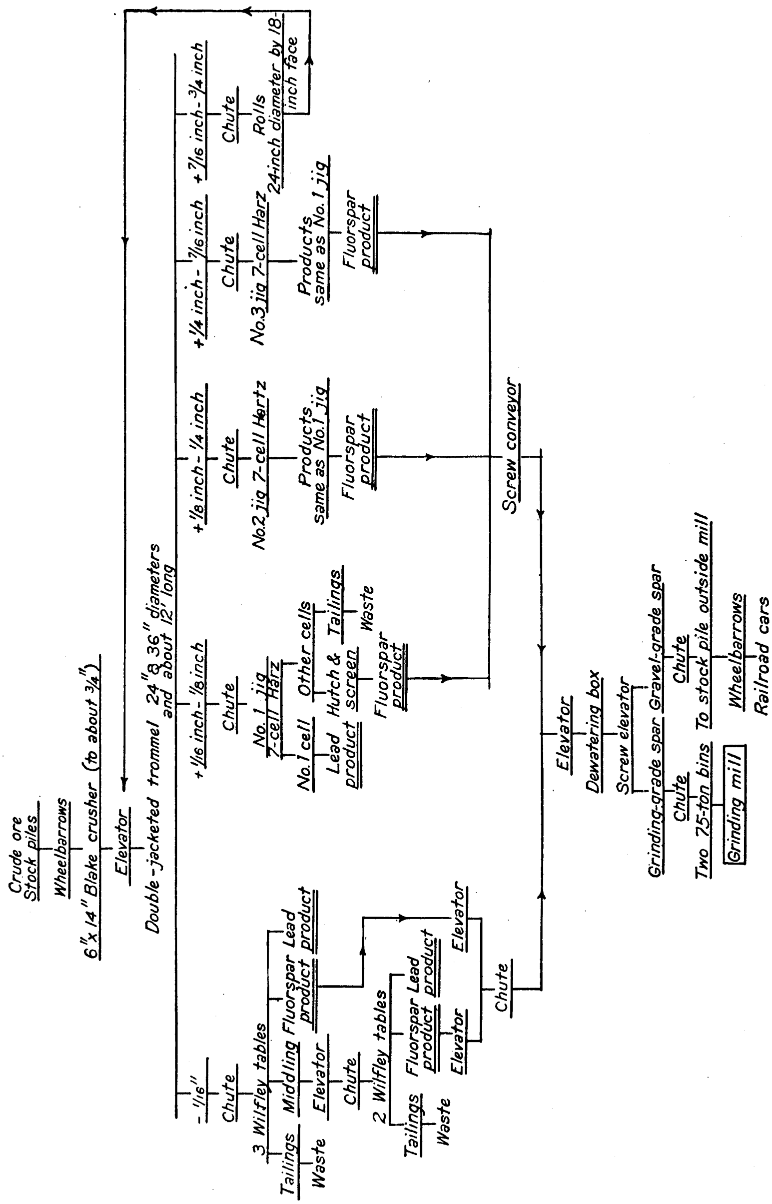

FIGURE 10.—Flow sheet of fluorspar concentrating mill of Franklin Fluorspar Co., Marion, Ky.

and retabled, and, if there is sphalerite in the ore, a low-grade zinc product. Jig waste from the spar jigs is sent to a waste dump and from the lead jig is recrushed with the lead-jig middlings.

This method of milling successfully separates fluorspar and galena and removes most of the calcite and silica, but will not separate satisfactorily sphalerite and barite. In the Illinois-Kentucky district barite does not occur in large enough quantity to constitute a serious problem; in fact, the largest mines are free from barite. Many attempts have been made to devise a process for separating barite and fluorspar, but none have been successful. In the central Kentucky district and at some of the western mines, such as at Wagon Wheel Gap, Colo., and Tonuco, N. Mex., barite occurs in important quantities.

MILL AT WAGON WHEEL GAP, COLO.

The aerial tramway buckets discharge on a grizzly at the mill, a general view of which is shown in Figure 11. The fines, 1 inch

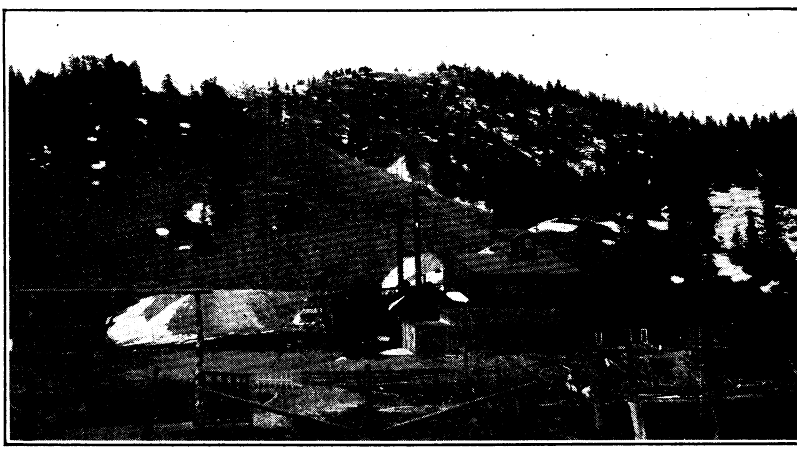

FIGURE 11.—Mill of American Fluorspar Co., Wagon Wheel Gap, Colo.

and less, pass through to the mill bin and the lumps to two sorting tables, where the waste is picked out. Disposal of the jig products is variable, depending on the character of the material produced. The tables shown are only used intermittently and are not an integral part of the continuous flow sheet. (Fig. 12.) The separation of the barite has been the principal difficulty in the milling operations and so far it has not been successfully accomplished by mechanical means. Analyses of carload shipments for a number of years averaged about as follows: CaF_2 86 per cent, $BaSO_4$ 5 per cent, SiO_2 4.5 per cent, Al_2O_3 2.5 per cent, and $CaCO_3$ 1 per cent.

A Dorr thickener 10 feet deep by 36 feet in diameter has been constructed but has never been used, although it was used to dewater the slimes from the mill so as not to pollute the stream. Power is supplied at the mill by a 100-horsepower Corliss-type engine and steam is generated by two boilers, one 150 horsepower and the other 80 horsepower, both of the return tubular type. Coal is purchased from the mines of the San Luis Valley district, with a railroad haul of approximately 100 miles.

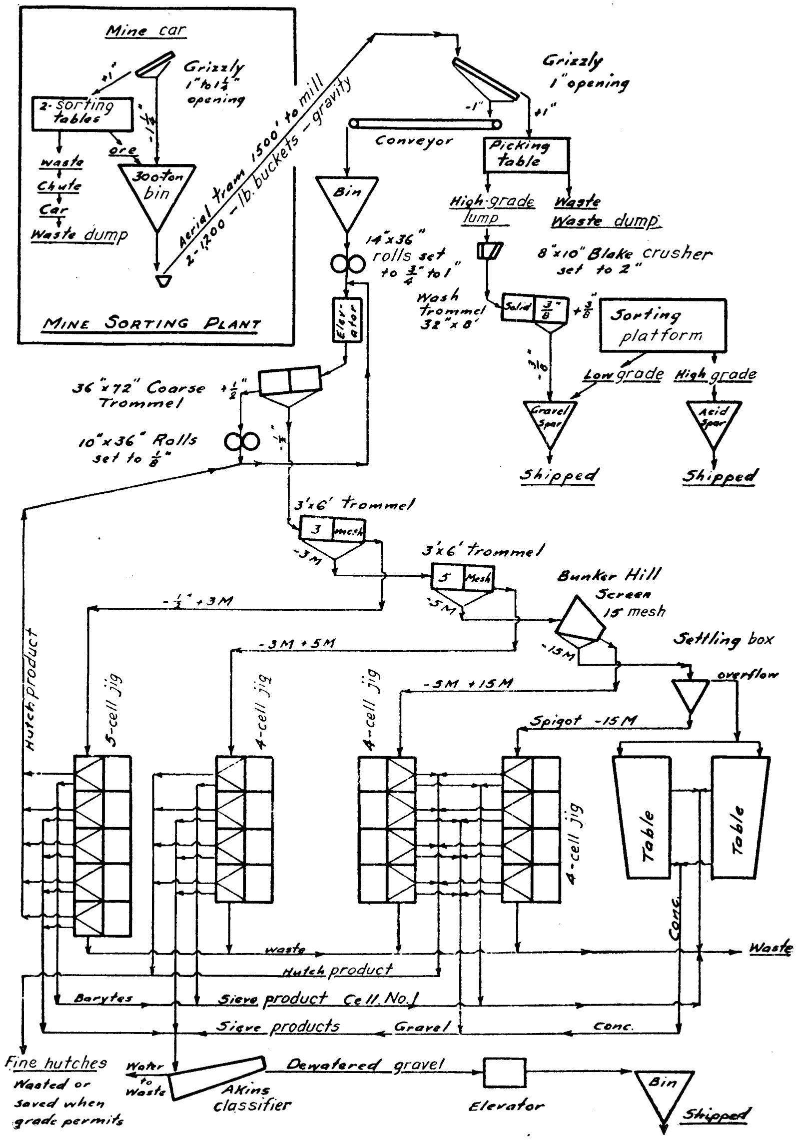

FIGURE 12.—Flow sheet of American Fluorspar Co. mill, Wagon Wheel Gap, Colo.

SEPARATION OF SPHALERITE

In parts of some mines in the Illinois-Kentucky district sphalerite or zinc sulphide occurs in considerable quantities. The ordinary methods of jigging the table concentration will not separate fluorspar and sphalerite successfully. Sphalerite is an injurious impurity in fluorspar concentrates and fluorspar in sphalerite concentrates. Hence a very complete separation must be made. The only large producer that has so far been troubled with this problem is the Fairview Fluorspar & Lead Co., near Rosiclare, Ill. The zinciferous fluorspar is practically confined to one section of this mine, and the company has been stock-piling this ore for several years.

This problem has been studied at the Bureau of Mines experiment station at Rolla, and a report prepared by John Gross.[8]

The Fairview Fluorspar & Lead Co. (now the Franklin Fluorspar Co.) also studied this problem and finally decided to erect an experi-

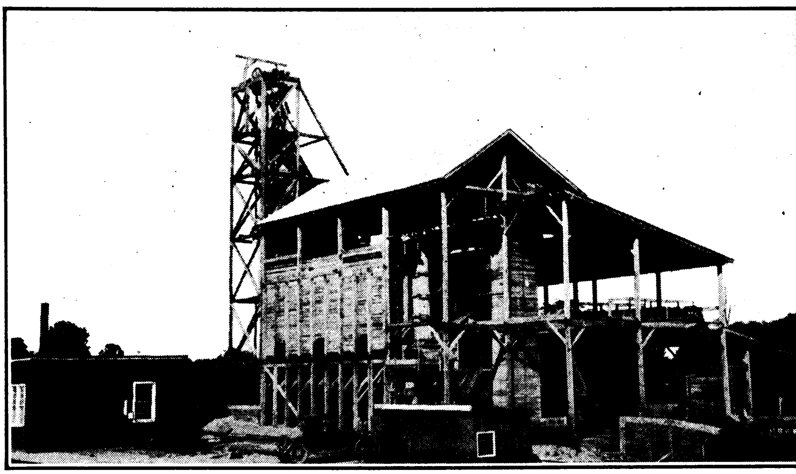

FIGURE 13.—Flotation mill, Fairview Fluorspar & Lead Co. (now the Franklin Fluorspar Co.), near Rosiclare, Ill.

mental plant to treat this ore by flotation on a commercial scale. This plant was completed in 1921 (see fig. 13) and a few experimental runs made when the demand for fluorspar declined sharply, and further work was suspended. The flow sheet, Figure 14, shows the general methods used in this mill, but it is not definite and final, as much experimenting was done later. Test runs indicated that a good zinc product could be made by flotation for several hours at a time, but that for some unknown reason a favorable condition could not be maintained indefinitely. This problem was solved later, and commercial zinc products were made. The tailings from flotation machines were not high enough in fluorspar to be worth saving.

[8] Gross, John, Separation of sphalerite, silica, and calcite from fluorspar: Reports of Investigations, Serial 2264, Bureau of Mines, July, 1921, 3 pp.

DECREPITATION PROCESS

An unusual milling method is used at the Rock Candy mill in British Columbia. (See p. 145.) Here the fluorspar is closely associated with quartz and other gangue minerals such as barytes, pyrite,

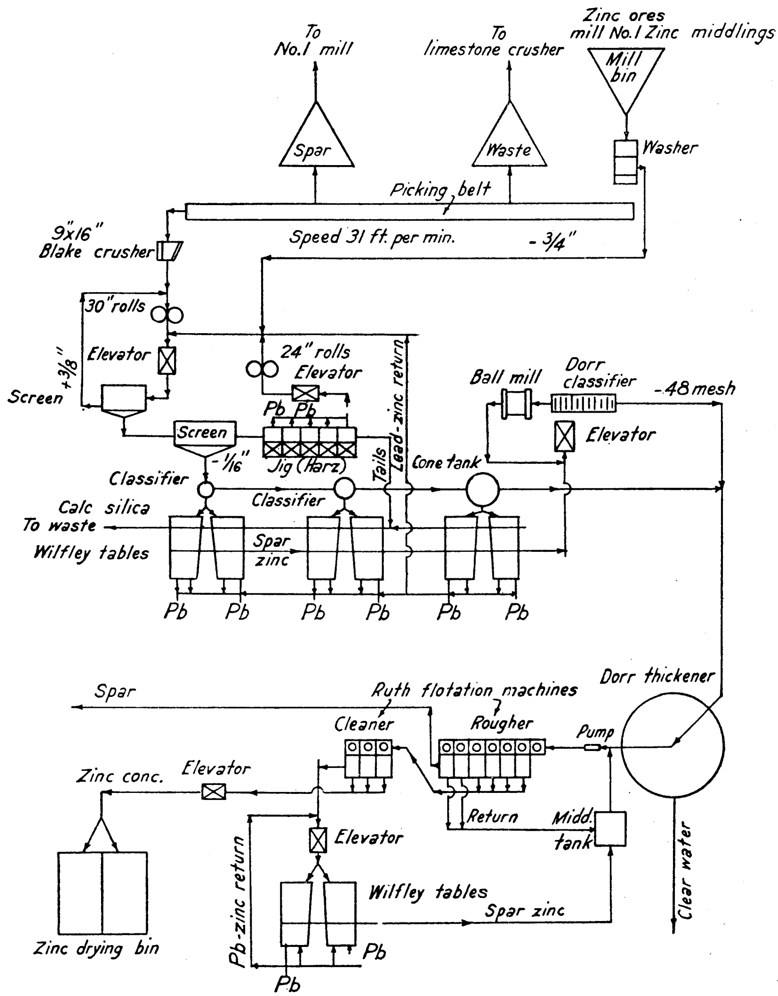

FIGURE 14.—Approximate flow sheet of the Fairview Flourspar & Lead Co. (now the Franklin Fluorspar Co.) flotation mill

and galena. The milling method used depends upon the fact that fluorspar when heated to a moderate temperature decrepitates or flies apart, while the quartz is hardly affected. Screening the heated product allows separation.

The flow sheet in 1919 was described in an official mining report.[9]

[9] Minister of Mines, British Columbia, Annual Report for 1919: Vancouver, 1920, pp. 164–165.

The rotary drier is heated by the waste gases from the three rotary kilns, which are 8 feet long by 3 feet 2 inches in diameter and make three revolutions per minute. A temperature of 1,200° F. is necessary for decrepitation. The best results are obtained with the minus 8-mesh plus 15-mesh ore, which yields a product containing about 2 per cent silica. The minus 15-mesh middling contains about 5 per cent silica and is used for hydrofluoric acid manufacture or for adjusting grades of concentrates.

The daily capacity of the mill in 1919 was stated to be 100 tons, probably mill heads; 16 men were employed and a recovery of 26 per cent was obtained, based on mill heads, the concentrates averaging 84 per cent CaF_2 with 6 per cent SiO_2. In 1920 the average mill recovery for the year had increased to about 38 per cent, but the grade of the product was not wholly satisfactory. Three concentrating tables, two Wilfley and one Deister, were added to the mill to attempt to decrease the silica content of the fines. The table concentrates were dumped into the hot product from No. 1 and No. 2 kilns, so that most of the moisture was evaporated before screening. The greatest annual production reached at this mill was 7,477 tons of concentrates in 1920.

In 1921, 6,291 tons of rejects from this mill were shipped to Trail, British Columbia, and there treated in a flotation plant. Flotation concentrates shipped were 1,909 tons, valued at $49,630, or about $26 per ton.

DETAILS OF FLUORSPAR JIGGING AND TABLING

Fluorspar milling by jigging and table concentration differs from the milling of metallic ores chiefly in two ways. First, and of primary importance, is the fact that in fluorspar milling the concentrates form a very large proportion of the mill feed, usually 75 per cent or more, while in metallic ore concentration the concentrates usually are a small percentage of the feed. Second, there is a much smaller difference in specific gravity between ore and gangue in fluorspar milling than in most metallic ore concentration.

In milling fluorspar, when the gangue is calcite, the lowest-grade ore which can be milled economically and produce a marketable product is probably one containing not less than 50 per cent fluorspar and 50 per cent calcite or limestone. If the gangue is silica and the fluorspar and gangue are closely associated probably the ore should contain a minimum of 75 per cent fluorspar and 25 per cent silica for economical concentration. If the fluorspar and silica are not intergrown and break apart cleanly and easily, with no combined middlings, an ore containing as much as 50 per cent of impurity might be successfully milled. When the fluorspar is mixed only with sand or clay or pieces of rock large enough to be removed by hand sorting, a crude ore containing as little as 25 per cent fluorspar and 75 per cent waste may often be milled successfully. Under these circumstances, however, the ore would be concentrated by hand sorting or log washing, either alone or followed by jigging. Throughout the text the term " recovery " is used to designate the ratio of weight of concentrates produced to weight of mill feed and not the ratio of fluorite in the concentrates to the fluorite in the feed.

In the southern Illinois district the mill recoveries are 75 to 85 per cent; in other words, the jig and table tailings amount to only 15 to 25 per cent of the feed. Thus in jigging ample provision must be made for the removal of large quantities of concentrates. The Harz-type jig with five cells is used so generally as to be considered almost the standard. Large jig beds and fine screens are used to make as little hutch product as possible. Concentrates are obtained from both the hutch and the screen draw-off and these two products are not kept separate. Figure 15 shows a typical jig, such as is used by the Fairview Fluorspar & Lead Co. (now the Franklin Fluorspar Co.).

Large draw-offs must be used to remove the screen concentrates from the jig bed rapidly. Sometimes a large side draw-off, and at others, double side draw-offs were noted. Generally, however, a special type of center draw-off, developed at the Fairview (now Franklin) mill, is commonly employed. (See fig. 16.)

In jigging fluorspar ore high in lead (galena), a separate lead jig should be used for making the finished lead concentrates. The products of the first cells of the other jigs, consisting largely of lead concentrates, should be sent to the lead jigs for cleaning. Lead-fluorspar middlings from the second cells of the spar jigs should be recrushed and also sent to the lead jigs. The middlings from the lead jigs should be recrushed and, if coarse, rejigged; if fine they should be sent to tables.

In milling fluorspar, concentrating tables are efficient only for separating lead (galena) from fluorspar or from a mixture of fluorspar, calcite, silica (free), and zinc (sphalerite). Tables will not separate fluorspar and calcite or fluorspar and free silica efficiently. In the Rosiclare district operators have tried all types and kinds of tables, with great variation in shapes of riffles, speeds, angles of inclination, and so on, but no efficient separation has resulted.

GRINDING PLANTS

In the Illinois-Kentucky district grinding plants for the production of high-grade ground fluorspar for the acid, glass, and enameling industries are operated by the Franklin Fluorspar Co., at Rosi-

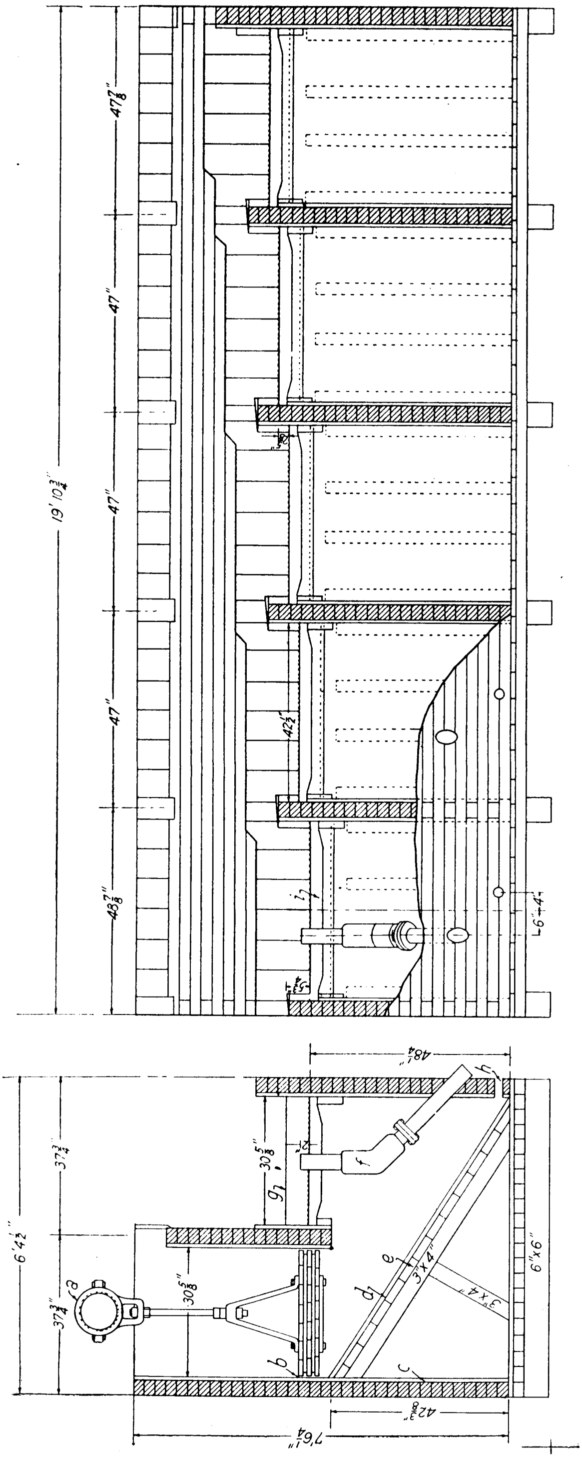

FIGURE 15.—Typical jig: *a*, Standard 3 7/16-inch split eccentric; *b*, ¼-inch clearance; *c*, 1-inch lining; *d*, 1-inch flooring; *e*, 2-inch flooring; *f*, standard drawoff; *g*, top of tailboard; *h*, 2-inch faucet; *i*, standard 30 by 42 inch frame

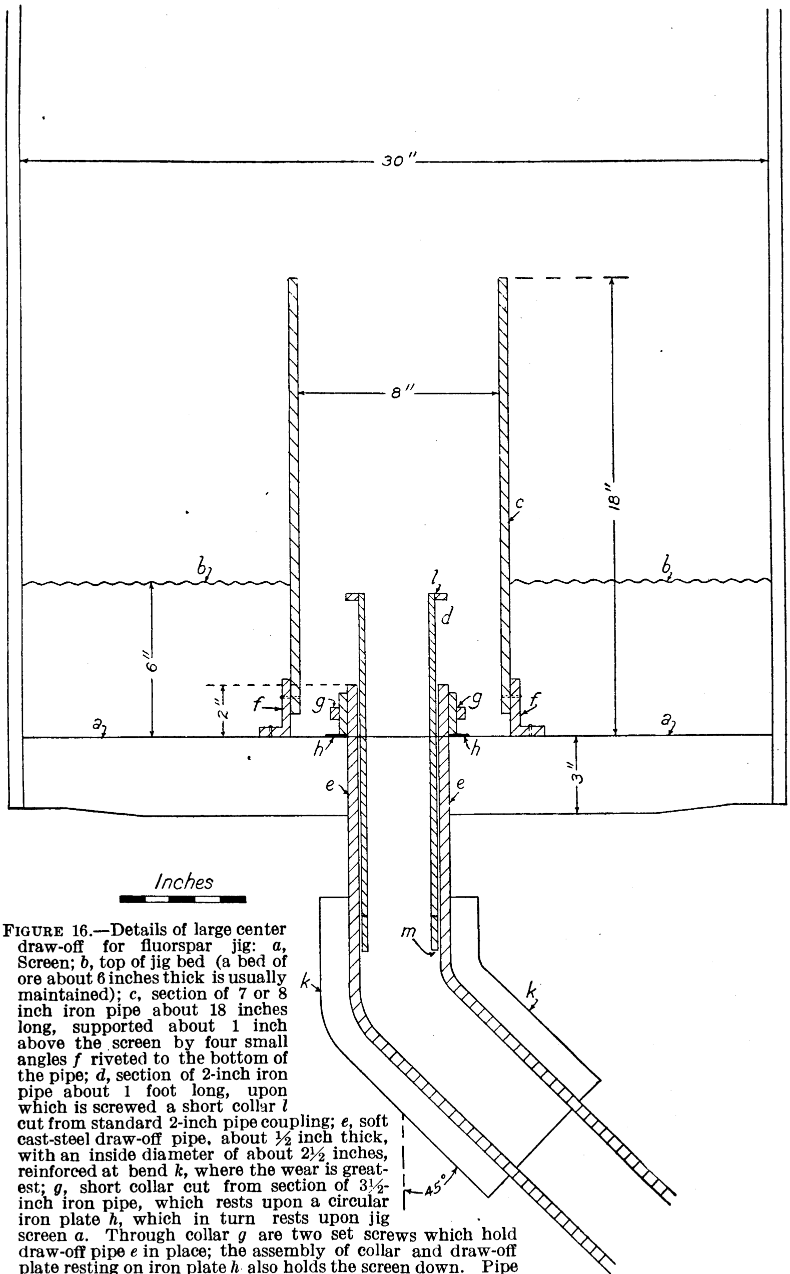

FIGURE 16.—Details of large center draw-off for fluorspar jig: *a*, Screen; *b*, top of jig bed (a bed of ore about 6 inches thick is usually maintained); *c*, section of 7 or 8 inch iron pipe about 18 inches long, supported about 1 inch above the screen by four small angles *f* riveted to the bottom of the pipe; *d*, section of 2-inch iron pipe about 1 foot long, upon which is screwed a short collar *l* cut from standard 2-inch pipe coupling; *e*, soft cast-steel draw-off pipe, about ½ inch thick, with an inside diameter of about 2½ inches, reinforced at bend *k*, where the wear is greatest; *g*, short collar cut from section of 3½-inch iron pipe, which rests upon a circular iron plate *h*, which in turn rests upon jig screen *a*. Through collar *g* are two set screws which hold draw-off pipe *e* in place; the assembly of collar and draw-off plate resting on iron plate *h* also holds the screen down. Pipe *d* fits inside draw-off pipe *e* just tightly enough so that it will stay in place when set at any height. When the jig is running and the bed has formed, fluorspar concentrates collect on the screen at the bottom of the bed. The weight of the bed forces the concentrates under the lower edge of pipe *c* between the supports *f*; once inside the well formed by pipe *c* the concentrates rise to the top of pipe *d* and flow into this pipe and down through draw-off pipe *e* and thence outside the jig. Pipe *d* may be adjusted by raising or lowering; if it is raised the discharge is slowed down or even stopped, if lowered the discharge is accelerated, so the correct height must be determined by experiments. Pipe *d* is lowered by tapping on its top and raised with a long steel hook, which is lowered through the pipe, lapping up on the bottom of the pipe at *m*. This discharge will serve a jig bed as large as 30 by 45 inches. If larger beds are used larger pipe *d* and draw-off pipe *e* must be used, or two such discharges placed in each bed.

clare, Ill., and Marion, Ky., and the Rosiclare Lead & Fluorspar Mining Co., at Rosiclare, Ill.

FAIRVIEW FLUORSPAR & LEAD CO. (NOW FRANKLIN FLUORSPAR CO.), ILLINOIS

The mill, located near the Good Hope shaft of the Fairview Fluorspar & Lead Co. (now the Franklin Fluorspar Co.), has a rated capacity of 20 tons of crude ore per hour. In recent years the mill recovery has been about 70 per cent. About 90 per cent of the product is gravel-grade spar, 7.5 per cent ground (glass and enamel grade), and 2.5 per cent acid spar. In addition there is recovered, on an average, about 30 tons of lead concentrates per month. These concentrates run about 8 ounces per ton in silver. which usually about pays for the smelting charges.

The mill requires about 150 horsepower, which is furnished by steam engines in the adjoining power plant. About 1,000 to 1,200 gallons of water per minute is needed for milling; mine water stored in a mill pond supplies this demand.

The fluorspar concentrates from the mill flow through a chute into large concrete drainage tanks. After draining, the product is transferred into similar large concrete storage bins, whence it is loaded directly into open-top railroad cars for shipment. The product is transferred from bin to bin and from bin to car with a locomotive crane or fixed derrick equipped with a grab bucket.

If shipments are to be made by river barge the spar is loaded into railroad cars and hauled a short distance to the barge-loading point on the Ohio River, where it is transferred into the barges by crane.

The calcite and limestone mill tailings and mine waste are hauled in an ore car to the agricultural limestone mill, only a few hundred yards away, where it is crushed in accordance with the following flow sheet and sold as agricultural limestone.

This plant is run by a 75-horsepower Corliss engine for which steam is piped from the central boiler plant.

Ore high in zinc (sphalerite or zinc sulphide) occurs in part of the deposit. This zinc has been carefully separated out on the picking belt or in milling the stock piled. In 1920–21 another mill was built near the main mill to concentrate this zinc ore by flotation. (See fig. 14.)

ROSICLARE LEAD & FLUORSPAR MINING CO., ILLINOIS

The Rosiclare mill is close to the plant shaft, and mine skips from the Rosiclaire mine dump directly into a large mill bin in the top of the sizing and sorting section of the mill. The ore from the Daisy mine is transported from the mine to the mill in standard-gauge railway cars, dumped into a concrete bin at one end of the sizing and sorting mill, and drawn off from the bottom of this bin into cars in a tunnel below the bin. The cars are hoisted to the top of the mill building, trammed over to the other end of the building, and dumped into the main ore bin.

The milling method is explained by the flow sheet, Figure 17.

The methods used in this mill closely resemble those used at Fairview, except that jigs of the Faust type are used in place of the Harz type customarily used.

This mill can handle about 400 tons of crude ore in 9 hours. With a recovery of 70 per cent, this gives 280 tons in 9 hours, or a little over 30 tons per hour of fluorspar concentrates.

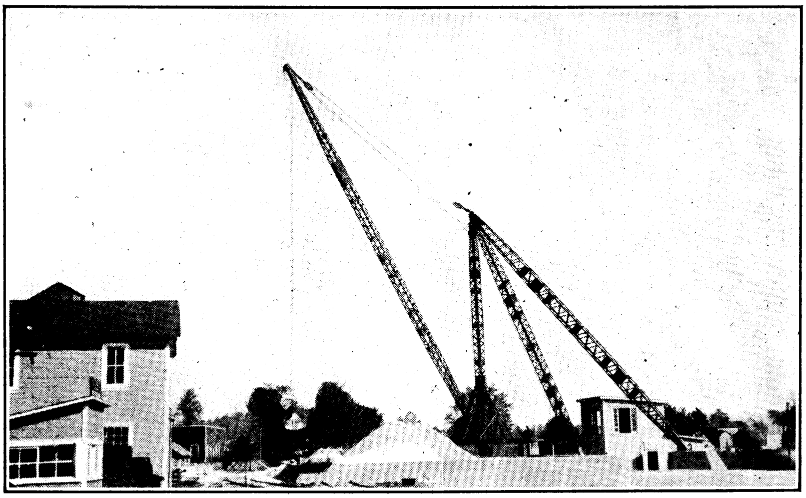

FIGURE 18.—Gravel-fluorspar loading derrick, Rosiclare Lead & Fluorspar Mining Co., Rosiclare, Ill.

The finished gravel spar is dewatered, stored, and loaded as at Fairview, except that the ore is loaded entirely with a derrick of structural steel with a 100-foot boom and 80-foot radius. (See fig. 18.)

FRANKLIN FLUORSPAR CO., KENTUCKY

The main Kentucky mill of the Franklin Fluorspar Co. is on the railroad at Marion. The milling methods used here are shown in the flow sheets, Figures 10 and 19. This mill formerly belonged to the Kentucky Fluorspar Co.

This mill makes both fluxing gravel and the acid and glass and enamel grades of ground spar. The capacity of the mill per hour is 5 to 8 (average 6) tons of crude ore, and an 80 to 85 per cent recovery is made. The grinding section of the mill has a maximum capacity of 3 tons per hour. Power for the mill is furnished by two Corliss-type engines.

SIZES OF MILLS, COSTS, AND LOCATION

The size and capacity of fluorspar mills vary greatly, from the small single-log washer to the elaborate mill of the Rosiclare Lead & Fluorspar Mining Co. near Rosiclare, Ill. (see flow sheet, Fig. 17), which was built to handle about 40 tons of crude ore per hour. Such mills cost from a few hundred dollars to at least $500,000.

The capacity of mills can only be expressed as rough approximations which must be based on crude ore rather than finished products, because the nature and grade of the ore treated vary and recoveries of finished products fluctuate in consequence. The following table shows the location and capacity of certain large mills. The capacity is usually the rated rather than the actual capacity attained. In practice the quantity of ore fed to the mill is often much lower than the rated capacity, due to mining and hoisting conditions, poor quality of the ore, improper coordination of mining and milling, and so on.

Location and capacity of principal fluorspar mills in the United States

Company or name of mine	Location of mill	Capacity of crude ore, tons per hour
Illinois:		
Rosiclare Lead & Fluorspar Mining Co.	At mine, on railroad near Rosiclare, Ill.	[1] 40
Franklin Fluorspar Co.	do	20
Hillside Fluor Spar Mines	do	8–10
Chicago Fluorspar Co.	do	6–12
Benyon Fluorspar Co.	About 4 miles from mine, on Ohio River near Cave in Rock, Ill.	3–18
Illinois Fluorspar & Lead Co.	At mines, near Cave in Rock, Ill.	(?)
Douglas Fluorspar Mines Co.	At mines, near Karbers Ridge, Ill.	(?)
Kentucky:		
Franklin Fluorspar Co.	At Franklin mine, about 6 miles from Marion, Ky.	10
Do.	Several miles from nearest mines, on railroad at Marion, Ky.	5–8
Do.	At mine, on railroad near Mexico, Ky.	2
Keystone Fluorspar & Lead Co.	At mine, three-fourths mile from Mexico, Ky.	7–8
Lafayette Fluorspar Co.	At Lafayette mines, on railroad near Mexico, Ky.	(?)
Kentucky Fluorspar Co.	Several miles from nearest mines, on railroad at Marion, Ky.	4
Heyward Minerals Co.	At mine on Kentucky River in Jessamine County, near Mundy's Landing, Ky.	4–5
Eagle Fluor-Spar Co.	At Liberty Bond mine, near New Salem Church, about 8 miles southwest of Marion, Ky.	[1] 2½
United Mining Co.	At Bonanzo mine, near Lola, Ky.	(?)
North American Fluorspar & Lead Corporation.	At Klondyke mine, near Smithland, Ky.	(?)
Western States:		
Wagon Wheel Gap	At mine, 1¼ miles from railroad at Wagon Wheel Gap, Colo.	
Colorado Fluorspar Corporation	At mines, near Cowdrey, Colo.	
Tortugas	4 miles from mine and 1 mile from railroad at Mesilla Park, N. Mex.	
Tonuco	About 1 mile from mine, on railroad at Heathden, N. Mex.	
Great Eagle	At mine 30 miles from railroad at Lordsburg, N. Mex.	
J. Irving Crowell, owner	4½ to 6 miles from mines, on railroad at Beatty, Nev.	

[1] About.

Many large mills and a few smaller ones are located on railroads. A railroad connection is desirable and almost necessary for economical large-scale production. If ore from a number of widely scattered mines is to be treated the mill may be built at some central point on a railroad and the ore brought to it. The mill of the Franklin Fluorspar Co. at Marion, Ky., is in the latter class, as crude ore from many mines is brought to it by wagon, truck, and railroad car. At most of the more remote mines the ore is partly cleaned by log washing before it is hauled to Marion. As crude fluorspar ore usually contains 15 to 50 per cent or more waste it is always advisable to concentrate it as near the mine as possible to avoid transporting waste. At some places lack of enough water for milling prevents such treatment.

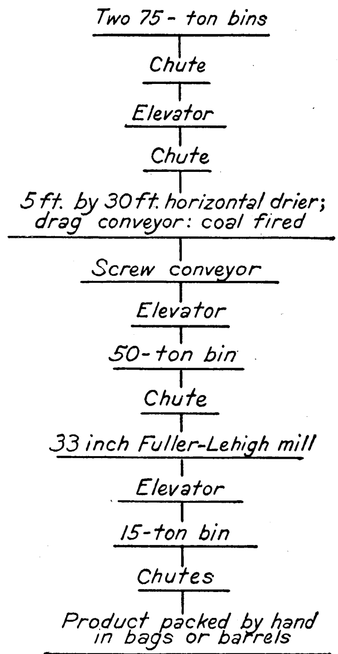

FIGURE 19.—Flow sheet of grinding mill, Franklin Fluorspar Co., Marion, Ky.

STORAGE AND SHIPMENT

PREPARATION FOR SHIPMENT

Ground fluorspar is usually elevated to small storage bins, from which it is drawn off and packed in bags or barrels for shipment. There seems to be little uniformity in the fineness of grinding among the various producers. One company makes two sizes, one that will pass a 50-mesh and one an 80-mesh screen. Another mill grinds to about 100 mesh; another (in the West) to only 16 mesh. The product of another company, which makes but one size of ground product, has the following average screen analysis:

Screen analysis of ground fluorspar

Mesh	Direct per cent	Cumulative per cent
On 48	0.25	0.25
On 65	1.50	1.75
On 100	6.50	8.25
On 150	8.00	16.25
On 200	11.00	27.25
Through 200	72.75	72.75
	100.00	

One company states that about 75 per cent of its ground spar is packed in canvas or burlap bags holding about 125 pounds each, and the remaining 25 per cent in wooden barrels holding 500 pounds. An operator at Beatty, Nev., proposes to ship ground fluorspar in small paper barrels.

STORAGE

Gravel-grade fluorspar is stored in several ways. At the two largest mines in the Illinois district finished gravel spar from the mill is run into a large concrete storage bin outside the mill, drained, and partly dried, and transferred to very large concrete storage bins, where the moisture is further reduced by drainage and air drying; the spar is then loaded into railroad cars for shipment. Figure 18 shows storage bins and loading derricks or cranes.

At the mill of the Hillside Fluor Spar Mines, near Rosiclare, Ill., the concentrated gravel fluorspar is distributed by a belt conveyor

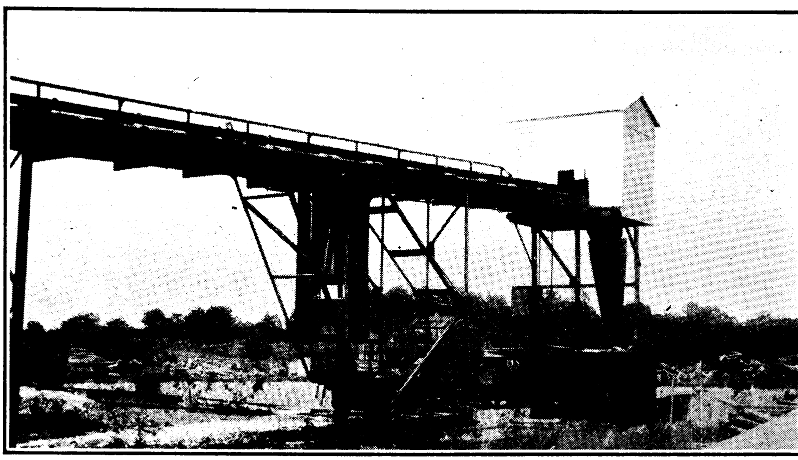

FIGURE 20.—Discharge end of car-loading conveyor, Hillside Fluor Spar Mines, near Rosiclare, Ill.

among a series of large concrete bins. Under the row of bins and extending to a railroad siding beyond is a 420-foot belt conveyor with a movable, self-propelled feeder for the conveyor over it, mounted on a carriage and propelled by an electric motor. The feeder may be run up under any bin and set to open the bin gates automatically and feed the belt with spar at an adjustable rate. At the railroad siding the conveyor, inclined upward, discharges through a chute into standard-gauge, hopper-bottom railroad cars. The discharge end of the conveyor is high enough so that the track can be bridged with a conveyor extension and stock piles built up on the far side of one track, should the bins be inadequate for storage. This system of bins and conveyors allows a 50-ton car to be loaded in 35 minutes. Figure 20 shows the discharge end of the conveyor.

SHIPMENT

RAILROAD SERVICE

Only four mines in the southern Illinois district have railroad service, and that only since July, 1919. Before the railroad was built fluorspar was shipped in barges on the Ohio River upstream to Shawneetown for transfer to railroad cars. When the railroad was completed as far as Golconda the Fairview Fluorspar & Lead Co. loaded standard-gauge railroad cars at the mill, hauled them about one-half mile to the river bank, loaded them on a car-ferry barge, towed them to Golconda, and delivered them to the railroad there. Now nearly all fluorspar is shipped by rail, but the spur track down to the river has been used in loading large river barges hold-

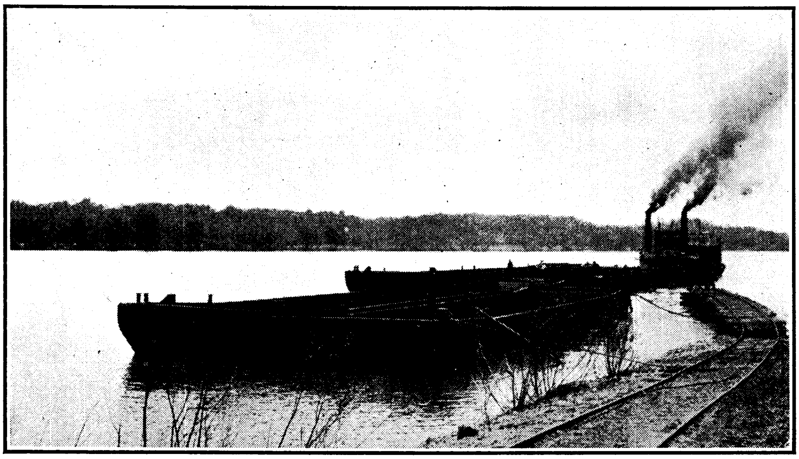

FIGURE 21.—Towboat and barges for fluorspar on Ohio River; Franklin Fluospar Co. landing near Rosiclare, Ill.

ing 850 to 1,000 tons with gravel spar for shipment to Pittsburgh. This method of shipment may be used increasingly in the future for shipments to companies operating barges on the river. Figure 21 shows barges and a towboat.

RIVER TRANSPORTATION

Several mines in the Cave in Rock (Ill.) district must still depend upon river transportation. Ore is hauled to the river and loaded into barges, which are towed to Shawneetown for further shipment in standard-gauge cars. River transportation is uncertain; moreover, the roads are so poor in winter and spring that haulage to the river is usually possible only seven months of the year.

ROAD HAULAGE

The problem of transportation from mine to railroad is even more acute in the western Kentucky district. With few exceptions the mines are 2 to 18 miles from the nearest railroad siding. No hard-surfaced roads serve the mines; the region has been deeply weathered, and the surface soil is mostly sticky red or brown clay. In wet weather the roads are impassable bogs, and in dry weather repeated passage of heavy loads of fluorspar produces deep ruts and gullies which make hauling, even by wagon, very difficult, slow, and expensive. Figure 22 illustrates hauling conditions at their best. Hauling is practically impossible five to seven months of the year and at intervals during and after rains throughout the rest of the year.

FIGURE 22.—Hauling fluorspar over poor roads in Kentucky

Practically all hauling is done by two or four horse wagons which hold 1 to 2 tons, usually on contract at a fixed price per ton. Contract prices vary somewhat with the seasons and with the condition of the roads, but average a little less than 25 cents per ton-mile. During the war one company tried hauling by heavy motor trucks. It cost more than wagon haulage, because of repairs and maintenance, but it was more dependable under war conditions. It has been found here, as elsewhere, that a small, irregular output can be moved at relatively low cost; as soon as an attempt is made to maintain a steady, large production haulage costs increase, for systematic, regular haulage must be maintained under all conditions. Several new hard-surfaced roads through parts of this district are in prospect, and it is expected that when they are completed the haulage problems for the mines served by these roads will be solved.

MISCELLANEOUS HAULAGE

Fluorspar prepared at the mines is hauled to the nearest railroad point, the most important being Marion and Mexico, and unloaded directly into a car or onto a shipping platform. Stock piles of spar are often allowed to accumulate at the railroad. From these piles the cars are loaded by wheelbarrow.

Sometimes the mine product or the log-washed product needs more cleaning before shipment. It is either hauled to one of the concentrating mills at Marion or to the loading dock at Mexico or Crayne, there loaded into railroad cars, shipped to Marion, and unloaded by wheelbarrow to stock piles in the yards of one of the mills.

At the Marion mills crude or semifinished fluorspar is stock piled in the mill yards and taken into the mills in wheelbarrows as needed. The finished gravel-grade spar is again taken to stock piles in wheelbarrows and reclaimed in the same way for final shipment.

UTILIZATION OF FLUORSPAR

The most important uses for fluorspar are in the manufacture of steel by the basic open-hearth process; in the manufacture of opalescent glassware and enamels for metals; in making a substitute for cryolite, used as a bath in producing metallic aluminum by electrolysis; in making hydrofluoric acid and other fluorine chemicals; as a flux in foundry practice, smelting refractory ores, and other metallurgical processes.

The distribution of domestic fluorspar shipments in the United States by uses is indicated in the following table.

Fluorspar shipped from mines in the United States, 1921–1925, by uses[1]

Use	1921		1922		1923		1924		1925	
	Percentage	Average price per ton	Percentage	Average price per ton	Percentage	Average price per ton	Percentage	Average price per ton	Percentage	Average value per ton
Steel	73.09	$15.94	86.44	$16.24	79.80	$18.23	83.49	$17.72	80.73	$16.16
Foundry	4.35	20.14	2.12	19.02	3.09	21.20	5.71	22.35	5.52	19.31
Glass and enamel ware	16.02	40.03	6.29	36.29	8.89	36.17	7.65	35.05	8.80	31.23
Hydrofluoric acid (including fluorspar used in manufacture of aluminum and refining of lead)	5.24	28.62	3.38	24.81	5.76	30.19	2.52	28.39	3.92	25.60
Miscellaneous	1.30	21.23	.15	18.02	1.52	20.85	.13	21.13	.10	39.00
	100.00	20.71	98.38	17.88	99.06	20.66	99.50	19.59	99.07	18.07
Exported to Canada	-------	-------	1.62	17.84	.94	22.13	.50	23.48	.93	16.66
	100.00	20.71	100.00	17.88	100.00	20.68	100.00	19.61	100.00	18.06

[1] Figures for 1921–1923 compiled by the U. S. Geological Survey; for 1924–1925 by the Bureau of Mines.

The steel industry has used most of the fluorspar imported.

An interesting fact is that the distribution of fluorspar consumption by uses in Germany before the war closely followed that in the United States. The distribution was reported to be as follows:[10] Iron and metal smelting industry, 79 to 84 per cent; glass industry, 10 to 15 per cent; chemical industry, 5 per cent; enamel industry, 5 per cent; optical industry, 5 per cent.

One large Illinois producer states that in recent years production has averaged about as follows: Gravel grade, 90 per cent; ground grades (glass and enamel), 7.5 per cent; acid lump, 2.5 per cent.

METALLURGICAL USES

The metallurgical uses of fluorspar depend upon its relatively low melting point (1,270 to 1,387° C.); upon its fluidity when melted; upon its ability to flux or form eutectics with silica, calcium and barium sulphates, alumina, and other refractory materials, making easily fusible and very fluid slags; and upon its ability to volatilize or slag off sulphur, phosphorus, and other deleterious impurities in iron and other metals. The chemical reactions which occur when fluorspar is used as a flux are not well understood, and authorities differ not only as to the chemical reactions but also as to the rôle fluorspar plays in smelting and the nature of the results obtained. In an effort to clarify the situation, metallurgists representing the best practice in this country were consulted and the literature was reviewed, but the differences of opinion have not yet been reconciled.

BASIC OPEN-HEARTH STEEL

Both lump and gravel fluorspars are employed in the manufacture of steel by the basic open-hearth process, but use of the latter is much more common. Gravel spar usually reaches steel mills in open-top railroad cars which may be dumped or unloaded with a crane and clamshell bucket. It is generally stored in open stock piles or large open or covered bins near the open-hearth building. Fluorspar is often stored at steel mills in large quantities, especially when the demand and prices are high. It is dumped in piles, kept at 800 to 1,000 pounds, in front of each furnace.

An open-hearth furnace has a rated capacity of 15 to about 75 tons of metal per heat (average amount usually 50 to 60 tons). Limestone in the proportion of about 10 per cent of the weight of the metal charge is first spread over the bottom; then the charge of pig iron and scrap is added and the heat is started. When the charge

[10] Commerce Reports, "Fluorspar industry active in Germany": Bureau of For. and Dom. Commerce, No. 33, Feb. 9, 1921, p. 788.

is melted the limestone rises to the top, often in large lumps, and floats on the surface of the bath.

This layer of limestone gradually becomes a thick spongy mass through which the gases from the molten metal rise with difficulty. When this slag becomes too thick it must be thinned or the viscosity reduced with fluorspar. R. B. Bostwick, superintendent of the open-hearth department, Duquesne Steel Works, Duquesne, Pa., describes the process as follows:

During the period known as "working the heat," that is, from the time the lime has risen from the bottom to the surface of the bath, to the time of tapping the heat, fluorspar is added in varying amounts. In this period the elimination of carbon or the regulation of its content and the working of the slag are the duties of the first helper, and in the manipulation of this slag, fluorspar renders its greatest assistance. The addition of the spar is made by shoveling it onto the surface of the slag by the helpers, in amounts which are determined by the viscosity of the slag, the temperature of the slag, and the judgment of the first helper.

It is our practice to add fluorspar in amounts not exceeding 6 pounds per ton of steel produced, or from 200 to 600 pounds per heat. In many heats it is unnecessary to add fluorspar, particularly where considerable ore (hematite) must be added to eliminate carbon. In such heats the oxide of iron in the slag confers sufficient fluidity on the slag.

The chief purpose of the fluorspar is to render the slag sufficiently fluid so as to hasten the transfer of heat from the flame to the steel beneath the slag, which reduces the time or duration of the heat, and that the slag may flow from the furnace without difficulty at tapping. Fluorspar accomplishes this by lowering the melting point of a portion of the slag, depending upon the amount added. With calcium silicate, the spar forms a eutectic of about 38 per cent CaF_2, permitting of carrying more lime in the slag in order to increase its basicity.

In addition to the above, fluorspar is held to serve another purpose by virtue of its chemical activity; namely, the elimination of sulphur through volatilization from the slag. The importance of this, however, is in question, and nothing conclusive has been proved.

Fluorspar is sometimes added in small quantities throughout the melt and sometimes just before tapping. Some operators believe that it is unwise to add fluorspar less than one-half hour before the heat is tapped. J. C. Davis, vice-president, Inland Steel Co., says:

When we use it at all, it is shortly after an open-hearth heat is melted and the lime is all up off the bottom. We use fluorspar only in case of an excessive amount of free lime in the slag or if the slag is too viscous. In our practice our standard heat has a weight of 26 tons, and in cases of too great viscosity of slag, or an excessive amount of free lime therein, we make an addition of from 20 to 50 pounds of fluorspar. If such an addition is not sufficient to bring about the desired fluidity or fusion of free lime, a further addition of like amount is made. In no case, however, do we add fluorspar within one-half hour prior to the time of tapping the heat. This precaution is taken to guard against the possibility of fluorides entering the metal as a result of reactions between CaF_2 in the slag and certain elements in the metal. It

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might be stated here that there has been considerable speculation as to the reactions involved when fluorspar is added to molten basic slag. The fluidity conferred to the slag may be explained by the following:

We know that the base and acid of a slag are alone relatively infusible. CaO melts at 1,900° C. and SiO_2 at 1,780° C. A combination of the two, however, $CaSiO_3$, melts at 1,512° C. Mixtures of silicate slags or minerals form eutectics. Thus $CaSiO_3$ melts at 1,512° C., $MgSiO_5$ at 1,524° C., but a mixture with 30 per cent of the latter and 70 per cent of lime silicate melts at 1,350° C. Furthermore, a silicate with more than one base fuses at a lower temperature than a one-base silicate. It is also known that $CaSiO_3$ forms a eutectic with 38.2 per cent CaF_2 (melts of 1,300° C.), which freezes at 1,130° C. It can therefore be assumed that under ordinary conditions CaF_2 does not enter into chemical combination with basic open-hearth slag, but rather is held in solution by basic silicates. Under gently oxidizing conditions, however, which sometimes exist in working a heat, it is entirely possible that some CaF_2, if present in the slag, is split up to form fluorides with silicon or phosphorus from the metal.

The possibility of such reactions taking place and the danger of fluorides remaining in the molten metal has caused us to greatly restrict the use of fluorspar for several years.

In summing up the rôle of fluorspar as a dephosphorizing agent in basic slags, Howe drew the following conclusions:

Fluorspar appears to favor dephosphorization: (1) By liquefying the slag, thus enabling it to assimilate the lime present, part of which might otherwise remain unmolten and inert and thus render the slag effectively basic; (2) probably by volatilizing Si from the metal, thus diminishing the formation of SiO_2 and thereby increasing the basicity; (3) in certain cases when conditions are not strongly oxidizing by volatilizing phosphorus as fluoride.

On account of its great influence, and an influence contrary to theory, we are convinced that fluorspar is a catalytic reagent in this case, or, in other words, an agent of transformation. The action, we believe, taking place may be shown by the following equations:

$$\underset{\text{Silica}}{3\,SiO_2} + \underset{\text{Fluorspar}}{2\,CaF_2} = \underset{\text{Silicon fluoride}}{SiF_4} + \underset{\text{Calcium silicate}}{2\,CaSiO_3} \quad \text{(No. 1)}$$

$$\underset{\text{Lime}}{3\,CaO} + \underset{\text{Silicon fluoride}}{SiF_4} = \underset{\text{Fluorspar}}{2\,CaF_2} + \underset{\text{Calcium silicate}}{CaSiO_3} \quad \text{(No. 2)}$$

In No. 1 the fluorspar reacts with the silica, giving us calcium silicate, a slag that is easily melted, and silicon fluoride, a gas. A part of this silicon fluoride gas no doubt escapes, but our theory is that the greater part of it reacts with the lime as in No. 2, giving us more calcium silicate and our fluorspar back again to complete No. 1 reaction a second time, and so on until the silicon fluoride has all escaped, when the reaction will cease. If this catalytic theory is correct, we have the silicon fluoride gas generated at intervals for some period, and in order to make sure that none of it is held in solution by the steel, no fluorspar should be added to a heat within 30 minutes of the tapping time.

CONSUMPTION

The average quantity of fluorspar used per ton of steel varies within wide limits from as low as 4 pounds to as high as 25 pounds. Statistics gathered by the Bureau of Mines in 1924, from steel companies which produce about two-thirds of the output of the United States, show that the consumption in that year varied from 3.3 to 24.9 pounds and averaged 7.8 pounds per ton of steel. One large steel company in the West uses 15 to 20 pounds of fluorspar per ton of steel because instead of limestone it employs dolomite, which makes a very thick, viscous slag. One of the largest fluorspar producers stated that the average consumption of his customers was about 10 pounds per ton of steel.

FUNCTION OF FLUORSPAR

The function of fluorspar has been partly explained above. Its action in removing sulphur is not well understood. In the past it has been generally assumed that the active agent in removing sulphur and phosphorus was limestone and that fluorspar aided only by allowing a more highly basic slag to be carried by increasing slag fluidity. However, Schleicher [11] contends that fluorspar itself is an effective agent in removing sulphur from steel. He shows that in nine heats without fluorspar the average sulphur content of the finished steel was 0.08 per cent and that the slag without fluorspar was more basic than with fluorspar. The ratio of the oxygen of the bases to that of the acids was 1.67 without fluorspar and 1.30 with fluorspar.

From his many tests he concluded: (1) If fluorspar is added to an open-hearth slag it is only decomposed and reduced to a certain extent, namely, 2 to 2½ per cent of the CaF_2 content; (2) that silica is first removed from the slag as silicon fluoride, but this silica is replaced from the furnace lining; (3) that fluorspar aids in volatilizing sulphur from the slag, enabling the slag to take up more sulphur from the bath. His conclusions regarding silica can only apply, of course, when an acid (silica) lining is used in the furnace, and not to the basic open-hearth process. He cites the following example to prove his theory of desulphurization: A 40-ton heat was very high in carbon and had a very thick slag. Ten minutes after about 10 per cent of fluorspar was added to the slag the metal, after a good deal of foaming, was soft. Before the spar was added there was 0.048 per cent of sulphur in the steel and 0.34 per cent in the slag. Ten minutes later it amounted to 0.064 per cent in the steel and only 0.09 per cent in the slag. Careful calculation showed that 10.8 kg. (23.8 pounds) of sulphur had volatilized. The finished metal showed 0.05 per cent sulphur, so the slag had reabsorbed sulphur from the metal. On account of this resulphurization of the slag, Schleicher suggests that after the last fluorspar

[11] Schleicher, S., ["Fluorspar in open-hearth steel practice"]: Stahl u. Eisen, Jahrg. 42, Mar. 17, 1921; abstract, Iron Age, vol. 102, Mar. 23, 1922, pp. 783–784.

is added the heat should remain in the furnace long enough to allow this action to take place.

Regarding the action of fluorspar on refractory linings, Jones[12] says: "No bad effects of the spar on the walls or roof of the open-hearth furnace have been known and it has been found as time goes on that open-hearth superintendents are increasing the amount of fluorspar used per ton of steel."

Fluorspar, then, performs the following functions in the basic open-hearth steel process:

1. It lowers the melting point of the slag, thus allowing lower furnace temperatures and increased operating speed.
2. It increases the fluidity of the slag, thus permitting escape of gases from the metal and better "working" of the metal, and making the slag easier to handle.
3. It aids in the removal of sulphur and phosphorus by volatilization and by slagging, either by direct action or by enabling a more highly basic slag to be used.

EFFECT OF SIZE OF GRAVEL FLUORSPAR

The particles of most gravel fluorspar range in size from a maximum of about three-fourths inch down to fine dust. A screen analysis of a typical gravel spar follows:

Screen analysis of gravel fluorspar

	Per cent
On ½-inch mesh	7.60
Through ½-inch, on ⅛-inch mesh	45.25
Through ⅛-inch, on 20 mesh	23.75
Through 20 mesh	23.40
Through 100 mesh	2.90
	100.00

Because fluorspar from some deposits or some methods of concentration can only be recovered in fine sizes—20 mesh and finer—an effort was made to find whether such fine material would be acceptable to the steel industry. Opinions on this subject differ greatly.

One operator stated that "Finely ground fluorspar can not be used successfully, as it will not sink through the slag, and consequently will be wasted." Another operator said: "Material as fine as 20 mesh is not satisfactory unless mixed with coarser material. Consumption of the fine material usually shows an increase over the ordinary gravel size."

[12] Jones, G. H., Fluorspar and its uses: Advance print of paper read before Am. Iron and Steel Inst. at New York, Oct. 27, 1922, p. 6.

The other side of the question is taken by an operator who states that "Fine-grained fluorspar can be used successfully, but more or less is lost by the draft in the furnace drawing out a good per cent of the finer spar." Another operator believes that fine-grained material can be used successfully and that dusting may be overcome by wetting the fluorspar.

Consumers in the steel trade apparently do not find the small proportion of fines in ordinary gravel spar objectionable, but one operator believes that "Lumps over one-half inch in diameter are a disadvantage, as they require more time and heat for their disintegration and assimilation by the slag." It is therefore apparent that a moderate amount of fines mixed with material up to one-half or five-eighths inch gives the best results, and that there are some disadvantages in using material of 20 mesh or finer exclusively. An attempt was made to briquet the fines produced at Beatty, Nev., but the experiment apparently was unsuccessful.

EFFECT OF IMPURITIES

In basic open-hearth steel practice calcium carbonate is the least objectionable impurity in fluorspar. It in itself is a flux used in the process and is therefore only a diluent which has been bought at fluorspar prices.

Silica is also a diluent but is not a flux, and requires a certain amount of fluorspar to flux it, thus reducing the amount of available fluorspar still further. Usually a maximum of 6 per cent silica is specified in contracts. Fohs[13] states that 1 part of silica requires about 2 parts of fluorspar to flux it, but most eastern producers and consumers figure on 2½ parts of fluorspar instead of 2. Using the 2½ to 1 ratio and taking as an example an English fluorspar analyzing 76 per cent CaF_2 and 17 per cent SiO_2, the available CaF_2 would be 76 per cent $-$ ($2\frac{1}{2} \times 17$ per cent $=$ 42.5 per cent), or 33.5 per cent; thus a high percentage of silica reduces the value of fluorspar very greatly. (See also p. 77.) In addition, a high silica content requires additional limestone to preserve the basicity of the slag, which is objectionable because a high limestone charge lengthens the time of heat in the furnace with subsequent reduction of tonnage.

A high silica content (above 5 or 6 per cent) is usually penalized by purchasers, but no premium is paid for silica content lower than the standard. The justification offered for this practice is that the man who charges the fluorspar into the open-hearth furnace knows nothing of its quality and uses the same amount whether the

[13] Fohs, F. Julius, Fluorspar deposits of Kentucky: Kentucky Geol. Survey Bull. 9, 1907, p. 154.

silica content is high or low. This same argument suggests the impropriety of penalizing high silica and low calcium fluoride content. Furthermore, as Jones [14] points out, the melter in actual practice uses only enough fluorspar to effect the desired results and thus can readily determine the grade of material used. Quality should be standardized and either no penalties exacted or both penalties and premiums paid.

The effect of barium sulphate (barite) is not as clearly understood, but most steel companies in the East object to more than a trace of this material. One western steel mill which regularly uses large quantities of fluorspar containing an average of 5 per cent barite finds it objectionable only as a diluent. This objection is based on two grounds: (1) That the addition of sulphur in any form is a bad practice; and (2) that barite produces a very heavy, viscous slag. The barite thus defeats the purposes for which fluorspar is used.

The addition of sulphur does not seem to be important, for barite contains only 13.7 per cent sulphur, and if the fluorspar contains 5 per cent barite, 10 pounds (the average charge per ton of steel) would contain only 0.5 pound of barite or 0.0685 pound of sulphur. Even though this all went into the steel, it would add only 0.0034 per cent sulphur to the steel, an amount too small to be taken into account. This very small addition of barite could hardly have an appreciable effect on the viscosity of the slag. Barite, therefore, probably acts chiefly as a diluent. Fohs states that 1 part of fluorspar will flux 1½ parts of barium sulphate.

SUBSTITUTES FOR FLUORSPAR

Most authorities consider fluorspar an essential in the manufacture of basic open-hearth steel. One operator says: "The ever-increasing sulphur content of raw materials and fuels necessitates carrying slags of higher lime content, which must be rendered sufficiently fluid for the proper working of heats. The addition of fluorspar makes this possible." Most of the other steel men from whom information was sought agreed substantially with this view, but one held that fluorspar was not always necessary and should be used in moderation. He said that his company used a relatively high proportion of manganese ore in conjunction with a relatively light lime burden, which almost invariably insures a good slag condition, so that ordinarily very little fluorspar is required to adjust the slag. First, it confers fluidity, as well as basicity, to the slag. It tends to prevent absorption of sulphur by iron in all stages of making the heat and to break up FeS when formed. It acts in the

[14] Jones, G. H., work cited, p. 4.

latter stages of the heat to deoxidize the bath and to lessen the total amount of nonmetallic inclusions.

Jones [15] points out that high-manganese pig iron increases the fluidity of the slag and therefore decreases the amount of fluorspar necessary for thinning out the slag. However, in some steel-making districts, particularly in the East, pig iron is apt to be high in phosphorus and low in manganese, and it is the general practice where scrap is plentiful and cheap to charge as little pig iron as possible. Iron of this character requires a high lime charge, because the small pig-iron charge, with consequent decreased amount of silicon and manganese, does not tend to create a fluid slag. Large additions of fluorspar are therefore necessary.

No operators consulted knew of any adequate fluorspar substitute that is now in general use or that, in their opinion, could be satisfactorily used at equal or even much increased cost. The most commonly known suggested substitute is calcium chloride, $CaCl_2$, a material now produced chiefly as a by-product in the manufacture of salt from brine or from the Solvay soda process. The output sold in the United States in 1919 was about 74,700 short tons, valued at about $1,043,000, or about $14 per ton. Production as a by-product is said to be greater than the consumption in present uses. In October, 1922, fused-lump calcium chloride was quoted at $22 to $23 per short ton, f. o. b. cars New York, in car lots.

One operator says:

> Calcium chloride is the best-known substitute for fluorspar. It works very well, and permits of carrying a very high lime content in the slag. No records of its use are available, but one authority gives 50 pounds per ton of steel as a good figure, which seems rather high. Compared with our present practice of 6 pounds of fluorspar per ton of steel, the above figure would make the use of calcium chloride, at present prices, prohibitive.

At equal prices per ton, and at a consumption of 10 pounds of fluorspar per ton of steel, according to the above figures, calcium chloride would cost five times as much as fluorspar. Furthermore, calcium chloride is very hygroscopic and deliquescent; that is, absorbs moisture from the air and dissolves, forming a solution. It would therefore be much more difficult than fluorspar to ship, store, and handle.

In the "Saniter" process of desulphurizing, dephosphorizing, and producing a liquid slag, the following mixture per ton of steel is used, according to Harbord and Hall: [16] Dry calcium chloride, 9 pounds; fluorspar, 9 pounds; lime, 15 pounds; and limestone, 8

[15] Jones, G. H., work cited, p. 5.

[16] Harbord, F. W., and Hall, J. W., Metallurgy of steel. New York, vol. 1, 1916, pp. 192–193.

pounds. As this process uses equal parts of fluorspar and calcium chloride and nearly as much fluorspar as the average in present practice, it can not be considered a substitute for fluorspar.

Other suggested substitutes for fluorspar are lime (CaO), other strongly basic salts such as certain salts of sodium and potassium, iron scale, bauxite, and ilmenite. None of these seem to have been used commercially. Ilmenite (iron titanium oxide $(Fe.Ti)_2O_3$) containing 45 to 52 per cent TiO_2 is reported to have been used experimentally and is claimed to be slightly more efficient than fluorspar. At present it is not produced in large quantities and sells for $25 to $40 per ton. It is claimed, however, that if substantial markets can be developed a 45 to 50 per cent TiO_2 product obtained by concentrating titaniferous magnetites can be laid down in the Pittsburgh district for $6 to $7 per ton. Without confirmatory evidence the possibility of substituting ilmenite for fluorspar seems slight, as titanium compounds have always been considered very objectionable in slags, making them heavy and viscous.

In summing up, therefore, fluorspar seems to be essential in the manufacture of steel by the basic open-hearth process. No substitutes have been developed which can compete with fluorspar, even at a greatly increased price. It is used in such relatively small quantities per ton of steel that the cost is almost negligible in comparison with that of the finished steel. Fluorspar will probably continue to be used, therefore, even if mining costs and prices increase appreciably.

FOUNDRY PRACTICE

Fluorspar is used to some extent in iron-foundry practice, usually in lump form, but of gravel grade (No. 2 lump). It is used, as in the open-hearth process, for desulphurizing and dephosphorizing the iron and producing a liquid slag and is of particular value when the iron has a high sulphur content, and when foundries use continuous rather than intermittent melting. In continuous melting the slag must be kept very liquid. It may be added in the cupola or in the ladle before the molten iron is poured. One observer states that in making malleable iron 3 per cent of ground fluorspar in the bottom of the ladle made the iron more malleable and increased the tensile strength by slagging off impurities. In the same way, gray cast iron was made softer without decreasing its wearing qualities. Another writer claims that adding 20 pounds of fluorspar per ton of metal in the cupola brings down the charge more rapidly and makes a thinner slag, hotter iron, and hence sharper castings.

OTHER METALLURGICAL USES

Fluorspar is used as a flux in electric furnaces for making steel, cast iron, and ferro-alloys. The quantity used varies, but probably averages at least 20 pounds per ton of metal.

In smelting refractory ores of gold, silver, and copper, fluorspar has been found very useful as a flux to make a fluid slag. Some writers believe that fluorspar acts on silica to form a silicon fluoride, possibly SiF_6, which is volatilized. Others believe that the action of fluorspar is largely mechanical, and that a greater part of it is found unchanged in the slag. Examples can probably be cited to prove both contentions and show that, as a matter of fact, the action of fluorspar depends upon the nature of the ore and fluxes, whether the lining is acid or basic, and the type of slag made. It forms fusible compounds with barium and calcium sulphates and assists in fluxing zinc as the sulphide or the oxide. When acid linings are used care should be taken not to use an excess of fluorspar, for rapid corrosion of the lining may result.

In the manufacture of rustless iron of the ferrochromium type in the electric furnace it is reported that iron is first melted and decarburized and then skimmed of slag. The surface of the metal is then covered with a mixture of 75 parts of limestone and 25 parts of high-grade fluorspar. This mixture is melted and preheated to form a bath to which chromite ore and a reducing agent are added. If enough heat has been stored up in the bath the reaction gives off heat and perfect fusion results. The resulting ferrochromium sinks through the slag and alloys with the iron below. This action continues until the iron contains about 12 per cent of chromium.

Fluorspar is used to some extent in smelting lead and silver ores and in refining lead and silver. Here, as in other metallurgical uses, fluorspar has value for its great fluxing properties, its ability to make a thin, fluid slag, its reduction of smelting temperature, and its power to volatilize or slag objectionable impurities.

USE IN GLASS MANUFACTURE

Fluorspar is widely used in manufacturing opal or opaque white glass and colored or cathedral glass. Light opal glass is used for electric, gas, or oil lamp globes, shades, and bulbs for diffusing light; and for vases, bowls, and other ornamental glassware. Dense opal glass is used for containers, such as jars, pots, and bottles, for liquids, foods, and toilet and medicinal preparations. In the form of slabs or plates it is used for table and counter tops, wainscoting, baseboards, shelves, linings for refrigerators, and so on. Some of the opal glasses are sold under trade names, such as "Vitrolite" and "Sani-Onyx."

Fluorspar was formerly used to some extent in the manufacture of plate, bottle, and window glass to assist in melting the batch and to make it more fluid. It is little used to-day for this purpose and opinions differ as to its value.

Fluorspar when used in glass manufacture is usually ground so that it will pass a 100-mesh screen, but some is much finer and some as coarse as 40 mesh. It is usually packed in bags or barrels, but is sometimes shipped in bulk in tight box cars lined with building paper. At glass factories it is stored in a dry place, either in packages or in bulk in wooden or concrete bins or silos conveniently located near the mixing room.

Opal-glass batches vary greatly and may contain 50 to 500 pounds of fluorspar per 1,000 pounds of sand. A typical batch for a rather dense opal glass, as given by one manufacturer, has about the following composition:

	Per cent
Silica (SiO_2)	60 to 66
Soda (Na_2O)	12 to 14
Alumina (Al_2O_3)	4 to 6
Calcium fluoride (CaF_2)	10 to 14

A manufacturer of opal glass in plate and slab form states that he uses 250 pounds of fluorspar per 1,000 pounds of sand. The fluorspar is used as a source of fluorine, which with alumina supplied by feldspar, kaolin, or lepidolite, imparts an opalescent whiteness to the glass. This color varies from light opalescence to a dense dead white, depending upon the amount of fluorine present.

GRADES AND IMPURITIES

There are no standard specifications for fluorspar for glass manufacture, and widely varying grades are in use. The most objectionable impurity is iron, which makes the glass greenish or yellowish brown. One large company sets a limit of 0.12 per cent of iron, expressed as the oxide (Fe_2O_3), and states that the average iron oxide content of the fluorspar it uses is about 0.06 per cent.

Silica is not an injurious impurity, as it is the chief ingredient of the batch (in the form of sand), but in excess forms a diluting agent in a rather expensive material. If proper price adjustments were made a fairly high silica content would probably be acceptable. One company reported using a Canadian fluorspar containing over 13 per cent silica. Another company stated that its low limit was 90 per cent CaF_2 and that it would object to receiving many cars averaging below 95 per cent CaF_2. However, under present conditions a standard glass-grade spar should contain at least 96 per cent CaF_2 and not over 2 to 2½ per cent SiO_2. This grade is known as No. 1 ground or A-1 ground.

Calcium carbonate is an objectionable impurity in that excess of calcium oxide causes breakage of the glass or brittleness, or "hardness" as the glassmaker calls it. Most glassmakers object to over 1 per cent $CaCO_3$ and if as much as 1 per cent is present it should not vary within wide limits. It is reported, however, that one western fluorspar producer shipped considerable quantities of fluorspar for opal-glass manufacture, containing about 2.5 per cent CaO_3, 3.5 per cent SiO_2, and 94 per cent CaF_2.

Lead and sulphur are objectionable impurities in that they require additional expensive oxidizing materials to neutralize or remove them. Barite and sphalerite would probably be objectionable on the same grounds. It is also probable that excessive quantities, say over 1 per cent, of any of these materials should cause rejection.

SUBSTITUTES

Fluorspar in glass manufacture is used as a source of fluorine, which may be supplied by other fluorides, such as cryolite (Na_3AlE_6). Cryolite is used extensively in glass manufacture; in fact, fluorspar is usually considered a substitute for cryolite rather than the reverse.

Fluorspar is probably used in glass manufacture more extensively than cryolite. Some glassmakers consider it much superior to cryolite, while others consider the use of too much fluorspar dangerous due to its usual content of calcium carbonate. Under present conditions, fluorspar is the cheapest source of fluorine.

Several manufactured fluorine salts, such as artificial cryolite, sodium silicofluoride (Na_2SiF_6, containing 60.6 per cent fluorine), and sodium fluoride (NaF, containing 45.3 per cent fluorine), are also used for this purpose. The chief value of these artificial salts lies in their purity, which allows them to be used by nontechnical men without mathematical calculations to allow for variation in composition of natural minerals.

The mineral lepidolite, used by some glassmakers, contains fluorine possibly up to 5 per cent and thus allows the fluorspar content of a batch to be reduced. It is used chiefly, however, as a source of alumina, potash, and lithia.

Bone ash and other calcium phosphates are used to some extent in Europe and formerly in this country in place of the fluorides in opalescent glass. This method, however, is now considered more expensive and less satisfactory than the use of fluorides.

Most manufacturers of opalescent glass consider fluorspar an essential raw material.

USE IN ENAMELS

Fluorspar is an important constituent in dense, opaque, white, and colored enamels used in coating sheet iron and steel, and cast-iron sinks, tubs, trays, kitchenware, and so on. It is also used in making enameled brick and tile and for other ceramic purposes where an opaque, easily fusible enamel is needed. The type and grade of fluorspar, methods of shipping and storing, effect of impurities, and so on are the same for this use as for making opal glass.

Fluorspar alone or with cryolite is used in enamel batches in quantities ranging from 2 to 15 per cent of the batch. Probably 5 to 7 per cent represents a fair average. Most enamelers consider fluorspar an essential, but some believe that cryolite is an adequate substitute, while others do not consider cryolite a substitute for fluorspar. Other possible substitutes are artificial cryolite, sodium fluoride, barium fluoride, and sodium silicofluoride.

HYDROFLUORIC ACID AND FLUORINE CHEMICALS

Large quantities of fluorspar are used in the manufacture of hydrofluoric acid (HF). For this purpose fluorspar is sold either ground to 80 to 100 mesh or in lump or gravel form (acid lump, acid gravel, or "Keystone" grade) and is ground at the consumer's plant. The requirements for acid-grade fluorspar vary slightly but usually approximate the following specifications: CaF_2 not less than 97½ to 98½ per cent, SiO_2 not over 1 to 1½ per cent, and $CaCO_3$ not over 1 to 1¼ per cent. These specifications usually must be strictly observed.

The manufacture of hydrofluoric acid consists essentially of treating ground fluorspar with concentrated sulphuric acid. The reaction involved, which is

$$CaF_2+H_2SO_4=2HF+CaSO_4,$$

will take place at ordinary temperatures, but complete dissociation is effected only at or above 130° C. The reaction is carried on in platinum or cast-iron retorts and the hydrofluoric acid, which distills off as a vapor, is collected in water in lead-lined condensers. Commercial acid consists of an aqueous solution of HF. Commercial acid grades are 30, 40, 48, and 52 per cent, and fuming.

Recent descriptions of modern methods of hydrofluoric acid manufacture are not available. Betts[17] has described methods in use some years ago. Fickes[18] describes a continuous method. Hy-

[17] Betts, Anson G., "The manufacture of hydrofluoric acid": Eng. and Min. Jour., vol. 83, p. 753.

[18] Fickes, Edwin S., Manufacturing of Hydrofluoric Acid: U. S. Patent 1316569, Sept. 23, 1919; Chem. and Met. Eng., vol. 22, No. 2, Jan. 14, 1920, p. 90.

drofluoric acid is used chiefly in etching glass and in the manufacture of fluorine chemicals.

Hydrofluosilicic acid (H_2SiF_6) is usually made by heating pure silica sand with powdered fluorspar and sulphuric acid in excess, is distilled as a gas and collected in distilled water, and is used chiefly as a source of the fluorsilicates. Magnesium fluorsilicate or magnesium silicofluoride ($MgSiF_6$) is made by treating magnesium hydroxide or carbonate with hydrofluosilicic acid. It is used to some extent in concrete hardeners.

Sodium fluoride (NaF) is made by treating sodium carbonate with hydrofluoric acid. It is used in ceramics, as a food preservative, as an antiseptic, as an antifermentative in alcohol distilleries and so on, and as a wood preservative.

Sodium silicofluoride, or sodium fluorsilicate (Na_2SiF_6) is made by neutralizing hydrofluosilicic acid with sodium carbonate. It is used in ceramics and in medicine, and is reported to be used as a substitute for oxalic acid for certain bleaching purposes.

Calcium silicofluoride or fluorsilicate ($CaSiF_6$) is made by the action of hydrofluosilicic acid on calcium carbonate and by subsequent recrystallization. It is used chiefly in ceramics.

Barium fluoride (BaF_2) is made by treating barium sulphide with hydrofluoric acid, followed by crystallization. It is used in enamels, as an antiseptic, and in embalming fluids.

Potassium fluoride, KF (anhydrous) or $KF \cdot 2H_2O$ (crystalline), is made by saturation of hydrofluoric acid with potassium carbonate. It is used in etching glass, and as a wood preservative.

OPTICAL FLUORSPAR

A relatively small but important use for clear, transparent, nearly colorless fluorspar is for the manufacture of certain types of lenses. Pogue[19] has written an excellent description of optical fluorspar:

> Clear, colorless, or faintly colored specimens, such as occur rather sparingly in some localities along with the crude material, are suitable for the manufacture of certain types of lenses and prisms employed in microscopes and other optical instruments. Although the largest known deposits of fluorite in the world occupy a belt of country extending from southeastern Illinois into western Kentucky, but centering in Hardin County, Ill., the availability for optical use of the product from this region has heretofore been neglected, and the United States has been dependent upon foreign sources for its material, which came largely through the hands of the German optical dealers.
>
> In connection with a recent geological survey of the fluorspar deposits of southern Illinois, the State geological survey, with this application in mind, has determined the presence of optical fluorite of excellent quality and in quantity probably sufficient to supply the needs of the United States.

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[19] Pogue, Joseph E., Optical fluorite in southern Illinois: Univ. of Illinois, State Geol. Surv. Div. Bull. 38, 1918, 6 pp.

Pogue has discussed the properties, uses, and value of optical fluorite in great detail.

OTHER USES

Large amounts of a rather low-grade acid fluorspar are employed in the manufacture of artificial cryolite, which is used with natural cryolite in the molten bath in which metallic aluminum is made by electrolysis. Artificial cryolite is made and used in this country only by the Aluminum Ore Co. (subsidiary of the Aluminum Co. of America). No details of the actual method of use are available. The artificial cryolite is reported to be less efficient than the natural mineral, due to an excess of water, so that some natural cryolite (possibly 20 to 25 per cent) must be used. Much artificial cryolite is made in Europe.

Massive fluorspar has been used to some extent as an ornamental stone, principally in Europe. Blue massive fluorspar found at Derbyshire, England, and known as Derbyshire spar or "blue John" is cut and shaped on lathes to make paper weights, vases, and other ornamental objects. Clear, colored fluorspar crystals are sometimes cut into gems for cheap jewelry, but they are too soft to have much value.

Minor uses of fluorspar reported are as follows: In the electrolytic refining of antimony and lead; as a flux in place of borax in melting gold and silver concentrates; as an ingredient of the bond for abrasive grains in manufacturing abrasive wheels; as a flux in the manufacture of alundum and other artificial abrasives and refractories made in electric furnaces; in the manufacture of carbon electrodes used for flaming-arc lamps and other purposes; in increasing the recovery of potash and in promoting fuel economy by reason of its fluxing action in the manufacture of Portland cement; and as a flux in the manufacture of white Portland cement.

Fluorspar "glass,"[20] used for joining glass tubes of different melting points, such as quartz and pyrex glass to lead glass, is now made by a company in the United States. Several years ago a "glass" made from fluorspar, known as Fritsch's glass, was produced in Germany, but little practical application was found for it. This material had to be melted in platinum crucibles and cast in platinum molds, a process said to be very destructive to the platinum.

SODIUM FLUORIDE AS A WOOD PRESERVATIVE

Sodium fluoride is recognized as a very valuable wood preservative, but wider use has been restricted by high prices. For this purpose it has several minor advantages over zinc chloride, such as lower

[20] Glass Industry, "Answer to question"; Vol. 3, No. 10, Oct., 1922, p. 209.

solubility, greater toxic efficiency, less corrosive action, and the fact that it is not injurious to paint applied to material treated with it. These advantages, however, have not warranted payment of the price charged.

In the March, 1926, issue of Chemical and Metallurgical Engineering, sodium fluoride was quoted at 8¾ to 9 cents per pound and zinc chloride at 7 to 7½ cents per pound in wholesale lots in the New York market. The price differential is much less than it was a few years ago. In spite of the higher price a large coal-mining company is stated to have used sodium fluoride since 1915 for treating mine timbers in preference to zinc chloride or coal-tar creosote.

From 1913 to 1918 an average of about 28,500,000 pounds of zinc chloride was used annually for preserving wood. It is estimated that in 1923 28,000,000 pounds of zinc chloride and 127,000,000 gallons of coal-tar creosote were so used, about half of the latter being imported. This indicates the possible scope of the market for sodium fluoride at a price comparable with that of zinc chloride. It has been suggested, however, that under competitive conditions the price of zinc chloride could probably be reduced.

The increasing scarcity and cost of timber both for mining and other purposes has recently made the problem of wood preservation of increasing interest and importance. Hornor and Tufft [21] have pointed out the need for mine timber preservation and have shown the savings which may be effected. Hornor [22] has prepared a bibliography of articles on the preservation of mine timber, railroad ties, and so on. Bulletin 235 states that "If it could be obtained at a price that compared favorably with that of zinc chloride it would undoubtedly be used extensively in this country for treating wood."

GRADES, SPECIFICATIONS, AND TESTS

The several grades of fluorspar are sold under various trade names, but the grades themselves are based on utilization and are fairly definite. There are no uniform standard specifications for any grade of fluorspar, but individual consumers often have specifications for fluorspar to suit their needs. Acceptable grades are usually defined by mutual agreement between buyer and seller. The following grades are maintained fairly closely by the large producers and consumers, but deviations are not uncommon.

Acid grade.—This grade, also called "Keystone" when in lump form, is the highest grade of commercial fluorspar, except optical

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[21] Hornor, R. R., and Tufft, H. E., Mine timber, its selection, storage, treatment, and utilization: Bull. 235, Bureau of Mines, 1925, 118 pp.

[22] Hornor, R. R., Bibliography of articles relating to the preservation of mine timber: Reports of Investigations, Serial No. 2343, Bureau of Mines, April, 1922.

spar. Usually a calcium fluoride content of 98 to 98.5 per cent is specified, and the silica content must be less than 1.0 to 1.5 per cent. The calcium carbonate content must usually be less than 1.25 per cent. Barite and zinc and lead minerals are objectionable impurities. Acid grade may be shipped in lump form or ground to 30 mesh or finer. Ground acid spar brings a price but slightly higher than that of lump.

Glass and enamel grade.—This grade, also known as No. 1 ground or A-1 grade, must usually contain 95 to 96 per cent or more of calcium fluoride and not over 2.5 to 3 per cent silica. It must be pure white when ground and contain no iron or other impurities which will impair the color of the glass or enamel. It is usually ground to 30 mesh or finer.

Gravel grade.—This grade of fluorspar, also known as fluxing gravel, spar, or metallurgical grade, is marketed in three subgrades, all used for the same purposes but varying somewhat in price. These grades, beginning with the highest, are (1) not less than 85 per cent calcium fluoride and not over 5 per cent silica; (2) not less than 85 per cent calcium fluoride and not over 6 per cent silica; and (3) not less than 80 per cent calcium fluoride and not over 5 per cent silica. Most eastern consumers specify not over 1 per cent barite, but some western consumers do not object to moderate amounts. Gravel-grade fluorspar is ordinarily crushed to a maximum size of one-half to five-eighths inch.

Fluxing lump.—This grade corresponds in quality to the gravel grade, but varies in size from lumps 5 or 6 inches in diameter down to fine dust. It is used for the same purposes as the gravel grade.

No. 1 lump.—This is a high-grade lump spar of a quality between acid fluorspar and that of glass and enamel grade.

No. 2 lump.—This grade is lump spar corresponding to the glass and enamel grade in quality. It is used as a flux in iron foundries making high-grade castings.

In all the chief uses for fluorspar the chemical rather than the physical properties are important. No physical tests are ordinarily made, and the chemical analysis is of chief interest.

Various methods of fluorspar analysis have been employed, but the method in most general use in the United States to-day was developed by Bidtel.[23] In the southern Illinois district Bidtel's method is usually shortened, for experience has shown that results accurate enough for commercial purposes may be obtained without observing certain precautions intended for ores high in impurities not common in that district. The only determinations that are regularly made

[23] Bidtel, E., "Valuation of fluorspar": Jour. Ind. and Eng. Chem., vol. 4, No. 3, March, 1912; also article, same title and same journal, vol. 6, No. 3, March, 1914, p. 265.

there are calcium carbonate ($CaCO_3$), silica (SiO_2), and calcium fluoride (CaF_2). In certain other districts additional determinations of barium, sulphate, iron, zinc, lead, and other elements may be necessary.

UTILIZATION OF BY-PRODUCTS

As costs of mining are increasing, particularly in the Illinois-Kentucky district, utilization of waste products or by-products to offset the added expense is an increasingly important problem.

GALENA

As previously noted, some deposits, especially those of southern Illinois, contain considerable galena. Parts of the Rosiclare vein in Illinois have a high enough lead content for the lead product to form an important part of the mill output. One mill averages at least 30 tons of lead concentrates per week when running at normal capacity. The galena also carries silver, averaging about 8 ounces per ton, which about pays for the smelting charges. At another mine the lead content of the vein has recently increased greatly and the mill for some time produced about 150 tons of lead concentrates per month. Some galena occurs in a few western Kentucky mines, but in general is much less abundant than in the Rosiclare vein. With the exception of the Galena King mine near Albuquerque, N. Mex., no western deposits visited contained galena or sphalerite.

SPHALERITE

Sphalerite or zinc sulphide occurs occasionally in the Rosiclare vein, particularly near the southwestern end, and in a few smaller veins in Illinois and Kentucky, for example, at the Big Four mine and the old Columbia and Evening Star (Cullen) mines in Kentucky. As stated, in the past sphalerite has been an objectionable impurity rather than a valuable by-product, but it is hoped that the new milling methods suggested will eventually change this situation.

BARITE

Barite has always been an objectionable impurity and as yet no separation methods have been successful. This problem is acute in the central Kentucky district; at Wagon Wheel Gap, Colo.; at Tonuco, N. Mex.; and in the Madoc district, Ontario. At the Tonuco mill the barite mill tailings have been stock piled separately, with the idea that they might sometime be reworked and sold as a commercial barite product. Prospects are not promising, however, as crude barite has a low value (about $7.80 in 1924) and freight rates from New Mexico to the principal consuming centers in the east are very high. At Wagon Wheel Gap no serious attempt has been made to separate the barite from the fluorspar, as the western steel mill which has been the principal consumer of this fluorspar has so far regarded barite as a diluent rather than a harmful impurity. In central Kentucky and Madoc, Ontario, the problem is very acute, however, for eastern steel mills object to even a very small amount of barite. In these districts the barite would form a valuable by-product if it could be separated and saved.

LIMESTONE AND CALCITE

Limestone and calcite usually occur abundantly in association with fluorspar in most important deposits. The calcite which occurs in such large quantities in the Rosiclare vein in Illinois is pure white, coarsely crystalline, and usually very pure. The Fairview Fluorspar & Lead Co. (now Franklin Fluorspar Co.) has made the only serious attempt to utilize this calcite. All mill tailings and calcite mine waste from the Good Hope mine are crushed to pass a one-fourth-inch mesh screen and sold as agricultural limestone. The size complies with recommendations of the Illinois agricultural experiment stations. Although the price received for agricultural limestone is relatively low, the plant has paid for itself and somewhat more than offsets the former cost of waste disposal. A small amount of pure calcite has been shipped to St. Louis for the manufacture of whiting.

The Chinn vein in Woodford and Mercer Counties, central Kentucky, in places carries fluorspar mixed with barite and white calcite, in other places chiefly barite and calcite, and in still other parts practically pure white calcite; the latter has been finely ground and utilized to some extent as a whiting substitute, but could hardly be considered a by-product of fluorspar mining, as part of the vein not worked for fluorspar was opened to obtain calcite.

Additional uses for limestone and calcite might be as follows: Fluxing limestone for iron blast-furnaces; road material; concrete aggregate; calcite granules for stucco dash, concrete block facings, and prepared roofing; raw material for the manufacture of burned lime; calcite and limestone chips for terrazzo.

MARKETS AND PRICES

As indicated under "Utilization," fluorspar is chiefly used in the basic open-hearth steel industry, in the manufacture of enamels for iron and steel, of opalescent glass, and of hydrofluoric acid, and in the aluminum industry for making artificial cryolite; the points of consumption are therefore the centers of these industries. The methods of shipping various grades of fluorspar have been noted.

Common practice is to quote prices on all grades of domestic fluorspar per short ton f. o. b. cars at the mills or the nearest railroad shipping point. Prices on imported fluorspar, particularly from England, are usually quoted per long ton (2,240 pounds). All gravel and lump fluorspar of fluxing grade, most acid lump, and some ground-glass and enamel-grade spar are shipped in bulk. When ground spar is shipped in bags or barrels, the price is quoted on the basis of bulk spar, and a nominal charge per ton is added for packing. For burlap bags holding 100 to 125 pounds the bag charge is 10 to 30 cents (depending upon their cost). The bags are returnable at the price paid if in good condition. If barrels are used (400 to 500 pounds capacity) a packing charge of $2 to $4 per ton is made.

Most large consumers buy the bulk of their fluorspar on contracts which usually cover a definite tonnage to be shipped within a certain time limit. The contract usually specifies the minimum analysis requirements which will be accepted and may include penalties for impurities exceeding the specified limits. Premiums are seldom paid for unusual purity; therefore producers tend to lower the grade of products to the minimum requirements.

When gravel-grade fluorspar is sold on penalty contracts, it is generally assumed, in the East at least, that 1 per cent of silica in fluorspar requires 2½ per cent of calcium fluoride to flux it; thus a gravel spar containing 85 per cent CaF_2 and 6 per cent SiO_2 (a standard grade) has available 85 per cent—($6 \times 2\frac{1}{2} = 15$ per cent) or 70 per cent CaF_2.

A gravel-grade spar containing 80 per cent CaF_2, 10 per cent $BaSO_4$ (barite), and 10 per cent SiO_2, assuming that $BaSO_4$ is only a mechanical diluent, is equivalent to 80 per cent—($10 \times 2\frac{1}{2} = 25$ per cent) or 55 per cent available CaF_2. However, as shown under "Utilization," each percentage of barite requires about two-thirds per cent of fluorspar to flux it; thus the available CaF_2 would be reduced still further by $10 \times \frac{2}{3}$, or about 6.7 per cent, leaving only 48.3 per cent available CaF_2 and illustrating the inefficiency of the use of fluorspar high in impurities, even though these are only diluents.

A standard 85 per cent CaF_2 gravel spar with 6 per cent SiO_2 is therefore equivalent to 70 per cent available CaF_2, which is considered standard. In penalty contracts, if the available CaF_2 falls below 70 per cent, the producer is penalized for each per cent below the standard. On such contracts a fluorspar containing 80 per cent CaF_2 and only 2 per cent SiO_2 would not be penalized, for the available CaF_2 is 75 per cent, or 5 points above the standard; but a spar containing 85 per cent CaF_2 and 10 per cent SiO_2 would be penalized 10 points, for the available CaF_2 is only 60 per cent.

Although prices are normally quoted f. o. b. mines or the nearest railroad shipping point, regardless of the location of the deposit, the prices in the Illinois-western Kentucky field actually set the level of prices in the country (with the exceptions noted later). The cost of fluorspar in Chicago is, then, the southern Illinois mine price plus freight from mine to Chicago. The price of fluorspar (for Chicago markets) f. o. b. Colorado mines must be equal to or lower than the cost of Illinois-Kentucky spar in Chicago (the nearest large eastern market) minus the freight rate from the mine in Colorado to Chicago. This mine price for Colorado mines also holds, theoretically at least, if shipments are made to consumers in Colorado or other western States. In practice the prices received for western fluorspar depend somewhat upon competitive conditions among western mines. In normal times little western fluorspar has reached eastern markets, and there have been but few western markets. The total consumption of all grades of fluorspar in the far western States has been estimated at not more than 10,000 tons per year, most of it of fluxing grade. Western fluorspar producers must compete among themselves for this business. Little eastern fluorspar has ever been shipped to far western markets.

Imported fluorspar has also been an important factor in setting the price level for the country. Before the war low-priced imported fluorspar, chiefly from England, could be shipped profitably as far west as Pittsburgh from the port of entry. Although this fluorspar was of lower grade than the domestic product, its delivered price more or less set the price for domestic fluorspar. During the war imports were so small and demand so great that this factor was of little importance. Since the war imports have been resumed, but British costs of production, ocean freights, and railroad freight rates have increased so much that competition between imported and domestic spar has only been important close to the Atlantic seaboard.

An import duty on fluorspar was first imposed by the tariff act of 1909, when a duty of $3 per long ton was put into effect. In 1913 this was reduced to $1.50 per long ton. By the tariff act of 1922 the import duty on fluorspar was increased to $5.60 per long ton. This duty has not been high enough to exclude imported spar, for it is now shipped as far west as Youngstown, Ohio. A few shipments of German fluorspar have been made by barge canal from New York City to Buffalo. Acid-grade spar, and to a lesser extent glass and enamel grade spar, can probably be imported economically because their unit value is higher. In general, the delivered price of imported fluorspar must be somewhat lower than that of domestic fluorspar of the same grade, due to uncertainty and irregularity of shipments and greater variation in quality.

Another factor in the price situation has been the policy of certain large consumers to encourage the development of new mines (sometimes in remote localities) by making contracts with such producers at prices higher than those for similar grades from the Illinois-Kentucky district.

One factor in the price situation which was perhaps more important in the past than it is now is the practice of small producers, particularly in western Kentucky, to cut prices to make quick sales or compensate for irregular shipments. The tonnage sold under such conditions, though not large, has tended to disturb price levels.

Pre-war fluorspar prices were so low that fluorspar mining in general was not profitable, partly due to destructive price cutting between large producers, partly to the low price at which imported spar could be obtained, and partly to a mistaken impression that our fluorspar deposits were practically inexhaustible.

During the war the demand became so acute that prices rose rapidly. In 1918, while some producers were making deliveries on old contracts at $5 to $10 per ton (for gravel grade), extreme prices received for gravel spar for prompt delivery reached $38 to $45 per ton. Average annual prices actually received during a period of rapid price changes do not reflect accurately the condition of the market or the price levels reached over short periods.

The table shows the average range in fluorspar prices from 1910 to 1924.

Fluorspar prices per short ton at mines or local shipping point[1]

Year	Gravel	Lump	Ground	Average price	Year	Gravel	Lump	Ground	Average price
1910	$5.43	$6.44	$10.72	$6.20	1918	$20.05	$24.12	$31.22	$20.72
1911	6.03	7.23	12.38	7.02	1919	23.80	30.38	43.02	25.49
1912	5.82	6.88	12.92	6.60	1920	23.24	29.85	43.32	25.26
1913	5.87	6.88	12.31	6.37	1921	16.11	21.39	40.00	20.71
1914	5.21	8.45	11.78	5,99	1922	16.36	18.56	36.42	17.88
1915	4.89	7.51	10.80	5.58	1923	18.61	23.32	36.86	20.68
1916	4.89	7.51	10.80	5.58	1924	18.02	22.19	35.89	19.61
1917	9.61	13.68	17.59	10.45					

[1] Figures for 1910–1923 were compiled by the U. S. Geological Survey; for 1924 by the Bureau of Mines.

In June, 1922, the following prices per short ton prevailed in the Illinois-Kentucky district f. o. b. cars at mines or nearest railroad shipping point:

Gravel grade:
- 85 per cent CaF_2 and not over 5 per cent SiO_2 ---- $17.50
- 85 per cent CaF_2 and not over 6 per cent SiO_2 ---- 17.00
- 80 per cent CaF_2 and not over 5 per cent SiO_2 ---- 16.00

Glass and enamel grade, ground, bulk ---- 35.00

Acid grade, ground, bulk (packages $4 per ton extra) ---- 40.00

In October, 1922, prices were advanced to the following levels:

Gravel grade:	
85 per cent CaF_2 and not over 5 per cent SiO_2	$21.50
85 per cent CaF_2 and not over 6 per cent SiO_2	21.00
80 per cent CaF_2 and not over 5 per cent SiO_2	20.00
Glass and enamel grade, ground, bulk	35.00
Acid grade, ground, bulk (packages $4 per ton extra)	45.00
No. 1 lump	30.00
No. 2 lump	25.00

In September, 1926, the price of gravel-grade fluorspar, f. o. b. Illinois, was $18 a ton. For the preceding year the price was $17.50 to $18.50 a ton.

INDIVIDUAL DISTRICTS AND MINES

ILLINOIS-WESTERN KENTUCKY DISTRICT

The most important fluorspar-producing region in the United States and probably in the world is the Illinois-western Kentucky district which centers about Rosiclare, on the Ohio River, in Hardin County, Ill. The largest producing mines are in Hardin County, Ill., and in Crittenden and Livingston Counties, just across the Ohio River in Kentucky. Smaller and less important deposits occur in Pope County, Ill. and in Caldwell, Christian, Lyon, and Trigg Counties, Ky.

Although the general character and geology of the Illinois and Kentucky districts are the same, the economic phases of the fluorspar-mining industry differ widely. In Illinois most of the production has come from the large Rosiclare vein, chiefly from the Rosiclare and Fairview mines, and from a subsidiary vein (or veins) at the Daisy and Blue Diggings mines. In Kentucky there are only a few moderately large mines, and past production has come from numerous small workings. In Illinois the owners almost invariably work the deposits, but in the past in Kentucky the properties have been largely worked by contractors, lessees, or even sublessees. In Illinois the three largest mines and a fourth, a smaller mine, have a direct railroad connection. In Kentucky a few mines have railroad connection. For these reasons the economic phases of the two districts will be treated here separately, although it is clearly recognized that for many purposes they should be considered as a unit.

GENERAL DESCRIPTION OF DEPOSITS

The area is underlain by a series of sedimentary rocks of Mississippian age (Paleozoic). These sedimentaries, which include limestones, sandstones, and shales, have been extensively faulted by a series of steeply dipping intersecting block faults, often practically vertical; but the strata usually remain nearly horizontal and have also been intruded by a few small dikes and sheets of basic igneous rocks (lamprophyre and mica-peridotite) which are now so greatly altered that identification is difficult. The amount of vertical displacement along the faults is exceedingly variable; in some faults practically no displacement is evident and in others displacements of as much as 1,600 feet have been observed.

With the exception of one or two beds the fluorspar deposits occur as veins in faults. Although there seems to be no relation between the extent of the vertical displacement of the faults and the amount of mineralization, the major fault zones—that is, those of the greatest longitudinal extent—have usually contained the most important commercial deposits. The fluorspar may be deposited within the faults itself (as in the Rosiclare vein) or may be found chiefly in minor faults that are subsidiary to the main fault but are parts of the main fault system (as along the Columbia and Tabb vein systems). As noted, the most favorable location for important deposits is along the parts of the faults where one or both walls are limestone or highly calcareous shales or sandstones or in the parts of the fissures which have been filled with calcite earlier.

Calcite is the mineral most commonly associated with fluorspar; it is found in important quantities in nearly all large deposits. Silica as quartz is a common associate, but usually occurs in small amounts disseminated through the ore and is often absent. In parts of some veins galena is relatively common, but in others is missing. Sphalerite is present in but few veins, but in some places (for example, in part of the Rosiclare vein at Fairview) is found in fairly large quantities. Barite is generally absent, but occurs in minor quantities in parts of a few deposits (for example, at the Green mine, near Cave in Rock, Ill.). Clay, sand, or fragments of limestone, shale, or sandstone wall rocks are usually mechanically mixed with the fluorspar as it is mined. There is iron oxide in a few mines as solid limonite (as at the Stewart mine in Hardin County, Ill.) and in iron-stained residual clay and sand.

ILLINOIS

The Illinois fluorspar district occupies an area of gently rolling country of rather low relief. Near the Ohio River, where the most important mines are located, the surface is only a little above the normal river level, and when the river is high the water inundates the ground around the shaft collars.

Although weathering has probably been extensive, erosion has removed most of the products of weathering, particularly near the river, and the present rock has little surface cover in many places. Vein outcrops can therefore be traced rather accurately.

The most important fault, with relation to production, is the Rosiclare fault or vein. The Daisy-Blue Diggings vein has been second in importance, if the assumption that these two mines work the same vein is correct. The third most productive source of fluorspar has been the bedded or blanket deposits of the Cave in Rock district. The remaining production has come from 12 or more small mines and prospects.

ROSICLARE VEIN

To obtain an adequate idea of the relative importance in the past of the Rosiclare vein in comparison with other operations, it might be noted that to date this vein has produced over 1,000,000 tons of fluorspar from two properties only; the Daisy-Blue Diggings vein has produced nearly 300,000 tons. The largest total production from any single property in Kentucky has been probably not over 40,000 tons, and the total past production of the State, according to Mineral Resources for 1925, has been 737,008 short tons.

The Rosiclare fault has been traced for about 4½ miles along the strike, and has been developed over a length of about 9,000 feet by underground workings. This vein is known to carry fluorspar as deep as 500 to 600 feet in places. The vertical displacement at Rosiclare is 200 to 250 feet. The strike varies from nearly north and south to about N. 20° E. and averages about N. 17° E. The dip varies but usually ranges from 72° west to vertical and averages about 76° west. The width of the fluorspar vein varies from a tight pinch to 25 or 30 feet, for short distances. Parts of the vein that contain less than 2 feet of fluorspar are ordinarily worked only in development openings. The lengths of the pinches through which drifts have been cut to good ore on the other side vary from a few feet to at least 350 feet. On some levels the length of the barren parts are not known. The average width of ore is difficult to estimate, but it seems evident that the width decreases with depth, and that the "ore pockets" are shorter and the barren zones longer on the lower levels. From all the evidence now available the main parts of the ore body seem to maintain their width better and extend to greater depth in the part of the vein near the main shaft of the Rosiclare Lead & Fluorspar Mining Co. than in any other place. Here ore 6 feet wide occurs north of the shaft on the 600-foot level. Southwest of this shaft the Extension shaft of the Fairview Fluorspar & Lead Co. (now Franklin Fluorspar Co.) shows that at a depth of about 400 feet the vein filling is mostly calcite with little or no fluorspar. Similarly, to the northeast, at the main shaft of the

Hillside Fluor Spar Mines, on the 350-foot level (June, 1922) the vein filling was largely calcite with occasional small veins and pockets of fluorspar. The distance between the vein walls does not seem to change much with increasing depth.

At some levels both walls are limestone; at others one wall is limestone and the other sandstone or shale. In general the footwall is firm, clean, and solid, whereas the hanging wall is more often irregular and tends to be weak. In some places little or no timber is required to support the walls, though timber is used to support the broken ore in the stopes; in other places the walls require heavy timbering.

Perhaps the greatest single problem in mining ore from the Rosiclare vein is the handling of the large quantity of water which flows into the mines through open channels in the limestone. At its southern end the vein is cut by the Ohio River, and most of the mine workings are well below the river level. The principal mines have been flooded repeatedly, especially in spring, causing long delays and involving great expense for dewatering. The mining companies have had to build heavy bulkheads and install expensive pumping equipment, and the cost of pumping excessive quantities of water from the increasing depths is one of the largest items in production cost. It has been estimated that under normal water conditions at one of the largest mines 164 tons of water must be pumped for each ton of fluorspar produced.

As mining methods and many general features of production are similar in the largest mines on the Rosiclare vein, a detailed description will be given of the method of one company only. An extended description of at least one mine is included, to give an adequate idea of the operation of a typical mine.

Fairview Fluorspar & Lead Co. (now Franklin Fluorspar Co.).—The property of the Fairview Fluorspar & Lead Co. (now the Franklin Fluorspar Co.) extends from the Ohio River on the southwest to the property line of the Rosiclare Lead & Fluorspar Mining Co. to the northeast, and contains about 4,800 feet of the Rosiclare vein outcrop. It also contains an unknown length of the Blue Diggings vein (possibly an extension of the Daisy vein of the Rosiclare Lead & Fluorspar Mining Co.) and an unknown length of the Golconda fault, now known to be mineralized.

The Rosiclare vein is opened in three distinct sections, not connected underground. The principal shafts in each section are: (1) The Extension and Annex shafts; (2) the Good Hope shaft; and (3) the No. 4 shaft. Only the first two sections have been worked in recent years. The mill is located in the central section, near the Good Hope shaft.

When the property was acquired by the Fairview Co. (about 1900) all operations were being conducted on a small and inefficient scale. Improvements and changes were gradually made, and in 1907–1908 production began on a large scale.

The ore body in the Good Hope mine varies from a tight pinch to 25 feet in width, and in the Extension mine from a pinch to 20 feet, but it is somewhat more uniform than in the Good Hope mine.

Shafts.—The Good Hope shaft is sunk in the footwall 6 feet from the vein at the surface and 120 feet from the vein at the 473-foot level. It is a timbered shaft with 3 compartments, 2 skipways and 1 pipe and ladderway, cut 6 by 16 feet down to the 80-foot level and 5 by 16 feet from there to the bottom (about 500 feet).

At the Extension shaft the vein is practically vertical and both the Extension and the Annex shafts are sunk in the hanging wall, the former about 30 feet from the vein and the latter about 85 feet from the vein. The Extension shaft is cut 5 by 16 feet from the surface to the 165-foot level and 5 by 14 feet from there to the bottom (400-foot level). The Annex shaft is cut 6 by 16 feet and is 300 feet deep. Both are timbered shafts and the compartments are arranged as in the Good Hope shaft.

The No. 4 shaft and the Blue Diggings shaft have not been used in the past few years.

Underground development.—The Good Hope shaft is mined by levels at the following vertical distances below the surface: 70, 145, 212, 281, 343, 400, and 473 feet. The Extension shaft is opened at the 90, 200, 300, and 400 foot levels; the 200-foot level practically corresponds to the 212-foot level of the Good Hope shaft, but the two lack about 150 feet of being connected.

Shaft stations are cut on the main levels, and at some levels ore pockets or skip-loading bins are excavated below the shaft stations. These bins may hold 50 to 500 tons each of broken ore. Near the shaft stations on various levels pump rooms, sumps, mule stables, powder magazines, and so on are cut.

As the Good Hope shaft is so near the vein at the surface, a 50-foot shaft pillar has been left in the vein on each side of the line of the shaft. About 200 feet south of the Good Hope shaft is an air shaft from the 70-foot level to the surface.

The main drifts are cut 9 feet high by 7 feet wide, or the width of the vein if it is over 7 feet, and on a grade toward the shaft of from 0.5 to 1.0 per cent. The grade of the drift bottom depends upon the volume of water to be handled in the drainage ditches cut on one side of the track. The unusual drift height of 9 feet is carried through the ore-bearing parts of the vein, for the stopes are started directly from the backs of the drifts. Usually no drift timbers are needed for support and nearly all wood used underground has some connection with actual mining. Through pinches or barren parts of the vein the drifts are cut somewhat smaller. Waste produced in drifting is dumped down into old empty stopes if possible; otherwise it is hoisted to the surface. The main drifts are usually kept at least 100 feet in advance of the stopes.

Mining methods.—In general the method of mining used is shrinkage stoping over stulls. The details of the method are about as follows:

After the main drifts have been advanced far enough stoping is started. Stopes are 100 to 1,000 feet in length, depending upon local conditions. In starting a stope a horizontal slice about 5 feet thick is removed by overhand stoping along the back of the drift, making the total height of the drift about 14 feet. Drilling is done from wooden horses or temporary working poles (light stulls) set across the drift.

Heavy stulls are next set along the drift on about 5-foot centers, at a height of about 6 feet on the footwall side and usually about 9 feet on the hanging-wall side, depending upon the width of the vein and the dip. Ore chutes with gates are built between alternate sets of stulls (chutes thus on 10-foot centers) and the spaces between chutes tightly lagged over with poles. Stopes are set off or separated from each other by bulkheads composed of a line of stulls lagged over on the stope side. Between stopes two such sets of stulls are placed and lagged, leaving a manway between to give access to the stopes and aid natural ventilation.

After the chutes and gates have been placed, stoping is started. Holes are drilled in the back with compressed-air stoping drills and the ore shot down. After each shot only enough ore is drawn off from the chutes below to leave working room in the stope for drilling the next round of holes. The back of the stope and the level of the broken ore in the stope are kept at about uniform levels; that is, one part of the stope is not worked out at a much faster rate than another part.

Stoping is continued upward to the level above, or a horizontal pillar or "arch" is left to support the drift above. If the ore is wide it is often loose and weak; then it is entirely removed and replaced by a row of stulls to carry the track in the drift above. "Arches" or drift pillars range from 5 to 20 feet in thickness, depending upon local conditions. Level intervals are normally 100 feet vertically, but additional levels are sometimes opened halfway between.

Waste is left standing in place if possible, but small blocks of waste must often be shot down with the ore and later removed in milling. In places the hanging wall is weak and loose slabs are found. These are caught up by stulls and left in place.

When the stope is finished and the final drawing off of the ore is started miners stay on the gradually lowering top of the broken ore, dressing down the walls and supporting them with stulls as necessary. After the ore is completely withdrawn, the stulls over the drift below are double lagged with poles, covering the chutes and the interspaces. Wall rock is then shot down to load the stulls, to protect them from later falls of rock, and to make a more or less air-tight carrier to assist ventilation.

Haulage.—The ore is drawn off from the stopes into hopper-bottom steel cars that hold about 20 cubic feet or approximately 1 ton each. These cars are hauled by mule or gasoline locomotive to the ore pocket at the shaft station. At the Extension mine the gasoline locomotive used will pull 10 loaded cars. The empties are spotted at the chutes by mules. If there is a loading pocket at the shaft station the ore is dumped from the cars over a heavy grizzly with bars set about 6 inches apart, and sledged through into the ore pocket. At levels where there is no ore pocket the grizzly is set over the top of a raise cut through from an ore pocket on a level below, and the ore is dropped to the lower level for hoisting. Usually part of the ore pocket is divided off to form a separate compartment for waste, which otherwise is handled the same as ore.

Hoisting.—From the ore pockets the ore is drawn off directly into skips of 1½ tons capacity and hoisted to the surface. The Good Hope shaft is equipped with a 10 by 14 inch hoist; the Extension shaft with a 12½ by 15 inch hoist (for ore and waste); and the Annex shaft with a 9 by 12 inch hoist (for men and timber); all are steam-driven double-drum friction hoists, coupled solid and used in balance.

At the Good Hope shaft the skips dump directly into a 100-ton mill bin. At the Extension shaft the ore is dumped into a 150-ton storage bin, from which it is drawn off into standard-gauge hopper-bottom cars, hauled to the mill, and dumped through a chute into an underground mill bin cut from rock about 80 feet below the surface and holding about 250 tons. From this bin the ore is hoisted in skips to the top of the mill. A total of 225 to 250 tons of ore can be hoisted per day from the two mines if two 8-hour shifts are worked.

Drainage and pumping.—As noted before, the drainage problem is very important in this district. Large sumps are cut near the shaft on each level (for example, one sump in the Good Hope shaft is 50 feet long, 10 feet wide, and 10 feet deep), and the water from the workings flows to the sump through drainage ditches along the sides of the drifts. As much water as possible is caught on the upper levels and is sometimes piped to the nearest sump below.

At the Good Hope shaft about 1,500 to 1,800 gallons of water are usually pumped to the surface per minute; at the Extension shaft about 1,300 to 1,500 gallons per minute. In unusually wet seasons these amounts may be nearly doubled.

At the Good Hope mine all pumping is now done from the 473-foot level, the present bottom level, where three steam pumps with a total capacity of 3,300 gallons per minute are installed. Two pumps (1,200 and 800 gallon capacities) are of the compound, duplex, outside, end-packed, condensing type with pet valves. The other pump is a three-stage turbine-driven centrifugal.

At the Extension mine on the 200-foot level are two noncondensing steam pumps with a total capacity of 1,500 gallons per minute; on the 300-foot level are three steam pumps with a total capacity of 2,500 gallons per minute. The exhaust steam of all pumps is discharged into the sumps.

For many years the pumps were drowned when the mines were flooded and dewatering with sinker pumps was very slow and costly. A few years ago bulkheads were built to protect pump rooms from flooding. The most elaborate bulkhead is installed on the 473-foot level of the Good Hope mine. The sketch, Figure 23, shows the general construction. Figure 24 shows the face of the bulkhead and details of the door.

This bulkhead is 15 feet thick and is wedge shaped, with the larger end toward the source of the underground stream. It has a very heavy cast-steel door, which may be quickly and tightly closed in case of flood. Through the bulkhead are run pipes, with valves on the pump-room side. When the mine is flooded the water may be drawn off through these pipes as rapidly as the pumps can handle it. Before this equipment was installed dewatering sometimes took six months; now it can be done in about 10 days.

The mine water is slightly alkaline and does not corrode pipes or pumps.

Drilling and blasting.—Nearly all types of compressed-air drills have been used here, but certain types are now more or less standard. For drifting, pneumatic-feed hollow-steel water stopers are used for the top holes and light rotating hammer drills (jackhammer type) for the toe holes; regular column or bar-mounted hammer drills of various sizes and types may be used for both classes of holes. For stoping, various makes of pneumatic-feed stoping drills are used, usually dry. All drill steel is hollow and hexagonal in section and usually has the ordinary cruciform bit. Sometimes, however, a six-pointed bit is used. This bit stays sharp longer in hard ground and holds its gauge better than the cruciform bit.

Compressed air for drilling is supplied by three 2-stage steam-driven air compressors in the power house at the surface near the Good Hope shaft. These three compressors have capacities of 900, 1,100, and 1,200 cubic feet of free air per minute.

For blasting, straight nitroglycerin dynamite is used, varying in strength from 30 to 60 per cent, although 40 per cent is used most.

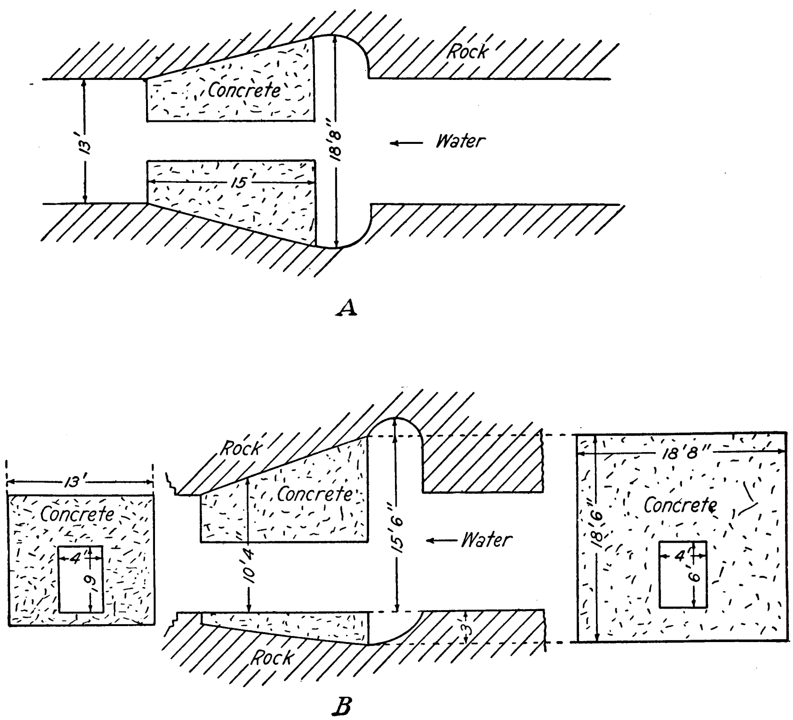

FIGURE 23.—Sketch of bulkhead on the 473-foot level of the Good Hope mine of the Fairview Fluorspar & Lead Co. (now the Franklin Fluorspar Co.), near Rosiclare, Ill.: *A*, Plan; *B*, elevation

Shooting is done at noon and at the end of the shift. The mine is normally run on two eight-hour shifts.

Ventilation.—Artificial ventilation is not ordinarily used. In advancing drifts, in raising, or in stoping before raises are put through to the level above, the air is sometimes bad, and artificial ventilation may be necessary. Small portable fans are then connected with the working faces by canvas or galvanized-iron pipes. Natural ventilation is normally ample, and the air is very good.

Lighting.—All shaft stations, pump rooms, and main drifts are lighted by electric lights, and the current is supplied by a generator in the power plant at the surface. Miners use ordinary carbide miners' lamps. Pump rooms and shaft stations are connected with the surface by mine phones.

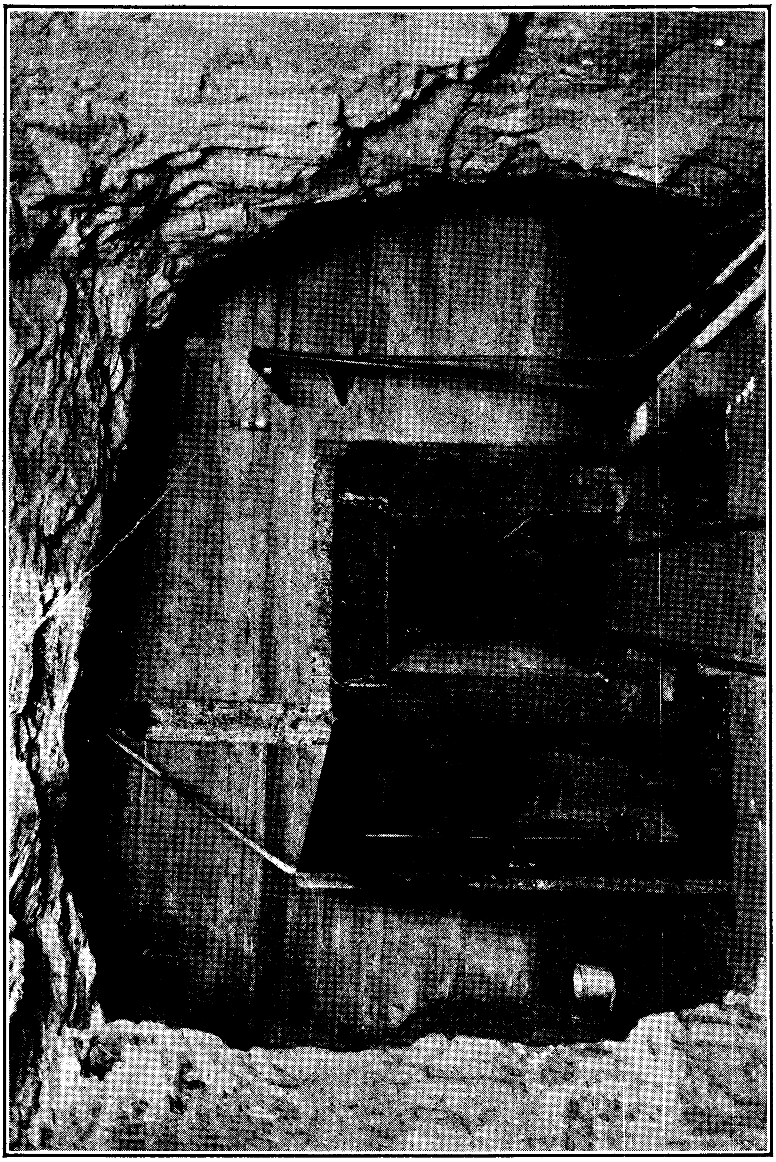

FIGURE 24.—Concrete bulkhead on the 473-foot level of the Good Hope mine of the Fair View Fluorspar & Lead Co. (now the Franklin Fluorspar Co.), near Rosiclare, Ill.

Surface plant.—The main power plant is near the Good Hope shaft. Steam is generated by four Heine-type water-tube boilers, of which two are 500, one 350, and one 250 horsepower. All are equipped with automatic chain-grate stokers. This power house also contains the three air compressors previously noted, one 125 and one 75 horsepower Corliss engine, which supply power for the mill, and a 50-kilowatt, direct-current dynamo used for lighting only.

In the power house at the Extension mine are three Heine-type hand-fired boilers, of 350, 300, and 125 horsepower, which generate steam chiefly for pumping at the Extension mine.

A large, well-equipped machine shop is near the mill. Not only are all of the minor and most of the major repairs made here but the company also builds its own ore skips, cages, mine cars, and so on. The Extension mine has a tool-sharpening shop with a compressed-air drill sharpener and an oil-fired forge.

Near the Extension shaft head is a timber-framing shop with power saws for framing shaft, bin, and mine timber.

The railroad rolling stock of the company includes one 15-ton and one 20-ton locomotive crane, a 60-ton standard-gauge railroad locomotive, a 12-yard western side-dump car for waste, etc., and a 40-ton steel, automatic air-dump, hopper-bottom car for transferring ore from the Extension mine to the mill.

Rosiclare Lead & Fluorspar Mining Co.—The main property of this company adjoins that of the Fairview Fluorspar & Lead Co. (now the Franklin Fluorspar Co.) on the latter's northeast boundary, and extends about 4,600 feet along the Rosiclare vein to the property of the Hillside Fluor Spar mines. This property also includes an undetermined length of the Daisy vein. In addition, the company owns part of the extension of the Rosiclare vein beyond the Hillside property to the northeast. Both the Rosiclare and the Daisy mines have railroad connections with a branch of the Illinois Central Railroad.

The Rosiclare vein on this property has about the same characteristics as on the Fairview property. The methods of development, mining, and milling, the types of equipment used, methods of fluorspar storage and shipment and so on, at this mine so closely resemble the corresponding features of the Fairview mine, just described, that a detailed description is unnecessary. Only a few of the more important features will be emphasized.

The Rosiclare mine began producing before 1870 and has produced almost steadily ever since, although only on a really large scale since about 1911. In the early days galena was sought principally, but for the past 20 years or more fluorspar has been the principal product.

Shafts.—In early workings a number of small, shallow shafts were sunk on the vein, but at present only three shafts are in use. The main shaft, known as the mill or plant shaft, is about 1,700 feet from the western property line and has three compartments, is 6½ by 15 feet in the clear, and in May, 1922, was sunk to a depth of 676 feet. The shaft is sunk 12 feet from the vein on the footwall side at the surface and is concreted from the surface to solid rock at the 90-foot level.

The Rosiclare shaft, used chiefly for men and timber, is sunk 560 feet southwest of the plant shaft. In May, 1922, it was 585 feet deep, sunk on the vein, and concreted 25 feet down from the surface. It also is a three-compartment shaft cut 6 by 13 feet in the clear.

A third shaft, the new air shaft, 2,300 feet northwest of the plant shaft, is 530 feet deep. It is a two-compartment shaft sunk in the hanging wall about 20 feet from the vein at the surface. The shaft is used only as an air shaft and an emergency exit from the mine.

Underground development.—Levels have been opened at 235, 320, 420, 520, and 620 feet below the surface. Most of the ore now being removed comes from stopes above the 620 and 520 foot levels. The ore developed on the 620-foot level averages about 6 feet in width, but very long sections of the vein contain no fluorspar. The average width of the ore and lengths of the separate ore bodies seem to decrease with depth, but the quality of the ore does not appear to change.

Mining method.—The mining method used here is the same as that at Fairview, but it is proposed that on the 600-foot level the shrinkage stopes will be started over back pillars instead of over timber, and that ore chutes be placed on 25-foot centers instead of every 10 feet, a change that would save timber and afford better support for the walls.

In drifting an automatic shoveling machine is sometimes used for loading ore or waste. This machine has a capacity of about 50 tons per eight-hour shift, and is said to replace at least five hand loaders if it has plenty of broken ore on which to work (say a pile 4 feet deep).

Haulage.—Three storage-battery locomotives take care of all main-line haulage. The ore is hauled to the shaft station in hopper-bottom steel cars that hold about 1 ton each and dumped over a grizzly with 8-inch spacing between bars. Large lumps are sledged through. Below the 600-foot level are a 250-ton ore pocket and a 30-ton waste pocket. Below the 500-foot level is an ore pocket, connected by an ore chute to the ore pocket below the 600-foot level. All hoisting is now done from the 600-foot level.

Drainage and pumping.—Pumping is now done from the 400, 500, and 600 foot levels. When the Fairview mines are not being pumped, 1,250 to 1,500 gallons of water per minute must be pumped from the Rosiclare. When the Fairview is pumping, the water handled by Rosiclare pumps is reduced by 500 to 700 gallons per minute. The pumps at Rosiclare are not protected by bulkheads, as at Fairview, and pumping must be done continuously. If the mine is flooded, dewatering by sinker pumps from the outside is very slow and expensive.

Hoisting, lighting, and ventilation.—Hoisting, lighting, and ventilation are handled at Rosiclare much the same as they are at Fairview. The Rosiclare surface plant also resembles that at Fairview. The milling method has already been described.

Hillside Fluor Spar Mines.—The property of this company consists of two 40-acre tracts on the Rosiclare vein, adjoining the northeastern boundary of the property of the Rosiclare Lead & Fluorspar Mining Co. The Rosiclare vein enters the western boundary of the property and probably leaves the property along the northern boundary line. The mine is served by an extension of the Illinois Central Railroad tracks from the Rosiclare mines.

Shaft.—The mine is opened by a four-compartment vertical shaft sunk in the footwall (50 feet east of the vein on the 250-foot level) to a depth of about 350 feet (June, 1922). At the shaft just below the 350-foot level an ore pocket holding about 75 tons has been cut. The shaft is cut 6 feet by 20 feet in the clear and concreted down to solid rock at the 170-foot level. The four compartments consist of two skipways, a pipeway, and a ladderway. In the concreted section steel shaft sets and a steel stairway are used.

Underground development.—The vein was explored at the 170-foot level, but mining conditions here were unfavorable, and the main levels now in use are 250 feet and 350 feet below the surface. In June, 1922, the 250-foot level had been driven 45 feet south and 75 feet north; the 350-foot level, 77 feet south and 133 feet north. The average strike of the vein was N. 20° E. and the dip 72 to 76° W. As the shaft is close to the western property line and the vein dips west, most of the ore must be taken from the part of the vein that lies northeast of the shaft. When the mine was examined the 250 and 350 foot levels south showed very little ore; at the face of the 250-foot level north the vein was about 15 feet wide and consisted of about 7 or 8 feet of calcite and about the same width of very good, hard, white fluorspar containing much galena; the face of the 350-foot level was largely calcite, but contained perhaps 25 to 30 per cent of fluorspar in small irregular bunches. No stoping had been done, but it was planned to adopt the shrinkage-stoping method used in the other large mines on the Rosiclare vein.

Haulage and hoisting.—The ore is hauled to the shaft, dumped into the ore pocket below the level, from which it is hoisted to the surface in steel skips holding about 5 tons each and dumped directly into a small bin at the head of the mill. Only one skip was being used; it was counterbalanced by a cage in the adjacent skipway.

Pumping, timbering, and waste disposal.—At the time of examination pumping was a very unimportant item; in fact, hardly enough water was obtained to supply the mill. Practically no timbering was done. Mine waste was handled underground in 1½-ton steel end-dump cars, which were hoisted to the surface in the cage and trammed by hand to the waste dump near the shaft head.

Milling.—The fluorspar mill at this property is the most modern and probably the most complete mechanically of all the fluorspar mills in the country. It is of modern concrete and steel construction, and was placed in commission early in 1922. A general view of the mill and the steel head-frame is shown in Figure 7. The capacity of the mill is about 200 tons of crude ore per 24-hour day, and 150 to 200 horsepower is required.

Some of the more important features of this mill are as follows: (1) Jigs of the Harz type and made of concrete; (2) unusually close sizing before jigging; (3) dewatering elevating scraper conveyors used for lead middlings and fluorspar concentrates; (4) unusual percentage of lead concentrates so far obtained; (5) individual or unit motor drives.

The gravel fluorspar concentrates are all collected on a dewatering elevating scraper conveyor which discharges on a long distributing conveyor running over the top of a series of eight large concrete storage bins. Beneath the bins is a tunnel in which is installed a belt conveyor which passes beneath all the bins and extends on outside the mill to the top of a small car-loading bin over the standard-gauge railroad siding. The total length of the belt conveyor is 420 feet between centers. At frequent intervals the bottoms of the bins are equipped with steel radial gates. A movable feeding device self-propelled by electric motor runs on a separate track astride the belt conveyor. This feeder can be run up under any chute whose gate it opens automatically, and receives the gravel spar from the bin and feeds it uniformly to the belt conveyor. This loading equipment can fill a 50-ton railroad car in 35 minutes. A general view of the outside part of the belt conveyor and car-loading bin is shown in Figure 25.

The power plant, housed in a brick, concrete, and steel building, consists of four 150-horsepower, hand-fired return tubular boilers, run alternately in batteries of two each; two Corliss-type, noncondensing engines, direct-connected to two 3-phase 60-cycle 2,200-volt generators, one 260 kilovolt amperes and one 450 kilovolt amperes; and two steam-driven air compressors, one duplex with a capacity of 650 cubic feet of free air per minute, and one simple 150-cubic-foot machine. The hoist is electrically driven, of double-drum type, one drum keyed to the shaft and one engaged by a clutch. The drums are 6 feet in diameter and have a hoisting speed of 600 feet per minute. The hoist is driven by a 150-horsepower 2,200-volt alternating current motor and is equipped with the Lilly automatic safety control. The maximum hoisting capacity is about 10 skips per hour from the 350-foot level.

DAISY VEIN

The Daisy vein, about 600 feet northwest of and nearly parallel to the Rosiclare vein, is opened by a shaft of the Rosiclare Lead & Fluorspar Mining Co., about 1 mile north of the plant shaft.

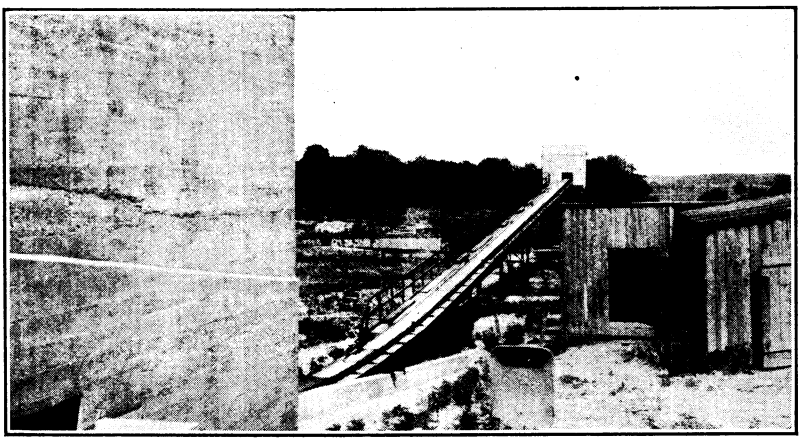

FIGURE 25.—Car-loading conveyor, Hillside Fluor Spar Mines, near Rosiclare, Ill.

The Daisy vein ranges from less than 1 inch to 32 feet in width; in the upper workings its average width is perhaps 15 feet for about 400 feet. It has an average dip of about 70° west. At the surface and to a depth of about 270 feet the hanging wall is a somewhat fractured shale, but below this level the wall is limestone. From the surface down the footwall is solid limestone. The old shaft by which the mine was formerly opened caved, and a new shaft was sunk in the footwall, the surface section being concreted. The first level, at which a crosscut was driven to the vein was 200 feet below the surface.

The ore in the Daisy mine is of excellent quality but is badly broken up and mixed with mud, particularly on the upper levels. The ore has been extracted by a system of square-set mining and the ore body has been worked down to the 400-foot level, although considerable recoverable ore still remains above that level.

When the mine was examined in June, 1922, the new shaft had not been completed and no ore was being mined. It was planned to install an electric hoist and electric pumps, so that no steam power plant would be needed.

BLUE DIGGINGS VEIN AND NEAR-BY PROSPECTS

The Fairview Fluorspar & Lead Co. formerly operated a mine on the Blue Diggings vein, which approximately parallels the Rosiclare vein a few hundred yards to the west. This mine, which is practically worked out and is not now operated, yielded about 225,000 tons of high-grade fluorspar during its 10 years of life (1910–1920). The ore body was about 1,000 feet long, averaged 14 feet in width on the 200-foot level, and was bottomed at the 500-foot level in ore about 2 feet wide and 100 feet long.

About 400 feet west of the Blue Diggings shaft the Golconda fault, previously not supposed to be mineralized, was located by churn drilling early in 1922. A prospect shaft sunk here cut the fault (in the Rosiclare sandstone) near the surface. At 50 feet depth the fault (still in sandstone) was mineralized to a small extent with pyrite, galena, and fluorspar. At a depth of 208 feet the limestone was entered, and at the 220-foot level a crosscut 40 feet long was driven to the vein. At this point the vein and walls were somewhat shattered, but the vein was about 16 feet wide with about 7 feet of excellent fluorspar. Drifts were started along the vein in both directions. The ground was so hard to hold that it was necessary to resort to square-set timbering.

In February, 1923, it was considered to have emerged from the prospect stage and was given the name of the "Argo mine." Continuance of work on the 220-foot level and sinking an exploratory winze in the vein below that level were planned. At the same time the old Blue Diggings shaft was to be dewatered and reequipped and a crosscut made to the Argo vein on the 500-foot level. This crosscut would be about 400 feet long. The Argo mine promises to be an important producer.

BEDDED OR "BLANKET" AND MISCELLANEOUS DEPOSITS

Spar Mountain Mining Co. (now Benyon Fluorspar Co.)—The properties of the Spar Mountain Mining Co. (now Benyon Fluorspar Co.) are northeast of the town of Cave in Rock, Hardin County, Ill., and about 4½ or 5 miles from it by road. The ore body consists of nearly flat-lying beds from a few inches to 9 feet or more thick. In some places the beds are practically horizontal and in others they dip as much as 5° or even more.

The hanging wall or roof is essentially sandstone but between the ore and the roof is a variable thickness (from a few inches to several feet) of rather soft, friable shale. The sandstone roof is usually strong and requires very little timbering, but the shale is ordinarily so weak and broken that it must be removed. The footwall or floor is limestone. The outcrop of the fluorspar bed has been traced about halfway around the top of the hill in which the deposits are located, and probably could be traced completely around the hill. The maximum size of the whole ore body is therefore limited to the cross-sectioned area of the hill in the plane of the vein.

Development.—The fluorspar bed has been opened in several places along the southern and eastern outcrops, where the ore has been found to be thickest. The bed has been worked where the ore is as thin as 2 feet, but only for short distances, and in workings subordinate to main workings where the bed is much thicker. The average thickness of the ore has been about 5 to 5½ feet in the best parts of the bed which have been worked. The thicker parts of the bed are of irregular size and extent, but the maximum dimensions of the largest body developed are about 600 by 150 by 5 to 5½ feet.

Mining method.—The mining method outlined below is followed as closely as local conditions permit. A main drift is cut in the vein from the outcrop straight back to the property line, and the grade maintained as uniformly as possible by cutting the floor or the roof where necessary. Some timbering is necessary at the portal, but in the solid few or no drift timbers are used. Rooms spaced so that those on one side of the drift are opposite rooms on the other side, are then cut 15 feet square on 25-foot centers, leaving 10-foot by 15-foot pillars to protect the drift. Stoping is then started beyond the pillars on each side, taking all the ore as it is encountered; thus the working face is a single long irregular wall, being continually extended away from the main drift. This method resembles longwall coal mining, but no back filling is used. The stoping is continued in all directions from the main drift as far as the ore is of minable thickness (2 feet being the minimum). Waste and very thin parts of the vein are left standing as pillars.

Timbering.—Where the roof is weak vertical timber props 6 inches to 1 foot or more in diameter are set. Ordinarily very few timbers are required. In the largest mine not more than one timber is probably used to each 400 square feet of roof surface.

Drilling and blasting.—Drilling is done with light hammer drills (of the jack-hammer type) mounted on arms on light steel columns. Columns as short as 2 feet are used in the thinner parts of the bed. After the ore is drilled and shot down it is passed back to the drift (in the thinner parts of the bed) by hand shoveling. Sometimes the ore is rehandled four or five times before it is finally loaded into the car. When the ore is high enough to permit, temporary spurs from the main track may be extended out close to the working faces.

Haulage.—The ore is loaded into steel cars holding about 1 ton and trammed by hand or by mules to the portal of the drift. For short distances, where the track grade against the loaded cars is too steep for hand or mule tramming, small compressed-air hoists mounted on columns are used. Outside the mine portals the ore is dumped into storage bins, from which it is drawn off and hauled in wagons to the mill at Cave in Rock.

Ventilation.—Ventilation has been obtained by a few air shafts to the surface and is good part of the year; during the summer months, it was said, natural ventilation had not been entirely adequate. It was planned to cut more air shafts, and if these did not provide enough ventilation, an artificial system was contemplated. Efficient artificial ventilation would be rather difficult because large open stopes are left in the present method of mining.

Transportation.—As roads between the mine and the mill are very poor, it is almost impossible to haul ore during the winter and early spring. Only about a six-month hauling season can ordinarily be relied upon, hence most mining and hauling is done in the summer and stocks are accumulated at the mill for treatment during the winter. In June, 1922, about 60 tons of crude ore per day were being produced from all openings; about 20 men were working underground and 10 men on the surface.

The company has produced gravel-grade fluorspar chiefly, but has also produced a small tonnage of acid and enamel grade. This company stands third among the Illinois properties in volume of past production.

Ohio Valley Fluorspar Co.—The properties of the Ohio Valley Fluorspar Co. adjoin those of the Benyon Fluorspar Co. on their southern and eastern boundaries. The fluorspar occurs chiefly as detached crystals, crystal fragments, and pieces of banded ore, embedded in a very sticky brown clay. This ore was evidently derived from the weathering down in place of the outcrop of part of the bedded deposit like that now worked by the Spar Mountain Co. as just described. The ore deposit is of very irregular thickness. In places fluorspar is absent and in other places it is 15 feet thick (evidently a local residual concentration). Perhaps the most noteworthy feature of this deposit is the unusual proportion of beautifully crystallized fluorspar which could be recovered as acid or enamel grade spar.

This deposit has been worked by several short irregular drifts and open cuts. The crude ore was hauled 5 miles in wagons to the river at Cave in Rock, where it was washed in a log washer, loaded into river barges by wheelbarrow, towed up the river to Shawneetown, and there transferred to railroad cars. In June, 1922, plans were under way for the erection of a small washing, jigging, and grinding mill at the mine.

Illinois Fluorspar & Lead Co. (Cave in Rock and Lead Hill mines).—The Illinois Fluorspar & Lead Co. was in the process of formation in June, 1922, and as an organization had not worked its properties, which comprise the old Cave in Rock and Lead Hill mines. These mines, located west of the Spar Mountain mines and about 5 to 6 miles by haulage road from Cave in Rock, have been worked intermittently by different parties for many years.

The underground workings were not accessible but more or less caved open-cut workings indicated that part of the ore was of the bedded type, like that at Spar Mountain, and part like that worked by the Ohio Valley Fluorspar Co. Stock piles at the mines also showed that a large proportion of the fluorspar could be recovered as acid and enamel grades and it is probable that a small amount of optical fluorspar could be obtained.

No milling equipment had been installed, but the company was planning to erect a mill at a barge landing on the river about 3 miles directly south of the Lead Hill mine and west of Cave in Rock.

Chicago Fluorspar Co. (Stewart mine).—The Stewart mine of the Chicago Fluorspar Co. is situated in Hardin County, Ill., about 5 miles in a direct line northwest of Rosiclare, at the terminus of a 3½-mile spur from the Golconda branch of the Illinois Central Railroad. The ore deposit consists of a nearly vertical vein with a strike of about N. 25° E. Only part of the vein contains fluorspar, but in the workable parts a fluorspar width up to 7 feet has been found.

The deposit is opened by a three-compartment timbered shaft cut about 8 by 16 feet in the hanging wall, with two hoisting compartments and a ladderway sunk about 300 feet. The vein at the bottom of the shaft was stated to consist of solid calcite containing no fluorspar. The only level which has been worked is about 188 feet below the surface. At this level drifts on the vein have been run about 500 feet from the shaft in each direction. Most of the ore so far produced has come from development openings and from taking up the bottom of the drifts as breast stopes. Much of the ore is very soft, gravelly, and mixed with mud, shale, and limonite nodules. Mud runs have given much trouble in the past. The walls on the 188-foot level are of solid limestone.

Milling.—The ore is trammed by hand to the shaft, dumped over, and sledged through a grizzly with 8-inch-square openings. The ore drops to a crosscut on the 245-foot level.

The ore is hoisted to the surface in buckets holding about 1,000 pounds, and dumped over a grizzly with 4½ by 5 inch openings, where the coarse waste is discarded and the coarse ore sledged through.

This mill has a rated capacity of 6 to 12 tons of crude ore per hour and makes about a 50 per cent recovery. The maximum production of fluorspar concentrates in the past has been 40 tons in an eight-hour day. The chief mill product has been gravel-grade spar, but some optical spar is recovered from the picking belt.

The power plant consists of a 150-horsepower Heine-type hand-fired water-tube boiler; a single-stage steam-driven air compressor with a capacity of 213 cubic feet of free air per minute; a small two-cylinder, single-drum geared hoist; and a 60-horsepower slide-valve mill engine.

Other Illinois mines.—In addition to the mines described there are a number of small mines which have produced a few hundred or at most a few thousand tons of fluorspar each during their entire past periods of production. These mines have not been important enough in the past and development has not progressed far enough to warrant description.

COSTS OF PRODUCTION IN ILLINOIS

Generalized estimates of the cost of production in the Illinois field can not be given due to the varying size and nature of the different mines. Probably no two companies have even approximately the same costs or the same distribution of costs. Although much detailed information on this subject was obtained it can not be used without revealing confidential statistics.

In general it may be stated that before the World War production costs and sales prices were nearly equal. Price cutting and competition from imported spar allowed the principal producers little or no profit. During the war the demand was very high and prices for prompt delivery of gravel spar rose from about $6.50 to as much as $40 or $45 per ton, production increased tremendously, and all the most available ore was removed as rapidly as possible. At the same time production costs increased very greatly. Under these unusual conditions some companies made fair profits, although much of the tonnage was contracted for at old prices and the producers did not obtain full benefit of the highest price levels.

Immediately after the war the operators faced permanently increased costs, due to much greater depth of mining and higher costs of labor and supplies, and abrupt decline in demand, with potential keen competition from imported spar. Prices were forced down from the war-time prices of $40 and over to $16 or $17.50 per ton for gravel spar. Although these prices were much higher than those before the war, they did not enable even large producers to operate at a profit because their expenses were so high. After the passage of the tariff act of 1922, which placed a $5.50 import duty on fluorspar, the producers could raise their prices about $4 per ton, a margin which allowed a small profit.

Except for a short period during the war Illinois producers have made little net profit in the past. It is also evident that production costs will not decrease, but must increase. If our fluorspar resources are to be developed to their fullest extent, prices must be high enough to pay for the increased costs and allow a margin for prospecting, development, and the working of narrow veins in depth.

WESTERN KENTUCKY

The topography of the western Kentucky fluorspar district resembles that of the Illinois district, with a few important differences. Most fluorspar deposits are far enough from the Ohio River and so high above the general ground-water level that they are not flooded as readily, and pumping problems have not been unusually vital. Furthermore, weathering has been much more pronounced, or the products of weathering have not been so extensively removed by erosion, so that solid-vein outcrops are not common. General conditions here have already been described under "Prospecting."

With the exception of the comparatively few mines 200 to 500 feet deep, most fluorspar mining in this district has consisted of small open cuts or shallow, unsystematic workings in residual deposits of disintegrated gravel fluorspar. Undoubtedly much of the past Kentucky fluorspar production has come from workings less than 100 feet or at the most 150 feet deep.

The following fluorspar mines in western Kentucky were examined by the writer or gave him adequate information in the summer of 1922.

Kentucky fluorspar mines

Operator [1]	Name of mine [2]	Location [3]
Kentucky Fluorspar Co	Mary Belle	Columbia fault, 5 miles west of Marion, Ky.
Do	Ada Florence	Columbia fault, 6 miles west of Marion, Ky.
Do	Beard	Near La Rue fault, 8 miles north of Marion, Ky.
Do	Susie Beeler	Marion fault, 5 miles west of Crayne, Ky.
Do	Leander White	Do.
Do	Dixie No. 2	Marion fault, in Marion, Ky.
Do	Tabb (Hoosier, west Kentucky).	Tabb fault, 2 miles southwest of Mexico, Ky.
Do	Wheatcroft	Tabb fault, 2½ miles southwest of Mexico, Ky.
Do	Pogue	Tabb fault, 3 miles southwest of Mexico, Ky.
Do	Yandell	Yandell, Tabb, and Matthews faults, 4 miles southwest of Mexico, Ky.
Do	Corn	Corn fault, 9 miles west of Marion, Ky.
Do	Brown	Hodge fault, 7 miles west of Mexico, Ky.
Fairview Fluorspar & Lead Co.	Franklin	Columbia fault, 6 miles west of Mexico, Ky.
Aluminum Ore Co	Haffaw	Tabb fault, railroad spur, 1 mile southwest of Mexico, Ky.
Keystone Fluorspar & Lead Co.	Blue and Marble (Moore & Davis, Keystone).	Tabb fault, three-fourths mile southwest of Mexico, Ky.
Guggenheim Mining Co	Tabor and Asbridge (Blue Grass).	Tabb fault, 3 miles southwest of Mexico, Ky.
Davis Mining Co	Matthews	Tabb fault, 4 miles southwest of Mexico, Ky.
United Mining Co	Bonanza	Lola fault 17 miles west of Marion, Ky. (near Lola, Ky.).
Myers & Crider	John Hodge	Hodge fault, 5 miles west of Mexico, Ky.
Do	Nancy Hanks	Evening Star fault, 12 miles west of Mexico, Ky.
Eagle Fluorspar Co	Cullen	Do
Do	Liberty Bond (Watson).	Stevens fault, 10 miles southwest of Marion, Ky.
Pope Mining Co	Pope	Do.
American Fluorspar Co	Lovelace	Hodge fault, 6½ miles west of Mexico, Ky.
Do	Holly	Hodge fault, 9 miles west of Marion, Ky.
Big Fair Fluorspar & Ore Co	Big Four	La Rue and Glendale faults, 9 miles west of Marion, Ky.
Superior Fluorspar Co	Keystone	Columbia fault, 5 miles west of Marion, Ky.
Do	Commodore	Columbia fault, 8 miles northwest of Marion, Ky.
North American Fluorspar & Lead Corporation.	Klondyke	Pittsburg fault, about 6½ miles northeast of Smithland, Ky.[4]
Do	Royal	Latrobe fault, about 3½ miles north of Smithland, Ky.[4]
United States Fluorspar Co	K-K	La Rue fault, west of Marion, Ky.
Crystal Fluorspar Mining Co	Crystal	Perigen fault, 9½ miles west of Marion, Ky.

[1] Operating owner or lessee.
[2] Former or subordinate names in parentheses.
[3] Fault, shipping point, and haulage distance by nearest route.
[4] Ship via barge on Cumberland River.

Several other mines have been rather important in the past, but now are idle and are reported to be worked out. Some other small mines and prospects have probably been as important as some of those mentioned, but now are either idle or very small producers, or it was impossible to obtain definite information regarding them. Many such small mines are opened and worked intermittently, but have little permanent effect upon the fluorspar industry. The following descriptions of individual properties made no attempt to cover all mines now in operation. By far the most important deposits from the standpoint of past, present, and probable future production are those on or near the Tabb vein system, from Mexico, Ky., west to the Yandell mine, a distance of about 3½ miles; the deposits on or near the Columbia vein system, from a little north of the Mary Belle mine to perhaps the Keystone mine, a distance of about 3 miles, probably rank second. Other deposits of moderate size are widely scattered over many major and minor fault systems, chiefly in Crittenden County. Many of these smaller mines are fairly important producers, but they have not as yet established important reserves; in fact, the ore has usually been removed as fast as it has been uncovered.

TABB VEIN SYSTEM

The Tabb system probably comprises a number of closely spaced, approximately parallel, and nearly vertical faults rather than a single fault. In some places only one vein has been discovered, but in others as many as three parallel veins are found. Sometimes several parallel veins all contain fluorspar, but more often one or more of the veins is probably barren and the fluorspar mineralization alternates back and forth from one vein to another.

As is common in the western Kentucky district, the surface of the vein usually consists of a widened and enriched zone of residual disintegrated gravel fluorspar, mixed with clay and sand, of variable depth, often 100 to 200 feet. In this zone the ore width is also extremely variable, ranging from a mere trace to over 60 feet for short distances. In the deeper and solid parts of the deposits the width of fluorspar is probably somewhat narrower than in the surface zone, but few data on this subject are available. At the Blue and Marble mine on the 200-foot level, an average width of 7 feet of solid fluorspar between solid limestone walls was observed for at least 325 feet.

Haffaw mine.—The Haffaw mine, owned and operated in 1922 by the Aluminum Ore Co., but now by the Franklin Fluorspar Co., consists of about 1,000 feet of the Tabb vein about 1 mile southwest of the railway station at Mexico, Ky. A spur from the Illinois Central Railroad has been constructed to the property.

Shafts.—The mine has been opened at several places by vertical shafts, but most of them were in the vein and have caved. The present working shaft is sunk on the footwall side about 140 feet south of the vein at the 200-foot level. The shaft has 3 compartments, 2 hoistways, and 1 ladderway, each 4 feet by 5 feet 4 inches in the clear, and is sunk to a depth of about 300 feet.

Mining.—Most mining has been above the 200-foot level, where the vein and the walls are so soft and disintegrated that hard-rock methods could not be used. In this zone close timbering is necessary; even then keeping workings open is difficult. When visited the mine was flooded and the underground workings could not be inspected, but mine maps indicate that most of the ore has been extracted unsystematically, particularly in the uppermost workings. The ore is hoisted in buckets of about 1,000 pounds capacity, and trammed to the mill.

Milling.—The milling problem differs somewhat here, because the company desires to make a high-grade product (95 or 96 per cent CaF_2) for its own use and not for sale. Making an 85 per cent gravel-grade spar product by milling is comparatively easy, but making a 95 per cent product without undue losses in tailings is much more difficult. All mill machinery is electrically driven. An adequate steam-electric power plant supplies power for the mine and mill.

Blue and Marble mine.—The Blue and Marble mine, owned and operated by the Keystone Fluorspar & Lead Co., contains about 1,800 feet of the Tabb vein and adjoins the southwest border of the Haffaw property.

Shafts.—The mine is opened by several shafts sunk on the vein. These shafts are all small (4 by 6 feet and 3½ by 6½ feet) and the deepest develop the vein to a depth of only 200 feet. Most ore recovered in the past has come from above the 150-foot level. Originally most of the shafts were worked as separate mines, but in June, 1922, drifts were being advanced to connect all the deeper shafts on the 200-foot level.

Mining.—Mining on this property in the past was very unsystematic, but the present operators have begun a systematic development program. After the shafts are all connected underground the operators will either deepen No. 3 shaft (near the center of the property and close to the mill) to 300 feet and use it as the main shaft, or sink a new and larger shaft in the footwall near No. 3 shaft. The new ground opened up on the lower levels will be mined out by shrinkage stoping as at Fairview and Rosiclare.

In June, 1922, most of the ore being mined came from the No. 1 shaft near the eastern boundary of the property. On the 200-foot level the vein was of solid white fluorspar between firm, solid walls of limestone. For 325 feet or more the vein averaged at least 7 feet in width. The fluorspar was apparently very low in silica and calcite but contained considerable galena. The ore was drawn off from shrinkage stopes into one-half-ton buckets, trammed by hand to the shaft on small narrow-gauge trucks. At the shaft the buckets were hoisted to the surface and dumped into a small bin, from which 1½-ton cars were loaded and hauled over a long trestle to the mill.

Milling.—This mill had a capacity of about 60 tons of crude ore per 8-hour shift, and was run by a 45-horsepower steam engine. A 150-horsepower fire-tube boiler supplied steam for the mill engine and for a 350-cubic foot single-stage air compressor. Later in 1922 it was reported that the mill had been completely overhauled and changes made which greatly increased the operating efficiency. The finished concentrates are hauled by wagon to a railroad siding near Mexico, about three-fourths mile.

Tabb mine.—The Tabb mine (also known as the Hoosier or the West Kentucky) was operated by the Kentucky Fluorspar Co. when visited and consists of about three-fourths mile of the Tabb vein system; it adjoins the western boundary of the Blue and Marble property. The vein has been worked at irregular intervals for many years in over a dozen small shafts, but the deepest mining has probably not been over 150 feet below the surface.

When the mine was examined in June, 1922, only a little shallow contract mining was being done at one or two points.

Other mines on the Tabb vein.—West of the Tabb mine on the Tabb vein are the Wheatcroft, Pogue, Tabor, Asbridge, Matthews, and Yandell mines. In June, 1922, very little work was being done at any but the Yandell. Although these properties have produced considerable ore in the past and are important potential producers, they have been worked so unsystematically on such a small scale that development has had little permanent value. Nearly all the ore has come from the disintegrated surface zone of residual gravel fluorspar. The richest parts of this zone have been mined out, as discovered, by shallow open cuts and small temporary shafts. The workings caved soon afterward and thus made the problem of later mining more difficult.

A small mill (not examined) has been in operation on the Tabor property, but at the other mines no milling has been done or the mine-run ore has been washed in simple log washers. The washed product has been hauled to the railroad siding near Mexico, Ky., and shipped directly to consumers or to fluorspar mills at Marion, Ky., for further milling.

COLUMBIA VEIN SYSTEM

The Columbia fault, 5 or 6 miles west of Marion, Ky., at its nearest point, strikes about N. 20° E. and dips from 78° west to vertical. Where the main part of the fault itself is mineralized the ore seems to consist primarily of zinc sulphide (sphalerite) with little fluorspar, as in the old Columbia mine.

Branching from the main fault at a slight angle of deviation are numerous parallel minor faults on the east side of the main vein. Most operators agree that the principal fluorspar mineralization, in several mines at least, occurs in these minor divergent faults close to the main vein. For example, the Mary Belle mine is not considered to be on the main fault.

Although the Columbia fault has been traced for many miles it has been mined for only about 3 miles, from near Crittenden Springs southwest to the Keystone mine. In this section only four mines are now in operation or equipped for operation, the Mary Belle, the Franklin, the Ada Florence, and the Keystone.

Mary Belle mine.—This property, containing about 2,200 feet of the Columbia vein system, is about 5 miles west of Marion, Ky., and before the general business depression in 1921 was the principal producing property of the Kentucky Fluorspar Co. It is developed by a main shaft and several minor shafts.

The main shaft is in two compartments (one hoistway and one manway); it is about 5 by 10 feet in the clear and is sunk in the footwall about 350 feet. From 150 feet below the surface, levels are opened every 50 feet vertically. The 200-foot level is the longest so far opened; it extends for a total length of about 1,300 feet along the vein.

On the upper levels the ore was extracted in open, overhand stopes, and stulls used for supporting the walls and keeping the miners up to the working face. On the lower levels an attempt has been made to let the ore accumulate in the stopes and thus develop the method of shrinkage stoping used at the Fairview and Rosiclare mines. As needs for ore have been pressing, however, this system has not as yet been completely adopted. The ore is hauled in wagons to the company's mill at Marion for concentration. In June, 1922, this mine was not in operation and could not be examined.

Franklin mine.—This property, owned by the Fairview Fluorspar & Lead Co. (now Franklin Fluorspar Co.), is on the Columbia vein system south of the Mary Belle mine and about 6 miles west of Marion, Ky., by road.

The mine is opened by a main shaft 4 by 8 feet in the clear, sunk in the footwall 30 feet from the vein at the surface to a total depth of about 450 feet. A new shaft in the footwall, 6 by 16 feet in the clear, about 80 feet from the vein on the 150-foot level, has been sunk 200 feet. Levels have been opened at 150, 300, and 380 feet vertically below the surface. The ore body is less than 1 foot to 14 feet wide, averaging about 6 feet. It is about 325 feet long on the 150-foot level and on the 300-foot level is about 250 feet long. The average width has not changed much with depth. Although the developed ore body had a maximum length of about 325 feet, the property contains about 2,600 feet of the vein outcrop, and recent prospecting has indicated good ore elsewhere on the property.

The ore is mined by a modification of the standard shrinkage-stope method. In places the walls are weak and much timbering is necessary to hold the ground. The underground and surface equipment is of about the same general type as that used in the Fairview mines, but less extensive. The ore from the mine is hoisted in skips and dumped into a crude-ore bin at the head of the mill. This mill has a capacity of about 10 tons of crude ore per hour and makes about an 80 per cent recovery, with a consumption of about 60 horsepower. About 95 per cent of the finished product is gravel-grade spar, and not over 5 per cent is of acid grade. A small amount of lead is also recovered. The finished product is hauled to the railroad at Marion for shipment.

Other mines on the Columbia vein.—The only other mines on the Columbia vein that have been operated in recent years are the Ada Florence and the Keystone, but neither was producing ore in June, 1922.

The Ada Florence mine, belonging to the Kentucky Fluorspar Co. (now the Franklin Fluorspar Co.), is still in the prospect stage. Several shafts have been sunk, the deepest being about 200 feet, but little ore has been developed.

The Keystone mine has been worked at various times from a number of small more or less temporary shafts, but little adequate permanent development is being done. When examined the mine was being pumped out preparatory to being reopened.

OTHER WESTERN KENTUCKY MINES

Many other mines in this district have been relatively important producers in the past and will doubtless contribute to future production; but few, if any, of these mines are as well equipped as those noted above. Nearly always contractors or minor lessees have worked these properties spasmodically by open cuts or shallow underground workings with temporary shafts; therefore, many of these mines have been worked, abandoned, and reworked several times, leaving the surface so badly cut up and caved that much ore has probably been permanently lost. Usually no records have been kept and no maps made, so that reworking such mines is difficult, expensive, and often dangerous.

The ore has ordinarily been extracted by very simple hand methods, with a minimum of machinery, and that small and temporary; and it has generally been at least partly concentrated by log washing on the property and then hauled to the nearest railroad shipping point, usually Marion or Mexico. At Marion two mills are now in operation (there have been more) where ore may be further prepared for market. One of these is a custom mill, which either buys the crude ore outright or mills it at a flat rate per ton.

Inasmuch as little definite information is available regarding the possibilities of these properties, detailed descriptions will not be given.

OTHER MILLS

In addition to the two mills already described under "Milling" and those named in this Kentucky section, there is a smaller mill operated by the Eagle Fluorspar Co. at the Liberty Bond mine, about 8 miles southwest of Marion (a 10-mile haul), near New Salem Church. It has a rated capacity of 4 tons of crude ore per hour, and power is supplied by a 100-horsepower Corliss-type steam engine.

The Kentucky Fluor Spar Co. operates a custom mill beside the railroad at Marion, Ky., near that of the Franklin Fluorspar Co. This mill has a capacity of about 2½ tons of crude ore per hour. Milling losses are very low and recoveries consequently are high, for the crude ore is very high-grade residual gravel. The mill product is acid-grade spar in the form of concentrated gravel. The lead content of the ore is low, probably averaging less than 0.5 per cent. The mill is run by a 25-horsepower oil engine.

ROYALTIES IN WESTERN KENTUCKY

Some years before the war the royalty paid for fluorspar on leased property averaged about 25 cents per net ton of product shipped, but just before the war had increased to about 50 cents and during the war rose to $1 and even to $1.50. Then the basis was sometimes changed to a certain percentage of the net selling price per ton f. o. b. cars. At first this was about 10 per cent, but royalties as high as 15 and even 20 per cent were sometimes paid for short leases. Leases with these higher royalties often included an option to purchase the properties. The highest royalty noted was 20 per cent of the net selling price, plus a guaranteed minimum royalty (amount not ascertained) per month. This lease was made in 1921 and was to run 15 years. A royalty as high as 20 per cent is seldom justified under normal conditions.

PRODUCTION COSTS

From 1902 to 1906, when the average selling price was about $6.50 per ton, the net return to one important company ranged from a loss of 46 cents per net ton to a profit of $2.27, and averaged about 75 cents per ton profit, exclusive of any charges for depletion or depreciation. When prices rose to unprecedented levels during the World War, some individual producers made large profits, which were lost in unprofitable expansion.

Haulage costs from mine to railroad normally average a little less than 25 cents per ton-mile for distances up to about 5 miles. For longer hauls the cost per ton-mile is somewhat less, so that an 8-mile haul may be made for $1.75 and a 12-mile haul for $2.50 per net ton. During the war haulage costs increased greatly but they are now about normal. Nearly all hauling is done in two or four horse wagons, on contract.

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Much mining is done on contract; sometimes the price includes hauling to a railroad or mill and sometimes only the actual extraction from the ground and log washing when necessary. In June, 1922, one contractor operating a mine about 8 miles from the railroad received $7 per net ton delivered to the railroad or mill stockyard. This price, of course, included no charges for interest, depletion, or depreciation, company overhead, taxes, remilling, and loading on cars. Another contractor, 4 miles from the railroad, received $6.50 per ton for fluorspar delivered at the railroad stockyard. At such low prices a contractor can not undertake permanent development.

On the whole, costs in the western Kentucky field have been lower than in southern Illinois, but these low costs have been attained by gutting the surface zones of accessible high-grade ore without planning for future systematic mining. Some ore will doubtless continue to be recovered thus, but costs in this field will be much higher in the future, eventually closely approaching those at large mines in southern Illinois.

CENTRAL KENTUCKY DISTRICT

There are a number of veins of fluorspar associated with calcite and barite in limestone in several counties of central Kentucky near Lexington and Nicholasville. These deposits are mainly of interest for their content of barite and calcite, and only one vein—the Chinn—has been worked commercially for fluorspar; it has a general strike of N. 70° W., its dip is nearly vertical, and has been traced for several miles on both sides of the Kentucky River in Woodford and Mercer Counties. It has been opened chiefly within a distance of 1 mile north and south of Mundys Landing, which is about 15 miles south of west from Nicholasville.

The vein occupies a fault fissure, and its total width varies from 1½ to 5½ feet.[24] The filling is of the banded fissure type with at least 14 distinct alternating depositions of fluorspar, barite, and calcite. The fluorspar bands are one-half to 8 inches, rarely as much as 18 inches wide; the barite bands, usually less than 2 inches but locally up to 8 inches wide; the calcite from one-half to 14 inches and rarely up to 18 inches wide.

This vein has been mined for fluorspar at three places, the Twin Chimney, the Dean, and the Moore mines, controlled in 1922 by the Heyward Minerals Co. The properties were not visited, and the descriptions given were furnished through the kindness of J. M. Blayney, who, with several others, inspected the mines in July, 1922.

[24] See Fohs, F. J., "Barytes deposits of Kentucky": Kentucky Geol. Surv., 4th ser. vol. 1, pt. 1, pp. 483–484.

This information has been supplemented by a small amount of material from several other sources. These mines are in the limestone bluffs which rise abruptly from the Kentucky River to about 150 feet above low-water mark. The Kentucky River is narrow and crooked here, and flows in a general northwesterly direction. The Twin Chimney and Dean mines are on the southwest side of the river. The Moore mine is on the northeast side of the river; although it is in the limestone bluff forming the original bank of the river, a strip of bottom land about 500 feet wide now lies between the water when at normal height and the bluff.

All three mines have the same general character. Their dip is practically vertical and the strike approximately north and south. The walls are tight, hard limestone which stands well. The vein filling is calcite, fluorspar, and barite. The calcite and fluorspar seem to be in about equal proportions of approximately 45 per cent each, the balance being mostly barite. A very small amount of zinc sulphide was noted, but no lead. The calcite usually occurs on the sides of the vein and the fluorspar and barite in the middle. The barite always occurs in stringers and spots in the fluorspar and never in the calcite. All three minerals are fairly pure and the calcite and fluorspar break freely. The barite also tends to break fairly freely, but not so freely as the other two minerals. An occasional mud pocket was also noted.

The veins are of the fault-fissure type, and in the Moore mine the grooves in the wall indicated that movement was at an angle of about 60° from the vertical, but in the Twin Chimney and Dean mines the movement appeared to be horizontal. Both walls were apparently of the same kind of limestone, and the width of the vein varied from a tight pinch to 3½ feet, the average width being about 2 feet. The ore shoots are fairly uniform and the ore breaks freely from the inclosing walls.

Moore mine.—The Moore mine is about 500 feet from the water when the river is normal. The mine is opened by an adit tunnel some 20 feet above the bottom land between the water and the limestone bluff in which the mine is located and is slightly above high-water mark. The company owns about 1,500 feet on the strike of this vein, and the main adit tunnel is driven about 1,000 feet on the vein. The face now shows about 2 feet of ore. Several mud pockets were said to terminate in sink holes at the surface. The vein was never more than 3½ feet wide, and practically all of the ore had been stoped or gophered, for the first 850 feet, above the tunnel to the surface, which was said to be about 120 feet at the highest point. The last 150 feet, however, is in virgin ground, and a stope is being opened above the level at this point. It was planned to leave an arch here to save timbers, and raises will be put through from the drift to the stope at 30-foot intervals. A filled or shrinkage stope will be used here, and the ore will be drawn through the raises into cars on the level below. The average width of this stope is about 2 feet. The ore will contain about 45 per cent of calcium fluoride and approximately the same amount of calcite, with considerable barite. The drift was being driven and the stope operated on one shift each per day. Jack-hammer drills are used. The drift was driven on a very steep grade, reported to be an average of 3 per cent, and two men were required to pull an empty car back to the face. The ore is trammed to the mouth of the tunnel, where it is dumped into a small bin holding about 10 tons. From this bin it is drawn into 2-ton cars and hauled up the river by motor on a 24-inch-gauge track about 1,000 feet to the old Moore mill near the water's edge and dumped into a bin holding approximately 100 tons. From this bin it is again drawn into small cars on an inclined track and lowered to the river into barges holding 100 tons. These barges are towed by gasoline boat about 1¾ miles down the river to the mill on the river bank at the Twin Chimney mine. The ore is then shoveled out of the barges into a small car on an inclined track and hoisted by steam to the bin at the head of the mill. The Moore mine when visited was producing about 15 or 20 tons of mine-run ore a day.

Equipment.—The old Moore mill had one small locomotive-type boiler of about 60-horsepower capacity which supplied steam for a sharpener and also for a single-stage, steam-driven air compressor with a capacity of about 150 cubic feet of free air per minute. Coal for the boiler was hauled from barges on the river.

Twin Chimney mine.—The Twin Chimney mine is on a steep bluff rising from the water's edge. The entrance for the mine is now an old inclined adit which pierces the bluff on the strike of the vein slightly above the high-water mark and dips downward at an inclination of about 30° from the horizontal for about 70 feet, where it connects with the shaft. This shaft was sunk on the vein from a point higher on the bluff and is 90 feet deep where it connects with the inclined adit. The collar of this shaft is level with the bin at the head of the mill. A drift on the vein has been driven at this point for about 300 feet. The face showed a tight pinch. Some ore had been found in this drift for the first 40 feet beyond the shaft, and the entire remaining distance was driven in a tight pinch. The width of the ore throughout the 40 feet would probably average 2 feet, and practically all of this ore has been removed.

A crosscut had been driven in the west wall some 50 feet beyond the shaft for 25 or 30 feet, evidently with the hope of cutting ore in a parallel or diverging vein, but no ore was found as the crosscut was in tight solid limestone its entire length. Another crosscut was being driven at the face of the drift in the west wall, with the hope of cutting ore.

The air in this mine was bad and the drift was only a few feet above low-water mark of the river. Water was said to enter the mine very freely; the water level in the mine was the same as that in the river, and this drift was filled with water much of the year or whenever the river was high. The shaft was said to extend 40 feet below this level, but much difficulty had been experienced in sinking it on account of the flow of water. Work was therefore abandoned. The top of the hill was said to be about 150 feet above the level of this tunnel. No ore was being removed from this mine at the time of examination. One jack-hammer drill was being used in driving the crosscut.

The mill is located at the mine. A small compressor driven by steam from the mill boilers supplied air for the drill.

Dean mine.—The Dean mine is about three-fourths of a mile down the river from the Twin Chimney mine, and on the same side of the river. It is opened by an adit tunnel, probably 10 or 15 feet above high water, and the mouth of the tunnel is within 75 feet of the water's edge, measured on the incline. This adit tunnel had been driven about 400 feet on the vein. The width of the vein varied from a tight pinch to about 3 feet, with an average width of about 2 feet. The face of the drift showed about 18 inches of ore which seemed to be of the same character as that of the other two mines, although higher in barite.

Much gophering has been done above the main adit tunnel and at places has extended through to the surface, which was said to be about 120 feet above the tunnel level. All ore is trammed to the surface, dumped into a small bin, drawn into a small car, and hoisted up an incline to another small bin about 30 feet higher, into which it is dumped and conveyed down an incline into barges on the river. The ore is then towed to the Twin Chimney mill and handled like ore from the Moore mine. The Dean mine was producing about 5 to 15 tons of mine-run ore daily when inspected.

The Twin Chimney and Dean mines were stated to be on the same vein; outcrops could be traced on the surface for 1¼ miles; all this land is owned by the Heyward Minerals Co.

Equipment.—Equipment at this mine consisted of one small boiler, probably 30 horsepower, one steam-driven air compressor with a capacity of about 50 cubic-feet of free air per minute, which supplied air for one drill of the jack-hammer type; and one small hoisting engine.

Mill.—The mill is on the side of the steep bluff forming the river bank at the Twin Chimney mine, the lower part of the mill being level with and beside the inclined adit tunnel. Coal is hoisted for the boilers by an incline using a steam hoist.

When examined the mill was receiving about 20 to 25 tons of mine-run ore daily from the Moore and Dean mines. The recovery of shipping-grade ore is approximately 7 tons, or 30 per cent. A sample analyzed as follows: CaF_2, 76.68 per cent; SiO_2, 0.99 per cent; $CaCO_3$, 20 per cent; and $BaSO_4$, 2.10 per cent.

Only the spar from the two jigs was considered shipping grade; the fines, which were being put over a concentrating table, were being stored near the mill in a pile which contained about 200 tons. A sample of this pile analyzed as follows: CaF_2, 66.50 per cent; SiO_2, 1.92 per cent; $CaCO_3$, 30.23 per cent; and $BaSO_4$, 0.60 per cent.

The mill heads were reported to average 47 per cent CaF_2. Near the mill was a bin filled with small pieces of selected lump spar, probably amounting to 75 tons; the spar seemed of very good quality and would probably average 98 per cent calcium fluoride. No acid spar was being picked at the time of examination. The largest monthly production from this mill is said to have been about 400 tons in March, 1922.

The finished product from the mill is loaded into tramcars and lowered down an incline to the river into barges holding about 100 tons each, which are then towed down the river 78 miles to Frankfort, Ky., where the spar is shoveled into small cars, hoisted up an incline, and loaded into railroad cars.

When the property was examined about 35 men were employed in the mines at the mill and on the river. Wages were $2 to $3.50 per eight-hour shift.

CONCLUSIONS

From the size of the present known deposits in this district, their inaccessibility by railroad transportation, and the mixture of fluorspar with barite, the importance of this district as a future source of fluorspar is uncertain. Conditions would be somewhat improved, of course, if the problem of commercial separation of barite and fluorspar were successfully solved.

COLORADO

The principal fluorspar workings in Colorado are in Mineral County near Wagon Wheel Gap, in Jackson County near Northgate station, and the Jamestown district in Boulder County. The production of fluorspar for the State has been given.

WAGON WHEEL GAP

Wagon Wheel Gap mine.—This property, which was owned by the American Fluorspar Co. until July, 1924, and then bought by the Colorado Fuel & Iron Co., is on the east side of Goose Creek directly opposite the Mineral Hot Springs, and is 1¼ miles south of Wagon Wheel Cap station, the shipping point on the Denver & Rio Grande Railroad. The property was first opened about 20 years ago by prospectors who mistook the fluorite outcrop for amethyst quartz or an extension of the amethyst vein at Creede. In 1911 the mineral was recognized as fluorspar and mining operations commenced. By 1913 development had progressed so far that 5,000 tons of ore was shipped in that year. During 1914 the mine was idle. It was reopened in 1915 and was worked intermittently until March, 1921, when it was closed for at least a year.

Past production.—Total fluorspar shipments up to 1921 are reported to have been 40,000 to 45,000 tons. The maximum production was reached in 1918, when 13,892 tons were shipped. In 1920, 12,000 tons were shipped, including 2,800 tons of high-grade, hand-picked lump, analyzing approximately 96.93 per cent CaF_2, 2.64 SiO_2, and 0.27 $CaCO_3$, nearly all of which went to the Aluminum Ore Co. In 1921 the total shipment, 2,828 tons of fluxing gravel, was sent to Pueblo, Colo. No shipments were made in 1922, up to April, but the gravel stock pile at the mill has been sold.

Ore deposit.—The Colorado Geological Survey [25] says that the vein which is exposed on the steep hillside east of Goose Creek may be traced about 2,500 feet east, where it appears to end in a small gulch or flat. The vein lies entirely within an area of volcanic rocks, consisting of beds of rhyolite tuff with some quartz latite and andesite. On the hilltop and very near the vein reddish rhyolite and quartz latite predominate, but near the present workings on the hillside andesite is the predominant rock and forms the walls of the vein.

The strike of the vein varies from N. 80° E. to due east, and the dip is 70 to 80° south. The vein is of the fissure type and of very irregular width vertically and horizontally. In places its maximum width is about 25 feet, but in the main working the average is about 6 or 8 feet. There are numerous branches, offshoots of the main vein, in the upper workings. On the north side of the hill, paralleling the vein, numerous fluorspar bowlders covered with wash have been found. At the extreme east end of the property the vein has the same strike and dip and near the point where it disappears is about 2 to 2½ feet wide. The vein filling is fluorspar, barite, fragments of country rock, and gouge in varying proportions. The wall

[25] Aurand, H. A., Fluorspar deposits of Colorado: Colorado Geol. Survey Bull. 18, 1920, 94 pp.

rock is much altered, leaving the walls weak and necessitating extensive timbering.

Development.—The mine is developed by an open cut on the outcrop near the apex of the hill. About 150 feet vertically below this point a drift has been driven on the vein for about 1,300 feet. The average width of the ore in this drift is about 10 feet. At the face the tunnel is in a mixture of clay and gravel fluorspar, the latter amounting to about 40 per cent. About 150 feet vertically below this end and 450 to 500 feet above the valley of Goose Creek to the west a tunnel was started in the country rock north of the outcrop, and was driven at an angle intersecting the vein 700 to 800 feet from its portal, then continued into the hill on the vein about 1,100 feet farther. This level was connected with the level above by a raise several hundred feet east of the point where the tunnel intersected the vein.

The vein is of very irregular width, varying from 10 inches to 25 feet and averaging about 8 feet. The vein in the face of this drift is about 12 feet wide and the filling is about 50 per cent fluorspar mixed with andesite breccia and soft gouge. The fluorspar in this mine varies from gravel to large solid blocks of massive spar. At places the vein filling was practically all fluorspar, sometimes a body was 25 feet wide. Practically all of the spar is nearly white, and it is difficult to distinguish barite from fluorspar in the mine.

A tunnel has also been started in the country rock north of the vein about 100 feet above the creek level and level with the top of the ore bin of the mill, and has been driven about 700 feet at an angle so that if continued on its present course it would intersect the vein about 1,000 feet from its portal. The present intention is not to cut the vein with this tunnel, but to parallel the vein about 25 feet north of it and remove the ore through crosscuts driven from the tunnel to the vein. About 40 feet below an old drift was driven on the vein for 400 to 600 feet, but it has caved and could not be entered.

Mining.—The method now in use for extracting the ore between levels is somewhat as follows: A section of ground 100 to 200 feet long is blocked out by raises at each end, generally to the level above. These end raises are then used for manways and timber is handled through them. The drifts are heavily timbered by drift sets, sometimes aided by cribs filled with waste to help carry the weight of the ore above. Chutes are installed back of the drift at about 25-foot centers and the space between the chutes tightly lagged. Back stopes are then put up for about 25 feet; here heavy stulls are placed from wall to wall and are lagged over, except at intervals where openings are left through which the ore from above (which usually caves badly) is drawn. Grizzlies with 6-inch openings are set here;

the fines pass and the bowlders are sledged through. The ore is then drawn through the lower chutes into 1-ton steel cars in the drifts, horse-trammed to the surface, and dumped into a chute leading to a sorting platform above a large ore bin holding 300 to 350 tons near the portal of the tunnel. The ore is trammed from this bin by a gravity aerial tramway about 1,500 feet down the hill to the mill. Figure 26 shows the bins at the upper end of the aerial tramway and indicates the topography.

As the walls are weak and the ore friable, large amounts of timber are used. Good quality spruce timber is plentiful, and a mill at the

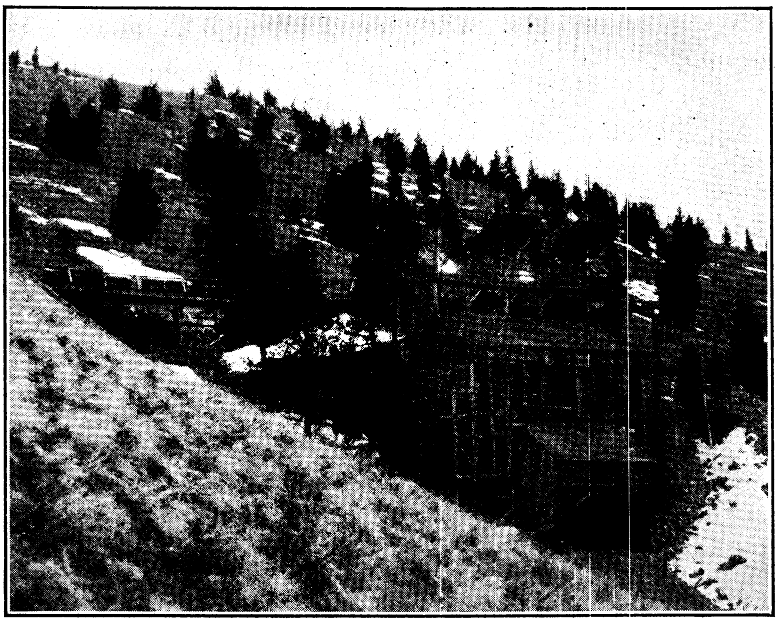

FIGURE 26.—Trestle, ore bins, and waste dump at main tunnel, American Fluorspar Mining Co., Wagon Wheel Gap, Colo.

foot of the mountain saws and frames timbers. An aerial tram from this sawmill to the upper tunnel is used only to convey timbers to the mine. In the early stages of underground mining square-sets were used in the stopes, but an effort is now being made to minimize the use of timber by the mining method described above.

Stopers and jack hammers are used for drilling, the air being supplied by a two-stage, steam-driven air compressor with a capacity of about 900 cubic feet per minute.

Transportation.—Concentrates from the mill are loaded into steel cars holding about 1,500 pounds each and hauled by horses in 12-car trains to the railroad, about 1¼ miles, where the cars are unloaded into standard-gauge railroad cars. Coal and other supplies are hauled on the return trip.

Future possibilities.—The working of this mine has been well planned and executed. As the walls of the vein are weak and irregular and the vein filling is treacherous, the present system of mining probably could not be improved upon. One cave, about 200 feet long, of vein material from the surface now extends to the lower workings. The caved ore, however, is being handled successfully and probably most of it can be recovered. It is only reasonable to assume that similar caves will occur on the vein. As the walls near the surface are weak and apt to slough into the vein, some ore may be lost. The timbering cost is high and must continue to increase. The character of the ore body apparently has not changed greatly with depth, although the vein is narrower in the lower than in the upper workings.

NORTH GATE

North Gate claims.—This property of the Colorado Fluorspar Corporation is in Jackson County, Colo., one-half mile northeast of King's ranch, 3 miles northwest of North Gate station on the Colorado, Wyoming & Eastern Railway. It is in the foothills of Medicine Bow Range near the northern edge of North Park and in the Medicine Bow Forest Reserve. The nearest post office is Cowdrey, 3.7 miles south of North Gate. North Gate is 80 miles southeast of Laramie, Wyo., the junction of the Colorado, Wyoming & Eastern Railway and the Union Pacific Railroad. The property consists of 7 claims; 4 are end to end and traverse the vein as the outcrop indicates, while the other 3 are near the first 4. In addition there is a tunnel site.

Prospectors for copper discovered the outcrop of the vein in 1900, but it was not identified as fluorspar until 1915, when claims were located by a prospector who later interested the present owners. A definite development system has been laid out.

Ore deposit.—The deposit extends along the side of a long, low hill which rises 400 to 500 feet above the valley floor at the railroad. The elevation at King's ranch is 8,032 feet, 50 to 75 feet above the railroad at North Gate. The hill in which the deposit occurs consists principally of rather coarse-grained pink granite intruded by numerous igneous dikes. Large pieces of feldspar and quartz show that pegmatite is present. Hard, glassy vein quartz was noted about 100 feet west of the main fluorspar vein.

The strike of the vein is approximately north and south and the dip practically vertical. The south end is about one-half mile west of the nearest point on the railroad, but across Pinkham Creek Canyon. The width of the deposit has not been accurately determined because identification of the walls is difficult due to alteration of the granite. The outcrop could be traced from its extreme southern point along the side of the hill north to the main shaft and beyond, a distance of perhaps 2,000 feet, but snow covered the outcrop farther north, making examination impossible. The outcrop was said to have been traced for a total distance of about 4,500 feet. No limestone was found in this locality either in place or in wash, therefore the fluorspar was not formed by limestone replacement and its quantity is limited to the fissure filling. At the extreme south end of the visible outcrop the vein seems to be terminated by a fault, whose presence is substantiated by Government maps showing a large east and west fault at about this point and other faults near by. These maps also show limestone formations cut by faults in this vicinity.

Development.—The property is opened by two shafts and several open cuts and pits on the outcrop. A prospect shaft 4 by 6 feet has been sunk about 20 feet deep 1,200 to 1,500 feet north of the extreme end of the outcrop. No crosscutting or additional work was done at this point. Apparently the shaft was sunk on the easterly edge of the deposit, and the full width of the deposit has not been mined at this point, as the vein outcrops strongly a few feet west of the shaft. Although the work done here was limited, the ore in sight seemed of the same general character and quality as that at similar depths in the more extensive workings described later.

About 700 feet north of the prospect shaft just noted and 75 to 100 feet above its collar an open cut about 40 feet long, 8 to 10 feet wide, and with a face about 10 feet high at its north end was made on the deposit. This cut shows fluorspar throughout its face and sides in more or less vertical fractures in the granite, which is highly altered here. Fluorspar appeared to constitute about 30 per cent of the vein material; it was solid and crystalline, contained no apparent barite or calcite and but little intergrown silica, and occurred in stringers 6 to 18 inches wide in the altered and fissured granite. Neither foot nor hanging wall of the deposit was in evidence, nor was there any evidence of movement or displacement.

At the highest point on the outcrop—about 25 feet above the level of the cut just described and 50 to 75 feet north of it—a 4 by 7 foot shaft was sunk on the vein 70 feet deep. At the bottom of this shaft a crosscut was driven about an equal distance east and west, with a total length of about 20 feet. The fluorspar occurred here also in practically vertical but irregular fractures in the granite. The fluorspar filling in these fractures is 3 to 18 inches wide. Other fractures in the granite were filled with a granite breccia, fluorspar bowlders, and quartz bowlders embedded in highly decomposed granite or mud gangue. The fluorspar filling in the vertical cracks in the granite is banded and massive, but in the mud gangue it often assumes concentric forms. Some of the fluorspar in the mud gangue could be recovered by hand picking, but part of it is so finely divided that it could be recovered only by milling, if at all. However, most of the spar at this point is massive and occurs as slabs in the fractures, and most of it could be recovered by careful mining and hand picking. About one-third of the vein, as exposed by this crosscut, is fluorspar. A sample of the widest stringer of fluorspar analyzed 95.59 per cent CaF_2, 2.89 per cent SiO_2, and 0.54 per cent $CaCO_3$. The faces of the crosscut were brecciated and decomposed granite, and there is no positive evidence that further stringers of fluorspar would not be encountered if the crosscut was extended in either or both directions; that is to say, there is no evidence of either foot or hanging wall. In the shaft no proof of faulting movement or displacement was noted. The fluorspar here contained no visible barite or calcite; however, some intergrown fluorspar and quartz occur. No fluorspar crystals were seen.

From the west side of the hill, about 130 feet vertically below the collar of the shaft described and about 100 feet to the south, a crosscut tunnel is being driven, which is expected to cut the deposit about 120 feet below the surface at that point. This tunnel was started in red granite and continued in it for about 90 feet where a body of nearly black, micaceous, schistose, fine-grained, rather soft rock, containing much finely disseminated pyrite, was found; and the face of the tunnel was still in this material, April, 1922.

Mining.—When the mine was examined, no effort had been made to extract any ore but that removed in development. The workings are dry, and no pumping will be necessary under the present plan of development. Timber, if needed, may be obtained cheaply near by. Development plans included the completion of the crosscut tunnel described; if disclosures there were favorable, the operators then planned to go to a point on the strike at the extreme southern point where croppings occur and drive a working tunnel on the vein. Completion of this tunnel was to conclude the plan of development, and it was estimated that this work would require two years. The company did not expect to ship any large amount of fluorspar until this part of the program is completed. The mine had been opened by simple hand methods, but a small gasoline-driven air compressor had been ordered to expedite drilling.

Milling possibilities.—If milling is found necessary, water will be piped by gravity from Pinkham Creek, about 1 mile from the mill site at the portal of the proposed tunnel on the strike. The ore now breaks clean from the inclosing granite and clay, and hand sorting would require but little cobbing. Hand sorting might produce fluorspar of grinding or even acid grade in small quantities. A selected hand specimen of the best fluorspar analyzed as follows: 99.49 per cent CaF_2, 0.07 per cent SiO_2, and 0.18 per cent $CaCO_3$.

Fuel for the generation of power can be supplied from the large lignite mines at Coalmont, about 31 miles south, which is now the southern terminus of the Colorado, Wyoming & Eastern Railway. This lignite is of high grade and nearly equal to bituminous coal.

JAMESTOWN DISTRICT

LOCATION, EXTENT, AND HISTORY

The Jamestown (known locally as Jimstown) mining district is about 16 miles northwest of Boulder, in Boulder County, Colo., at an elevation of about 7,000 feet. The district includes a number of mines which have produced gold, silver, and lead, and contain a fair amount of fluorspar. The metal-bearing ore of this district has been exhausted, but when fluorspar prices were high during the war a number of the mines were reopened. Some of the old gold-concentrating mills were used for concentrating fluorspar ore. Since the decline in prices mining ceased and the mills were dismantled.

PAST PRODUCTION

Fluorspar production in the district reached a maximum in 1918 and continued until fluorspar prices dropped in 1920, when mining ceased. No fluorspar production statistics for the district are available, but the total production probably did not exceed 15,000 to 20,000 tons.

ORE DEPOSITS

Most mines were opened by tunnels, although shafts were located on some; they were in such bad condition they could not be entered.

All the ore in the district occurs in a light-colored granite, which has been highly fractured and shattered; fluorspar fills the fissures only, there being no replacement. No calcite or limestone is evident anywhere. The typical ore is deep blue to purple, although white and pink fluorspar were also noted. The ore is finely granular and somewhat porous, resembling a porous purple sandstone; some of it is rather soft and crumbly and some of it is compact and hard. Irregular angular inclusions of granite of all sizes, from fresh to partly altered, are distributed through the ore. The principal accessory minerals in about the order of importance are pyrite, galena, and copper (as sulphide and carbonate). Feldspar and mica were noted at the Alice mine.

The ore resembles that of the Daisy mine at Beatty, Nev., except that it is much harder and seems to contain a smaller proportion of finely divided gangue. The Daisy ore has a filling of brown iron oxide between grains, while the ores of the Jamestown district contain no apparent filling, the impurities being granules which are indistinguishable from fluorspar grains. The iron content at the Daisy mine is disseminated limonite, while in the Jamestown district it is crystallized pyrite, often occurring in large aggregates. The fluorspar deposits of the Jamestown district have been described in Colorado Geological Survey Bulletin 18, already cited in footnote 25.

DEVELOPMENT

Although it was impossible to enter these mines, the development was evidently rather extensive; the work was not originally planned for production of fluorspar.

Emmet mine.—On the shipping platform near the portal of the tunnel of the Emmet mine were about 30 tons of mixed lump and fine mine-run ore, from which coarse waste had been picked. A sample analyzed 83.42 per cent CaF_2, 13.48 per cent SiO_2, and 1.42 per cent $CaCO_3$. The ore here is a mixture of white, glassy, crystalline fluorspar with the typical granular purple ore of the district.

Argo mine.—Argo mine fluorspar was not as massive as the above and contained no massive crystalline fluorspar. All the ore on the dump, said to be of high milling grade, was blue to purple, generally granular, soft to rather hard, light, and porous, resembling a porous, purple sandstone. The fluorspar contained many large and small inclusions of granite, as well as pyrite and a small amount of galena.

Alice mine.—The ore is similar to that of the Argo mine, but contains more pyrite, copper, and galena. Feldspar and mica, probably muscovite, in crystals up to 2 inches in diameter were noted. Judged from the size of the dumps, the mine was evidently large. There was only a small amount of low-grade fluorspar at the portal of the mine.

Warren mine.—The Warren mine was reported to contain a large body of the best milling ore in the district; one car of the concentrates from this ore was said to analyze 94 per cent CaF_2.

Mining methods.—Mining methods could not be studied, as the mine could not be entered.

Milling methods and equipment.—When the mine was examined, April, 1922, all mills in the district had been closed down and dismantled, and the only ones which could be rehabilitated were the Wano and the Golden Age. The Wano mill, an old gold mill used during the war for concentrating fluorspar, has some water power available during part of the year. The Lehman mill, the last to be closed down in this district, operated as a custom mill and obtained its ore supply from the principal mines. The general milling practice in this district was as follows:

The ore was partly hand-picked at the mine and hauled by wagon or truck to the mills, which were lower than the mines and one-half to 2 miles away. At the mill the ore was crushed and rolled to minus 20 mesh and the entire product tabled. A small amount of low-grade galena and considerable low-grade pyrite were obtained as by-products, but they had no commercial value. The fluorspar recovery averaged about 30 per cent of the mill heads and analyzed 70 to 80 per cent CaF_2; the remainder was mostly silica, but contained small amounts of pyrite.

Transportation and costs.—The concentrates were hauled from the mills about 16 miles to the railroad at Boulder over good mountain roads, practically all downhill. No detailed costs of production for this district were available. In December, 1920, the close of the shipping period, haulage from the mill to the railroad at Boulder cost $4 per ton. Labor at that time was $4 to $4.50 per eight-hour day.

Conclusions.—The facts that the district is remote from transportation and the ore not high grade and that most of it requires rather fine grinding for suitable separation, making the concentrates undesirable for fluxing grade, would seem to indicate that it would be difficult for this district to compete with other fields situated more advantageously. However, if prices were higher, much fluorspar might be available.

NEW MEXICO

Fluorspar has been produced at several mines in different parts of New Mexico. Some prospects which might develop into workable mines are, however, too far from transportation to make operation profitable at present prices.

DONA ANA COUNTY

Bishops Gap.—Bishops Gap is called Pyramid Peak on most maps.

Location and geology.—There are four fluorspar claims at the extreme south end of Organ Mountains, 9 miles (N. 60° E.) by present road from Mesquite, on the Santa Fe Railroad, 33 miles north of El Paso. The claims are about 1,000 feet above the level of the Rio Grande Valley.

The country rock is highly silicified gray limestone, steeply folded and tilted, with many fractures and some slight displacement. Fluorspar, where it shows in workings, is present as replacement of limestone and as fillings of fractures and crevices. The vein filling is principally quartz, with some calcium fluoride. There are numerous small stringers of rather high-grade fluorspar (samples analyzed contained 90 per cent CaF_2, 8.05 per cent SiO_2, 1.51 per cent $CaCO_3$, 92.51 per cent CaF_2, 6.81 per cent SiO_2, and 0.34 per cent $CaCO_3$) but most of the spar is too highly silicified even for fluxing. Samples analyzed contained 83.94 per cent CaF_2, 15.34 per cent SiO_2, and 0.12 per cent $CaCO_3$; 62.34 per cent CaF_2, 32.93 per cent SiO_2, 2.12 per cent $CaCO_3$, and 1.04 per cent $BaSO_4$; and 55.78 per cent CaF_2, 37.73 per cent SiO_2, 4.10 per cent $CaCO_3$, and 1.05 per cent $BaSO_4$.

No veins of solid fluorspar of any grade more than 18 inches wide were observed. The fractured area on the western claim strikes about north and south and dips 45 to 50° east. In places this area reaches a width of about 100 feet, but contains only narrow stringers of fluorspar. In many places barite is intimately mixed with the fluorspar. (Sample analysis, 36.22 per cent CaF_2, 41.22 per cent SiO_2, 17.02 per cent $CaCO_3$, and 4.22 per cent $BaSO_4$.) The erosion of this mountain is very pronounced, so there can be no residual deposits of fluorspar.

Development.—There was one pit 10 feet deep on each of the two west claims, and several small trenches and cuts are distributed over the four claims. On the west side of the ridge, about 100 feet below the apex of the vein, is an abandoned drift about 20 feet in. The face only showed barite and limestone.

Only prospecting has been done on this property and no shipments have been made.

Tortugas mine.—The Tortugas mine is 8 miles southeast of Las Cruces by present road and 5 miles from Mesilla Park, the shipping station on the Santa Fe. The mill is near the State agricultural college, about 1 mile from Mesilla Park and 4 miles from the mine. The property consists of two claims lying end to end on the vein strike and on the east side of Tortugas Mountain.

The mine and mill were closed down early in 1922. About 20,000 tons of fluorspar had been shipped, varying in grade from ground spar for glass (with the analysis 93.76 per cent CaF_2, 3.42 per cent SiO_2, and 2.50 per cent $CaCO_3$) to low-grade fluxing spar (with the analysis 80.91 per cent CaF_2, 5.64 per cent SiO_2, and 13.15 per cent $CaCO_3$).

Ore deposit.—The country rock is limestone, and has been slightly faulted. The vein strikes approximately north and south, and dips 80° east. A length of 1,000 feet is shown by workings. The stoping width near the surface was 2 to 5 feet and narrowed with depth. Throughout the workings the ore is generally frozen to both walls and extends in places into fracture joints and small pockets. The vein filling is fluorspar mixed with calcite and some silica. No barite was noted.

Development.—The mine is opened by an inclined shaft 150 feet deep through an open stope on the vein. This stope is 2 to 5 feet wide near the surface and extends to a depth of 100 feet for 100 feet north of the shaft and about 50 feet south. Both the north and south faces show pinches, as the ore does not exceed 1 foot in width. Practically no stoping has been done below the 100-foot level. On the 150-foot level a drift has been cut 100 feet north through ore averaging about 2 feet in width, including a lens or short pocket about 3½ feet wide and 15 feet long. In places the vein on this level narrows to 8 or 10 inches, and at the north end shows a face of fluorspar 18 to 24 inches wide. This drift has also been extended about 20 feet south of the shaft, where the face showed a tight pinch. A sample from the vein analyzed 93.22 per cent CaF_2, 3.59 per cent SiO_2, and 2.49 per cent $CaCO_3$, and an average sample from the vein 50 feet north of shaft on the 150-foot level, 86.60 per cent CaF_2, 4.56 per cent SiO_2, and 8.65 per cent $CaCO_3$.

Above the 100-foot level on the north side of the shaft a block of ground about 40 feet high and 100 feet long had not been stoped. The average width of this deposit was about 2 feet. The pits and cuts opened on the claims, aside from the workings mentioned, show a vein width of a few inches to 2 feet.

Mining.—The ore was apparently mined by underhand stoping. Timbers were only used for ladders and walkways. Drilling was done by small air drills and the air was supplied by one 9 by 8 inch belt-driven air compressor driven by one 30-horsepower kerosene engine which also operated a small crusher at the loading platform at the foot of an aerial tramway. The ore is lifted in small buckets by a gasoline-engine hoist and carried by the aerial tramway, which has a vertical drop of about 300 feet, about 1,200 feet down the mountain to a loading platform. The buckets carry about 600 pounds, and empties are hoisted to the top. The aerial tramway has a capacity of about 1½ tons per hour and is supplemented when necessary by burros carrying 200-pound loads and making eight trips per day from the collar of the shaft to the loading platform at the bottom of the aerial tram. At the platform the ore is crushed by an 11 by 8 inch Blake-type crusher to about three-fourths-inch size and hauled to the mill.

Milling.—Power and water for the mill are supplied by the near-by New Mexico Agricultural College. The water comes from a drilled well.

The ore at the mill (sample analyzed 77.41 per cent CaF_2, 6.51 per cent SiO_2, and 15.68 per cent $CaCO_3$) is unloaded into a small mill bin. The jigs have a capacity of 2 tons of heads per hour and the ball mill of 1 ton per hour. Milling loss is 50 per cent and the tailings run about 30 per cent fluorspar. The actual output was about 50 tons every seven days. The coarse jig product was hand sorted, and with the product from the two best cells of each jig formed the grinding product. All but about 100 to 150 tons of the hutch product was discarded; this was shipped as fluxing spar. The screen product that was not used for grinding grade was thrown with the hutch product. There was no uniform method of handling the products of the jigs, but the mill operators were guided by the appearance of the spar in screening and selecting for grinding purposes. The product of the grinding mill passed a 16-mesh screen.

Cost of production.—The costs of labor and supplies per ton of finished product, f. o. b. cars, were said to be as follows:

Ore delivered under contract to crusher at foot of aerial tram	$4.00
Haulage to mill	1.00
Add 50 per cent for mill loss	2.50
Milling charge on finished product	2.25
Haulage from mill to station	.50
Total	10.25

Tonuco mine.—The Tonuco mine is 1 mile from Heathden (formerly called Detroit Siding), the shipping point on the El Paso division of the Santa Fe, 7 miles south of Rincon. The mine, comprising a group of approximately 20 claims, is located on Tonuco Mountain, approximately 1,000 feet above the level of the railroad and the Rio Grande.

Between the opening of the mine, April 1, 1919, and the completion of the mill in June, 1921, about 2,500 tons of fluxing lump was shipped. A steel company in Pueblo, Colo., received most of the later shipments.

Ore deposit.—The country rock seems to be limestone intruded by large dikes of fine-grained diabase which has been fractured and filled with fluorspar intergrown with quartz and barite. These fracture fillings constitute the veins which have been worked for fluorspar. No fault displacements were apparent, although the ore seemed to be deposited principally in one major fracture. This main vein apparently bends, the southerly end striking S. 30° E., whereas the northerly end seems to strike north of west. In the main working tunnel the dip is 45° west. From the ground stoped out the vein appeared to range in width, from 2 to 25 feet near the surface to about 42 inches 150 feet below. The total length of outcroppings, as pits and tunnels on the surface show, is at least one-half mile.

Development.—The main workings consist of a tunnel, the portal of which is about 75 feet below the apex of the outcrop. For the first 75 feet of the tunnel the vein was 2 to 4 feet wide, the next 75 feet was 12 to 15 feet wide, and the remaining 130 feet was in a pinch and contained practically no ore. In this barren part of the tunnel two 40 to 50 foot crosscuts were driven in the footwall and showed no ore. A winze was sunk 70 feet on the vein, 86 feet from the portal, and showed about 42 inches of ore throughout its entire depth. An average sample of ore at the bottom of the inclined winze analyzed 54.08 per cent CaF_2, 14.70 per cent SiO_2, 1.83 per cent $CaCO_3$, and 26.48 per cent $BaSO_4$. The ore-bearing part of this tunnel has been stoped out to the surface and ranged in width from 2 to 25 feet. A sample from the loading bin at the sizing plant at the portal of the main tunnel analyzed 54.92 per cent CaF_2, 30.16 per cent SiO_2, 1.46 per cent $CaCO_3$, and 10.70 per cent $BaSO_4$.

About one-half mile south on the strike of the vein a tunnel was driven north 50 feet on the vein from the opposite side. This tunnel starts on an outcrop of spar about 3 feet wide, a width which continues for the length of the tunnel. This tunnel is about 100 feet lower than the first tunnel. The fluorspar had a hard, siliceous, glassy, quartzlike appearance. No barite was noted at this point. Between these two tunnels are two small surface cuts on the outcrop which showed very little fluorspar.

On the hanging-wall side of the vein, about 100 feet west of the main tunnel portal, is a shaft about 30 feet deep, which was not deep enough to cut the vein.

Across the hollow to the north, opposite the portal of the main tunnel, and about 250 feet north of it and on the same horizon, a tunnel was driven north on the vein about 20 feet which showed only 4 to 6 inches of fluorspar.

On the extreme northwest end of the claims overlooking the Rio Grande Valley, and about 100 feet below the horizon of the main tunnel, a tunnel was driven about 50 feet into the mountain. The ore was spotted with an average width of about 2 feet. A winze was sunk about 20 feet in the heading of the tunnel, but was not accessible for examination. This tunnel was north of the bend in the vein.

About 60 feet below and about 25 feet south of the portal of the last-mentioned tunnel is another about 335 feet long, which starts southeast and bends to the south toward the end. It had not cut the vein.

Mining.—Drilling was done by air drills, the air being furnished by a 9 by 8 inch air compressor driven by a 25-horsepower oil engine. The ore was removed by overhead stoping and very little timber was used, small pillars being left at irregular intervals to support the walls. Ore was trammed to the surface in 1-ton cars and dumped over a grizzly, through a rock crusher at the portal of the main tunnel, sized, and hand picked.

Milling.—The main milling plant is at the railroad about 1 mile from the main tunnel and cost about $15,000. This mill has been remodeled several times to effect separation of the barite and silica from the fluorspar, but the problem has not been solved. A sample taken from the mill heads analyzed 47.33 per cent CaF_2, 29.49 per cent SiO_2, 1.03 per cent $CaCO_3$, and 17.26 per cent $BaSO_4$; a sample of gravel from a car on siding ready to ship analyzed 78.52 per cent CaF_2, 10.33 per cent SiO_2, 0.50 per cent $CaCo_3$, and 9.70 per cent $BaSO_4$. A sample from the draw-off from the best two cells on fine jig analyzed 79.87 per cent CaF_2, 13.62 per cent SiO_2, 0.71 per cent $CaCO_3$, and 5.20 per cent $BaSO_4$.

The barite product from the mill has been segregated in a separate dump in the hope of being able to develop some method of producing a marketable barite product later. This dump now contains about 200 tons of low-grade barite.

SIERRA COUNTY

Nakaye mine.—The Nakaye property comprises about seven claims on the extreme southwest end of the Caballos Mountains, 6 miles northeast of Derry and 20 miles northwest of Hatch, the shipping point, on the Santa Fe Railroad. These claims are about 1,000 feet above the level of Derry and about 500 feet above the base of the mountain.

The mine was opened in 1919, but there were no shipments. From January, 1920, to April, 1922, about 3,000 tons of fluxing lump were shipped; all went to Pueblo, Colo., except a small amount to eastern iron foundries.

Ore deposit.—The country rock is flat-lying bedded gray limestone with little, if any, faulting. At least one horizon of these beds has been impregnated with calcite, fluorspar, and some silica. The solution apparently ascended through crevices and spread out through fissures in a favorable bed. Some fluorspar apparently is vein and vug filling and some is replacement of limestone. The bed where replacement occurred is 6 to 10 feet thick and has a well-defined top but an irregular bottom. The form of the deposit was probably due to the ascending solutions being arrested at the top of the bed by an impervious stratum of limestone. Fluorspar replacements were of very irregular distribution and size; at the top they were rather extensive and frequently connected, but lower down the replacements were narrower and contained more unreplaced bodies of limestone, which gave deposits of ore 10 to 20 feet wide at the top and narrower and very irregular at the bottom. In these deposits the only apparent impurities were inclusions of unreplaced limestone, secondary calcite, and some peculiarly crystallized barite.

Development.—At the north end of the claims is an open cut about 75 to 100 feet long, 30 to 50 feet wide, and of a maximum depth of 15 feet. About 450 feet south of this open cut is another opening whence two tunnels extend 125 feet at the most. The area opened by these tunnels was much shattered and replacements very irregular. The main tunnel was 12 feet at its widest point, and opened into an oval room 40 feet across by about 30 feet long on the strike of the fissure; approximately 50 per cent of the material extracted was spar. About 600 feet south of these workings was an open cut which showed a little ore in a nearly vertical fissure intersecting a blanket bed.

Several hundred feet north of the open cut mentioned first and at least 100 feet lower on the mountain was a shaft said to be 40 feet deep. This shaft could not be entered, but a mining engineer at Silver City stated that at 25 feet a drift had been cut 15 feet south, showing a little shattered ore. He stated that 3 to 4 feet of ore analyzing about 35 per cent silica was at the bottom of the shaft.

Mining.—Mexicans mined the ore on contract with simple hand methods and no machinery. The ore was shot down in the face of the room; the large pieces of fluorspar were then wheeled to the shipping platform and the large pieces of waste to the waste dump. The balance of the mine run was wheeled to the portal of the tunnel, where it was dumped over a ½-inch screen. The undersize was rejected and the oversize hand picked, the waste being thrown over the waste dump, and the remaining spar taken to the shipping platform and shipped with the large lump. A sample of the rejected fine material which passed the screen analyzed 83.52 per cent CaF_2, 4.56 per cent SiO_2, and 15.70 per cent $CaCO_3$; a sample of screen oversize analyzed 70.81 per cent CaF_2 0.78 per cent SiO_2, and 28.09 per cent $CaCO_3$.

Transportation.—The road for the 6 miles from the mine to Derry is rough and too steep for trucks. The ore has been hauled in wagons carrying maximum 2-ton loads. Although the 14 miles of road from Derry to Hatch was very good, wagon haulage was found to be cheaper.

Cost of production.—No accurate figures on detailed production costs could be obtained. Haulage cost $4.50 to $5.50 per ton, and one operator estimated the haulage, labor, and supply cost f. o. b. cars at Hatch at about $10 per ton. The Mexican miners worked 8 hours per day at wages of $1.50 to $2.50. There was no camp at the mine and miners came on horseback from ranches.

Delicias, Fortune Teller, and Bulldog claims.—This property comprises 21 claims—of which 13 lie to the south in the Delicias group, 5 in the Fortune Teller group, and 3 in the Bulldog group to the north—lying from 2½ to 5 miles over the mountains northeast of Nakaye and on the eastern slope of the Caballos Mountains. These claims are 9 to 13 miles northwest of Gramma, on the Santa Fe Railroad, which would be the shipping point. There is no road to these claims, which had not been worked up to 1922; only a small amount of assessment had been done.

Ore deposit.—The claims were not personally examined and information was obtained from several sources. The assessment work was said to be inadequate to determine the extent of the ore deposits. Assessors believed that the ore was similar in character to that at Nakaye, but on all claims but the Bulldog ore occurred in stringers and gashes in limestone, whereas it occurred in blanket formation at the latter. One man said that the widest showing of ore was 4 to 4½ feet, while another said that the maximum width was 3 feet.

GRANT COUNTY

Great Eagle mine.—The Great Eagle mine is on the Gila River in the foothills of the Burro Mountains in Grant County, N. Mex., near Red Rock post office, 30 miles north of Lordsburg, on the Southern Pacific Railroad. The property consists of two claims, the Great Eagle and the Spar No. 2, the greater part of which lies across the Gila River to the northwest.

This property was first worked in 1917; before January 1, 1921, about 1,500 tons of fluxing-lump fluorspar were shipped. From 1921 to April, 1922, about 200 tons of fluxing lump and about 100 tons of ground fluorspar were shipped.

Ore deposit.—The fluorspar occurs in a vein in red granite, highly altered at the surface. Slickensides and gouge prove the presence of a definite fault fissure. The vein strikes N. 30° to 35° W., is practically vertical, and consists of irregular stringers of fluorspar, grading into quartz and granite breccia. The vein material never shows solid spar throughout its width, and the intergrowth of fluorspar and quartz is seldom more than 3 to 6 feet wide. The widest place in the stoped area was about 20 feet, but several horses of granite were included. At places in the vein are masses of bowldery intergrowths of fluorspar and quartz, resembling those at Tonuco, which were banded more or less concentrically like agate, and averaged 3 to 8 inches in diameter.

Of the total vein filling not over 50 per cent is fluorspar or fluorspar-quartz intergrowth, and not over 20 per cent is recoverable even as fluxing fluorspar. In the upper part of the vein there is much staining by iron oxide, which turns to iron pyrite in the deepest workings. No barite or calcite was noted on this property.

The vein is in a large hill adjoining the Gila River and outcrops over the top of the hill from the plain on one side to the river on the opposite side, a distance of about 1,000 feet. The top of the hill is about 170 feet above the level of the river.

Development.—The main workings of this mine consist of an adit tunnel driven in the west wall at an angle of about 30° to the vein, intersecting it about 100 feet from the portal and continuing along the vein 250 feet or more. This level is 60 feet above the water level of the Gila River.

The main production to date has been mined from an open stope above this level, extending 210 feet. The stoping width was 8 to 20 feet, the vein filling being described above. The vein at both ends of this area was similar and contained no recoverable fluorspar. About 90 feet in from the point where the tunnel cut the vein a winze had been sunk on the vein 60 feet to water level. An inclined adit on the vein, starting 60 feet above the water level on the outcrop on the south side of the hill, was driven to intersect the bottom of the winze mentioned above, but was not advanced far enough to connect. This inclined adit tunnel showed no ore to a point about 10 feet above the Gila River or 50 feet below the main workings, which was as far as it could be examined on account of accumulated mine seepage. The winze was inaccessible for examination, but was reported to show the same general character of ore, except that iron pyrite had replaced the iron oxide. On the extreme north side of the hill overlooking the Gila River were a series of pits on the outcrop of the vein which all showed the same general character of ore as the other workings. The higher pits, which were widest and best, were about 8 feet wide. None of these pits was over 4 or 5 feet deep.

Mining.—Drilling was done by jack hammers and stoping drills. The air was supplied by an air compressor with a capacity of 350 cubic feet of free air per minute, driven by one 50-horsepower oil engine. There was also a small auxiliary compressor of 125 cubic feet capacity. The only timber used in this mine was a small amount used to support a winze on the vein. The workings were in bad condition, as the walls caved badly. Due to the character of the vein filling and the fractured condition of the walls, any mining below the present level will require timbering.

Practically no pumping has been done to date, but the nature of the ground indicates that a heavy flow of water may be found below the level of the Gila River.

Milling.—The ore is trammed from the mine to the mill near the portal of the tunnel, where it is crushed, sized, and hand picked. The hand-picked material was then ground in a small Hardinge mill. A sample of ground spar taken from the mill analyzed 95.29 per cent CaF_2, 4.13 per cent SiO_2, and 0.44 per cent $CaCO_3$. The capacity of the Hardinge mill was 1 ton per hour of a product, of which 90 per cent would pass a 100-mesh screen.

Transportation.—The first 9 miles of the road from the mine to Lordsburg, the shipping point, is rough, exceedingly difficult for motor trucking, and impassable at times from floods in arroyas. The remaining 21 miles from the mine to Lordsburg is over level ground.

Old Glory claims.—Across the Gila River to the north is the group of seven Old Glory claims. The line of the vein is marked by a depression. These claims have not been developed and only the assessment work has been done. Little or no ore was shown in the assessment pits, and the claims were not examined.

Gila district.—The Gila property is 30 miles northwest of Tyrone, on the Gila River near Gila, across the mountain from the Great Eagle property and about 30 miles from the railroad. This property was not visited.

The vein was reported to range 1 to 4 feet in width and the ore was said to be similar to that of the Great Eagle mine. The property was opened in 1918 and operated for a few months, but distance from the railroad (about 30 miles, part of which is pack trail) made profitable operation impossible. The only information on costs was that they were prohibitive.

LUNA COUNTY

Deming district.—There are fluorspar deposits in the Fluorite Ridge about 8 miles northeast of Deming, and also in the Florida Mountains about the same distance southeast of Deming. Information on the extent of the claims comprising these properties was not obtained.

Past production.—In 1909 and 1910 these properties produced and shipped, mainly to Pueblo, Colo., about 5,000 tons of fluxing fluorspar. During the next two or three years several thousand additional tons were mined and shipped, then the deposits were considered exhausted. When prices of fluorspar were high during the war, however, a few additional cars were produced.

Ore deposit.—These deposits were not visited, but part of them were described in a United States Geological Survey bulletin.[26]

Cook's Range district.—A mining engineer of Silver City reports that there is a small deposit of fluorspar at the extreme north end of Cook's Range, about 17 miles northeast of Spaulding. The property, sometimes called the Sadler, was not examined. A few cars of fluxing fluorspar were said to have been shipped in 1918, the average analysis being 82 per cent CaF_2, 12 per cent SiO_2, and 2 per cent $CaCO_3$. The road was said to be fairly good and mostly down grade.

[26] Darton, N. H., and Burchard, E. F., Contributions to Economic Geology; Fluorspar near Deming N. Mex.; U. S. Geol. Survey Bull. 470, 1910, pp. 533–545.

BERNALILLO COUNTY

Galena King mine.—This property includes 5 patented claims, 4 called "Octoroon" and 1 "Nellie," and 3 or more claims not yet patented. They are about 16 miles southeast of Albuquerque, about 1,800 feet above the level of the Rio Grande at that point, in the Manzano Mountains and Manzano National Forest. As boundaries of the Isleta Indian Reservation have been altered, these claims are now on the reservation and no new locations may be made.

Past production.—This mine was opened in 1910 as a lead mine and no attention was paid to the fluorspar. Three cars of hand-sorted gelena ore were shipped, assaying between 53 and 68 per cent lead and about 1½ ounces of silver. Several years ago 1 car of fluorspar was shipped to Pueblo, Colo., but no other shipments have been made. In 1921 a little work was done on this property in an endeavor to develop commercial fluorspar.

Ore deposit.—The vein occupies a fault fissure in the formation with a strike nearly north and south, and dips about 80° west. The lower part of the mountain is red granite gneiss overlaid in the upper part by nearly horizontal sedimentary beds which include limestone. All openings made were in granite gneiss. The vein ranges in width from a tight pinch to about 2½ feet. In places numerous small caves and cavities were present. The vein material is granite breccia, incrusted and cemented with fluorspar, and in places with barite and galena. At some points the vein material was two-thirds breccia and one-third fluorspar, and at other points was nearly solid fluorspar and barite, with some galena. The greatest width of fluorspar was about 2 feet, and this over a length of about 5 feet. The average width of the fluorspar throughout the workings was not over 6 inches. The maximum width noted was in the upper workings, the vein in the lower tunnel being much narrower. In the upper workings barite constituted 10 to 50 per cent of the vein filling, but in the lower workings barite was noted only occasionally.

The most noteworthy feature of this mine was the exceptionally well-developed crystallization of fluorspar and barite.

Development and mining.—A tunnel started on the outcrop was driven on the vein for 300 to 400 feet. At a vertical distance of about 175 feet below this drift a crosscut was driven 300 feet through granite to its intersection with the vein, and was then continued on the vein 200 feet more. Near the point where the crosscut entered the vein a winze was sunk, which was said to be 100 feet deep, but was not entered. Thirty-five feet beyond this point a raise had been cut on the vein connecting the two tunnels. In the upper tunnel about 40 feet in, beyond the raise from below, a winze said to be 40 feet deep was sunk; the bottom 15 feet had been refilled with spar and waste. From this winze a short drift 12 to 15 feet long was driven in one direction. The face of this drift was in a pinch showing only a trace of ore. Near the portal of each main tunnel were dumps containing a total of perhaps 10 to 20 tons of hand-picked spar; a sample analyzed 69.69 per cent CaF_2, 8.84 per cent SiO_2, 2.14 per cent $CaCO_3$, and 12.75 per cent $BaSO_4$. There were also some 15 or 20 tons of mixed broken ore in the mine.

This mine has been developed entirely by hand methods, as there was no machinery on the property. Ore was trammed to the portal in 1-ton cars and hand sorted.

ARIZONA

DUNCAN DISTRICT

There are a few fluorspar prospects 8 to 16 miles northeast of Duncan, Greenlee County, Ariz., near the Arizona-New Mexico line, some being in Arizona and some in New Mexico. These prospects were not visited.

When fluorspar prices were high during the war, several fluorspar claims were located in this district. The owners included the Safford Fluorspar Mining Co., the Maple Leaf Syndicate (Phillips mine at Goat Camp Springs), and Joe Hardy, all of Duncan, Ariz.

CASTLE DOME DISTRICT

The Castle Dome district lies north of Yuma and Dome, Yuma County. A principal property is near Castle Dome, 20 miles from Yuma and 26 miles from Dome. For a number of years several mines in this district have yielded a small irregular production of fluorspar, part of it being a by-product from other mining operations. Operators included the Reorganized United Mines Co. (Big Dome mine), Juan Laguna, and the Castle Range Mining Co., all of Dome, Ariz. These properties were not examined. No separate production statistics are available, but this district never produced more than a few hundred tons annually.

A few other deposits have been reported in Arizona near Aquila, Tombstone, and Naco.

NEVADA

BEATTY DISTRICT, NYE COUNTY

LOCATION AND EXTENT OF CLAIMS

There are 22 fluorspar claims in Nye County, Nev., of which 9 (constituting the Daisy group and including, besides the Daisy, the Fluorite, Blue Bird, and Yellow Spar claims) are on the northeast end of Bare Mountains, 4½ to 6 miles southeast of and 1,000 to 1,200 feet above Beatty, the shipping point on the Tonopah & Tidewater Railroad. The remaining 13 claims are known as the Diamond Queen group and are located 7 miles over the mountains southeast of the Daisy group and at about the same elevation. The Diamond Queen group is about 11½ miles over the mountain southeast of Beatty, and 22 miles from Beatty by the only practical haulage road. These claims are leased to the Continental Fluorspar Co.

PAST PRODUCTION

It was stated, April, 1922, that 25 cars had been shipped since the opening of the property in 1918, 1 car going to an eastern steel mill, and the remainder to Pacific coast steel plants.

ORE DEPOSIT

The formation throughout the workings owned by this company is a dark-gray limestone faulted in many directions and intruded by rhyolite. The general character of the Bare Mountains is evidenced by the large marble holdings of the American Carrara Marble Co. near Carrara on the west side of the mountains. Here in succession are beds of quartzite, shale, and a great thickness of marble of many colors, extensively faulted, with displacements up to at least 1,400 feet.

DEVELOPMENT

Fluorite claim.—This is the most westerly of the Daisy group, and is nearest Beatty. On the west end of this claim an inclined shaft has been sunk in the vein to a depth of 75 feet, dipping about 80° south. This shaft showed 2 to 4 feet of brecciated limestone wall material cemented and partly replaced with soft, fine, granular, purple fluorspar. From the bottom of the shaft a drift S. 80° E. was driven for about 45 feet. The face showed a tight pinch, but the general appearance was about the same as at the shaft. In the opposite direction no work had been done. This working showed evidences of complicated faulting, as slickensides and much clay gouge showed. The general vein filling probably did not contain over 50 per cent fluorspar. A small amount of manganese stain was noted, mainly in the gouge. There were also cavities lined with calcite.

A second shaft on the same claim was sunk 48 feet about 200 feet eastward. From the bottom of this shaft a drift was cut 65 feet northeast and 20 feet west. The ore here appeared about the same as in the shaft first described.

Daisy claim.—This claim was opened by a shaft about 600 feet east of the second shaft described on the Fluorite claim. It was the main working shaft of the entire property and practically the only deposit from which production has come in the past. Here the vein strikes S. 70° W. and dips 80 to 85° southeast. The collars of all three shafts on the Fluorite and Daisy claims were nearly in a straight line, but the vein strikes were all different. The Daisy shaft was sunk 160 feet on the vein. The vein, which shows at the surface in places, was covered at the shaft by 18 to 24 inches of loosely cemented wash, and was 17 feet wide, but narrowed to 5 feet at one place in the shaft. Within 5 feet of the bottom of the shaft the ore terminates abruptly and no effort had been made to find its extension.

At the 80-foot level there is a drift that extends 148 feet to the east. The face of this drift showed about 4 feet of soft purple fluorspar, a sample of which analyzed as follows: 75.31 per cent CaF_2, 4.15 per cent SiO_2, and 19.84 per cent $CaCO_3$. This ore seemed to have about the same general character as most of the ore in the mine. The vein on the 80-foot level was 4 to 20 feet wide, averaging about 12 feet. On this drift, about one-half the distance from the shaft to the face, a raise had been put up to the surface and a stope, possibly 20 feet long, had been opened from this raise. This stope was about 10 feet wide, all in ore, and holes 4 feet deep in the hanging-wall side did not reach the hanging wall. A drift had been driven about 85 feet to the west, and the face showed a tight pinch. Two 10 to 25 foot crosscuts at this point, driven north and south, followed small stringers which pinched a few feet from the main drift. Ore to the west of the shaft was much narrower and of poorer grade than that to the east. All the ore in this mine was of the same soft, granular, purple type as in the other shafts. The cementing material was light gray and soft. No pieces of solid fluorspar and no barite or quartz were noted. Fine narrow veinlets or stains of soft limonite were noted and clay gouge was prominent in many places.

Yellow Spar claim.—This claim is over the mountain about 1 mile south and somewhat higher than the Fluorite claim. A wagon road has been built to within one-fourth mile of the main opening and the rest of the distance is covered by a burro trail.

On this claim are three or four openings along the outcrop, only one of which was of any extent. It consisted of a tunnel 15 feet long, in the face of which an inclined winze was sunk 8 to 10 feet in an effort to locate the ore shoot. These workings were about 5 feet wide and contained two or three veins of massive yellow fluorspar, each 10 to 18 inches wide. The fluorspar content of the drift was about 50 per cent, largely in the form of bowlders of concentric and radial nodules of amber-colored spar 6 to 8 inches in diameter.

Between the veins was a filling of limestone breccia, recrystallized quartz in vugs, and yellow and purple fluorspar grading into solid hard limonite. About one-half car of this ore had been shipped as fluxing lump.

Blue Bird claim.—This claim is on the northwest side of the Bare Mountains, about one-half mile west of the first shaft on the Fluorite claim and at about the same elevation. Only assessment work has been done here. One pit about 8 feet deep has been sunk, which cut one stringer of granular purple fluorspar 10 to 18 inches wide. This stringer contained a few small brittle lumps of blue fluorspar, but much soft silica cement was present. A sample taken here analyzed 91.22 per cent CaF_2, 6.92 per cent SiO_2, and 1.37 per cent $CaCO_3$. Small, irregular, detached bunches of purple ore contained drusy quartz, chalcedony, or flint. Limonite was also present. About 20 feet below this pit a tunnel has been started to cut the ore.

Diamond Queen claim.—This claim is at the abandoned mining town of Fluorine, about 11½ miles over the mountain southeast from Beatty and 22 miles by the road around the southern end of the mountains via Carrara.

Much surface prospecting has been done along the side of the mountain over a distance of 150 feet; the openings extend into the mountain 4 to 10 feet, and at one place as much as 25 feet. At the extreme end of the 25-foot opening into the mountain a winze was sunk on an incline about 10 feet deep. Work on this claim showed a small amount of fluorspar scattered through the altered surface of the limestone and in places extending into the fractures in the limestone. About 150 feet higher up the hill from the workings just cited is a tunnel. The waste dump from this tunnel showed a small amount of scattered fluorspar.

Mining.—As the ore was soft and friable, very little drilling was necessary in mining it. Holes were put in with an auger bit and very little powder was needed.

The only timbering used was a few drift sets and bins, but if a large amount of ore should be stoped more timbering would be necessary. The timber was obtained by dismantling houses at Rhyolite, an abandoned mining camp about 8 or 9 miles from the mine, which at one time had a population of 15,000 to 20,000 people. This camp would not supply a very large amount of mine timber, although some light material could probably be obtained for some time to come. Any other timber used in these mining operations must be shipped in by rail.

The mine does not make any water and there is no water for any purpose nearer than Beatty.

The ore was trammed to the shaft in small steel buckets holding about 900 pounds, hoisted over wooden skids, and dumped into an overhead bin holding about 25 tons, from which the wagons were loaded. A 15-horsepower gasoline-driven hoist was used.

Milling.—A concentrating and grinding mill on a railroad siding at Beatty was started before 1920, but was not completed at the time of examination, although much of the machinery was in place and the remainder on the ground. It had been in experimental operation in May, 1920.

The principal problem in milling is to recover the very finely granular fluorspar in sizes as coarse as possible. As the marketing of very fine gravel-grade spar is difficult, an attempt was made to briquet this material, but the process was unsuccessful. At the time of examination the proposed plan was to table the entire product, shipping the coarser material as gravel-grade spar and grinding the fines for the glass and enameling trade; thus the tables would be used largely for sizing. All of the ore was to be crushed wet and the fines wet ground. The operators estimated a milling loss of not over 10 per cent.

Drying the gravel and ground products in separate driers of a special type is planned. These driers consist of cast-iron pipes about 25 feet long by 12 inches in diameter, which revolve in a brickwork setting, the ore passing through the inside and flames from the burning of crude oil passing around the outside of the pipes. The plant is driven by two 40-horsepower crude-oil engines. Water for the mill will be obtained from a drilled well 29 feet deep, which was said to furnish 280,000 gallons per 24 hours. The mill capacity was expected to be 75 to 100 tons per 24 hours. The proposed mill equipment includes a Blake-type crusher and a rotary crusher. Three concentrating tables are to take the product from the rotary crusher, and will make tailings and fine and coarse concentrates. The coarse concentrates are to be dried to ship and the fines, after dewatering in a cone, are to be ground in a 36-inch and 30-inch Sturtevant vertical emery mill, and the ground product dried.

CALIFORNIA

There is a fluorspar prospect in San Bernardino County about 8 miles south of Afton, on the Union Pacific Railroad, and about 8 miles west of Mesquite on the Tonopah & Tidewater Railroad. It has been known for some years, but no fluorspar has been shipped, although a small amount was produced several years ago.

This deposit was not examined, and the following information was obtained from several unpublished reports. The fluorspar occurs in stringers and veins in felsite. These veins are 6 inches to several feet wide and dip 60° to nearly vertical. At the most extensive occurrence a number of shallow cuts expose veins of fluorspar 2 inches to 2 feet wide over a mineralized zone about 600 feet wide by 1,500 feet long. At other places development work shows veins of fluorspar mixed with silica 3 to 5 feet wide. Analyses show that the ore carries 36 to 86 per cent CaF_2, 8 to 41 per cent SiO_2, and 2 to 11 per cent $CaCO_3$. Most of the ore contains over 20 per cent silica, which is so intimately mixed with the fluorspar that separation by sorting or milling would be very difficult.

This property is very inaccessible. According to information obtained at Ludlow, there are long stretches of very heavy wind-blown sand between the railroad and the mountains on which this deposit is located, making haulage very difficult. Any ordinary road would probably be obliterated quickly by shifting sands.

UTAH

There is a fluorspar deposit in the Wild Cat Mountains, Tooele County, Utah, 20 miles by haulage road southwest of Clive, a station 74 miles west of Salt Lake City on the Western Pacific Railroad.[27] The group of mining claims that covers this deposit was located in April, 1892, and has since been patented by the Silver Queen Mining Co. and later leased to the Fluorite Mines Co., of Salt Lake City, Utah. This property was not examined and the information given here was obtained from several sources.

No record of fluorspar production before 1901 is available. In 1914 and between 1918 and 1920 the property produced about 430 tons of fluorspar and about 200 tons of silver-copper ore. In 1921 there was no fluorspar production. Nearly all the production shipped from this mine has been taken by metallurgical industries of Salt Lake City, although shipment of a small tonnage of high-grade material to the Pacific coast was reported.

WASHINGTON

The following information was obtained from a report on the mineral resources of Washington published by the State geological survey. A 16-foot vein of fluorspar is reported near Keller, in the southern part of Ferry County. The vein strikes N. 65° W. and stands vertical between walls of granite. This deposit was worked in 1918 and some fluorspar was shipped. No further information was available on this deposit.

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[27] Heikes, V. C., "A fluorspar deposit in Utah": U. S. Geol. Survey, Mineral Resources of the United States for 1921, 1924, pp. 48–49.

NEW HAMPSHIRE

LOCATION OF DEPOSITS

The only known fluorspar deposits in New Hampshire which have been worked commercially are in Cheshire County, about 2½ miles (in a direct line) southwest of Westmoreland village, and about 8 miles by wagon road from Westmoreland depot, the shipping point, on the Boston & Maine Railroad. The deposits are scattered over an area of perhaps 2 square miles along the sides of low mountains. The average elevation of the deposits worked would probably be about 1,000 feet above sea level or 300 to 400 feet above the neighboring valleys.

OWNERSHIP AND PAST PRODUCTION

The principal deposits are all owned locally, but those which have produced in recent years were worked under lease by the American Steel & Wire Co. This company has worked these deposits for many years to supply its plant at Worcester, Mass. Production has never been large, but definite figures before 1920 are not available. In 1920 the output was 202 short tons and 567 tons in 1921.

In 1918 the American Tube & Stamping Co. of Bridgeport, Conn., prospected several properties (the Aldrich, Paine, and Bill), and produced about one carload of fluorspar, but no important deposits were discovered and work was stopped.

DESCRIPTIONS OF INDIVIDUAL DEPOSITS

Stoddard No. 2 mine.—The mine was opened on a vein ranging from a tight pinch to 5 feet in width striking N. 40° E. (mag.) and standing nearly vertical. An open cut, possibly 100 feet long and usually only a few feet deep, opened the major part of the exposed vein. Near the center of the cut a shaft was sunk 50 feet deep, and some mining was done. The hand-sorted ore near the surface was reported to average 94 to 96 per cent CaF_2, but deeper in the shaft the grade became poorer and near the bottom it had fallen to 78 to 80 per cent CaF_2. The bottom of the shaft was in solid quartz and the flood of water was so strong that no further work was done.

Very little fluorspar in place was evident at the surface, but apparently not over 25 per cent of the vein matter was fluorspar, the rest being quartz. Much fluorspar and quartz were badly intergrown. The wall rocks on both sides were granite or granite gneiss. The ore was dumped over an inclined sorting trough and washed down by water. The ore was all hard and free from clay or sand. This deposit only produced a few carloads of ore and apparently all of the known ore has been exhausted for all of the equipment has been removed. Information on this mine was obtained from local sources.

Stoddard No. 1.—This mine has supplied the principal production from this group of properties and, in fact, from the State. The strike of the vein averages about N. 45 to 50° E. (mag.), and the dip is about 64 to 75° E. The vein has been worked as an open cut 25 to 50 feet deep over a distance of possibly 400 or 500 feet. Estimation of the width of the vein matter was difficult because on each side of the vein was a layer of soft decomposed granite from a few inches to 2 or 3 feet thick and this material had to be removed in mining. However, it is reported that the vein ranged 3 to 9 feet in width and averaged about 6 feet near the top but the width decreased with depth. No ore in place could be seen but from material on the dump the vein matter probably did not average more than 25 to 50 per cent fluorspar, the rest of the material being largely quartz, both free and intergrown with fluorspar. Near the south end of the open cut a small single-compartment shaft was sunk 118 feet, but the last 25 feet was in solid quartz. At the 70-foot level drifts were cut about 60 feet each way. The deepest ore was said to be found near the shaft. The ore was mined in open stopes by underhand methods and stulls used to support the walls when necessary. As in all of the other deposits of this district, the wall rocks were granite or granite gneiss.

The mine was filled with water and badly caved, therefore the underground workings were inaccessible. It was stated that practically all known ore had been mined out, and all of the machinery has been removed. The surface equipment here was about the same as at Stoddard No. 2, but more extensive. The ore from the shaft evidently had been hoisted in a bucket over a wooden skidway.

The waste dumps were extensive and indicated a high percentage of waste in the vein matter. No objectionable impurities such as barite were noted.

Pierce mine.—This vein has a strike of about N. 50° E. (mag.) and dips about 35° E. It was mined in 1920, 1921, and the first part of 1922, and was the last property to be worked; it was closed down in April, 1922. The total production from this property probably has not been over 1,000 tons. The vein has been opened in two places by shallow pits. Pit No. 2 was about 20 feet deep, 70 feet long, and 40 feet wide. The width was due to the removal of overburden on the inclined vein. The vein matter seemed to have varied 1 to 7 feet in width. Apparently all the ore had been removed except in one corner of the pit, where there was a feeder or chimney through which the mineralizing solutions may have come. Pit No. 1, about 100 feet west of pit No. 2, was about 60 feet deep, 100 feet long, and 30 to 40 feet wide. The ore was 1 to 7 feet wide and bottomed in pure quartz. All of the ore has been worked out. Between No. 1 and No. 2 pits was a stock pile containing about 50 tons. The ore was all pure white, hard, granular, and opaque. Mixed with the ore was much barite and in places galena, chalcopyrite, pyrite, and malachite. The fluorspar was intergrown with quartz and considable cobbing and hand sorting would probably be necessary to produce a marketable grade.

Equipment at this property had evidently been used at other mines. It consisted of one 30-horsepower wood-fired locomotive-type boiler, two small double-cylinder double-drum hoists, one single-stage steam-driven air compressor with a capacity of about 80 cubic feet of free air per minute (it will run one hammer drill), one small vertical engine which runs a saw to cut up firewood, and two derricks.

Wheeler property.—This property has never been worked and has not even been developed, and therefore was not visited.

Springer property.—This property was operated for a short time in 1920 and about 9 tons were produced, all of the ore in sight being removed. The property was not visited.

Aldrich and Paine mines.—No ore ever found. Property not visited.

Bill mine.—A pocket of about 40 tons of fluorspar was worked out in 1918. This material was stated to be largely specimen material. No other ore was found and the property was abandoned. Not visited.

GENERAL CONSIDERATIONS

The haul from all of these properties averages 7 to 8 miles, mostly down grade over fairly good mountain roads. Haulage was by motor trucks in summer and by sleds in winter.

No milling has ever been done here and the only concentration involved hand sorting and washing in a trough washer. The ore shipped, therefore, was all hand-picked fluxing lump. No grinding or acid-grade spar was noted. Most fluorspar was pure white, but some was greenish. Crystalline and compact granular forms were noted. Much of the quartz gangue was apparently so intergrown with the fluorspar that it could not be separated mechanically to yield a low-silica product.

With the exception of the Stoddard No. 1, the deposits were all very small and even there costs were probably high. From the ore still visible most of the ore was probably low; evidently part of it at least was high in barite. Practically all the known ore has been exhausted and it is doubtful if any considerable production will ever come from these deposits. The country is rolling and covered in most places with a mantle of dirt, and vegetation is rather heavy, making prospecting difficult. There are no evidences of faulting or of any definite system of fissures which may be easily followed, hence prospecting must be guided by the finding of float or the general directions of the known veins. Other deposits may be found, but until they are this district can not be relied upon to produce any important tonnage of fluorspar.

No openings were being worked and no information was available as to when they might be reopened.

TENNESSEE [28]

Fluorspar deposits occur in several localities in Tennessee, and a small commercial production was obtained from 1902 to 1906 and again in 1917–18. Known deposits of possible commercial value are in Smith, Wilson, Trousdale, Putnam, London, McMinn, and Monroe Counties.

Fluorspar development work was first started in 1901 in Smith County between Rome in that county and Bellwood, Wilson County, about 1 mile west of the Cumberland River and about 87 feet above the river level. The Tennessee Fluorspar Co. was formed to mine this property and a small, unrecorded production resulted in 1902. No mill was erected and the ore was shipped crude in river barges to Carthage and thence by rail chiefly to Birmingham, Louisville, Cincinnati, and New York.

Various Tennessee State reports say that this deposit was 100 feet wide and was prospected to a depth of 85 feet when water was encountered and the work stopped. Fohs [29] states that near the surface in a limy clay were bowlders of massive crystalline fluorspar, weighing 10 to 1,500 pounds each. When a shaft was sunk, limestone was encountered at a depth of 25 feet; immediately below was a vein of fluorspar 8 feet thick, dipping 10 to 20° west and striking northwest. The footwall, consisting of gray "lime-sand" or clay resulting from the alteration of limestone, was coated with crystallized calcite that looked like the fluorspar. A later report states that at a depth of 120 feet in the inclined shaft fluorspar occurred in beautiful white crystallized aggregates. Another report says that these deposits are fissure veins in Ordovician limestones that closely resemble the deposits of the central Kentucky district. No igneous

[28] See Hayden, H. H., "Fluorspar in Tennessee": Am. Jour. Sci., vol. 4, 1822, p. 51.
Ninth to Twentieth Annual Reports of Mining Department of Tennessee.
Safford, J. M., Geology of Tennessee. 1869, pp. 224, 268, and 284.
Southern Railway, Tennessee Marble Industry; Southern Field: Vol. 2, No. 5, November, 1906, p. 10.
Articles on "Fluorspar," by F. Julius Fohs, Mineral Industry, vol. 14, 1905, pp. 198–203; vol. 15, 1906, pp. 323–332.
Nelson, Wilbur A., Mineral Products along the Tennessee Central Railroad: Tennessee Geol. Survey, Resources of Tennessee, vol. 3, No. 3, July, 1913, p. 151.
See also footnote references on following pages.

[29] Fohs, F. Julius, Fluorspar: Mineral Industry, vol. 14, 1905, p. 200.

rocks have been noted near these deposits. A partial analysis of fluorspar shipped from this mine, as given in several Tennessee State reports, is as follows: CaF_2 96.18 per cent, SiO_2 0.64 per cent, and S 0.17 per cent. Neither lead nor zinc ores accompanied the fluorspar.

In 1917–18 some work was again done on the deposits of this district and a small but unrecorded production resulted. No further work has been done.

In 1906, the Alcorn fluorspar mine near the old Alcorn station on the Tennessee Central Railroad, 2 miles east of Buffalo Valley, Putnam County, was prospected. Here were found lumps and crystals of yellow fluorspar within 1 or 2 feet of the surface. A pit was sunk 10 to 15 feet deep and fluorspar was found lining crevices in limestone, but no solid vein was developed. No lead or zinc ores were found here. About 20 tons of ore, all surface material, was shipped in 1906. No further production resulted.

In the barite deposits of the Sweetwater district, in London, McMinn, and Monroe Counties, eastern Tennessee, fluorspar occurs frequently, particularly at the Howard, Ballard, and Minton mines.

Due to the intimate admixture of fluorspar, barite, calcite, and chert, and to the impossibility of making a clean separation of these minerals by present known methods, it does not seem probable that these deposits have much commercial interest at present.

At National Cemetery, near Asheville, a vein of fluorspar and barite 1 to 2½ feet wide is reported. Another locality, probably only of mineralogical interest, is noted at Watauga Point, Carter County.

The following table from the annual report of the Tennessee State Mining Department gives the total recorded fluorspar production. All the recorded production but 20 tons from the Alcorn mine, valued at $160 in 1906, came from the mine near Rome, Smith County.

Tennessee fluorspar production

	Tons	Value
1902	(1)	----------
1903	1,000	$11,250
1904	0	0
1905	200	1,500
1906	120	860
1906–1917	(2)	----------
1917–18	(3)	----------

[1] Small, unreported production.
[2] No production.
[3] Small, unrecorded production.

In view of the reported character of the present known fluorspar deposits in Tennessee and the fact that no important production resulted during the period of very high fluorspar prices attending the World War, the status of the Tennessee deposits as an important future source of fluorspar is very uncertain.

NEW YORK

Fluorspar is reported in several localities in New York, and many years ago a few tons were shipped from small deposits. No mining has been done in recent years and it is probable that most occurrences are of mineralogical interest only. Newland[30] states that fluorspar is associated with certain magnetite deposits in the Adirondacks, particularly at Palmer Hill, occurring as small grains mixed with feldspar, magnetite, and quartz and constituting from a few per cent up to 50 per cent of the mass. If the magnetite ore were milled the fluorspar might be saved as a by-product. A similar deposit is noted in the Barton Hill section of the Minerville district.

At Macomb,[31] St. Lawrence County, a small vein of sea-green fluorite in limestone yielded about 15 tons of high-grade crystallized ore. On the east shore of Muscalonge Lake, about 4 miles northwest of Oxbow, Jefferson County, a vein was reported to have been worked on a considerable scale. There is another vein about 2 miles east of this deposit, on Vroomans Lake. Other occurrences in this region are at the lead mines of Rossie and Mineral Point, and near Gouveneur, De Kalb, Hammond, Fine, and Theresa. There are other deposits at Lockport and Rochester in the Niagara limestone; at Fayetteville, Onondaga County; Lowville, Lewis County; and Johnsburg, Warren County.

Probably very few, if any, of these deposits are large enough to warrant exploitation at present.

PENNSYLVANIA[32]

Fluorspar occurs at several places in Pennsylvania, mostly in the limestones of the Great Valley and in some of the iron or other mines. It apparently has never been mined in this State and the following localities are probably of mineralogical interest only.

At York, York County; Pine Grove, Cumberland County; S. Plum's farm, Franklin County; De Turks, Exeter Township, Berks County; Edwards quarry, Newlin Township, Chester County; Ironton, Lehigh County; Cornwall, Lebanon County; at Delaware Water Gap, Monroe County; at the Wheatley mine, Phoenixville, Chester County; and gneissic rocks at Frankford and Falls of Schuylkill, Philadelphia, both in Philadelphia County.

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[30] Newland, D. H., Mineral Resources of the State of New York: New York State Min. Bull. 223, 224, July–August, 1919, pp. 77–78.

[31] Whitlock, H. P., Minerals not commercially important; New York State Geologist, 23d Ann. Rept., 1903, pp. 187–188.

[32] See Brown, Amos P., and Ehrenfeld, Frederick, Minerals of Pennsylvania: Topog. and Geol. Survey of Pennsylvania, Rept. 9, 1913, p. 64.

TEXAS

A vein of white fluorspar about 1 foot thick has been reported in Burnet County about 4 miles from Burnet. Zinc-bearing fluorspar is also noted about 7 miles west of Burnet. Other localities reported are: Brewster County, sparing occurrences in association with quicksilver deposits; Gillespie County, near Enchanted Rock; Llano County, at Baringer Hill. No commercial production has ever been reported from these deposits.

VIRGINIA [33]

Fluorspar occurs in small quantities at several places in Virginia, but, as far as known, shipments have only been made from one locality. In 1906 small amounts were reported to have been obtained as a by-product in mining Albemarle County lead and zinc ores. At a mine in the eastern foothills of the Blue Ridge, about 2 miles northwest of Faber on the Southern Railway, a vein averaging 4 feet in width was opened at several places. The vein occurs in metamorphosed crystalline schists cut by basic igneous rocks of the diorite and diabase types, and consists of a series of lenses filled with fluorspar, galena, sphalerite, and some quartz. This vein has been traced several miles. No production statistics are available, but the output was probably very small. The grade of the ore is not reported but fluorspar is stated to be the predominant mineral and sphalerite the principal sulphide.

In the mica deposits of Amelia County, near Amelia Court House, the chlorophane variety of fluorspar is found. Specimens from this locality are extremely sensitive to heat. Kunz states "that it becomes distinctly luminous by the warmth of the hand, and that it shows a triboluminescence so marked that the slightest friction will cause it to emit a phosphorescent light. A spectroscopic examination, by Humphreys, of the Amelia County chlorophane showed that yttrium was present and ytterbium in some."

Fluorspar is also reported as occurring in small amounts with the lead and zinc ores in the Cambro-Ordovician limestones of southwest Virginia and in the same limestones in Clarke and other counties of the Valley region.

The only known deposits of possible commercial interest are probably those of Albemarle County, and developments there have not yet progressed far enough to make predictions possible.

[33] See Watson, Thomas L., Mineral Resources of Virginia: Virginia Jamestown Exposition Commission, 1907, pp. 215, 388, 542–544. Lead and Zinc Deposits of Virginia: Virginia Geol. Survey, vol. 1, 1905, 156 pp. Lead and Zinc Deposits of the Virginia-Tennessee region: Trans. Am. Inst. Min. Eng., vol. 36, 1905, British Columbia meeting, pp. 681–737.

OTHER STATES

Fluorspar occurrences have been reported in the following States, but they are probably only of mineralogical interest.

Arkansas.—Fluorspar has been reported near Lawrence, Garland County, near the mouth of Gulpa Creek, but it has never been mined.

Connecticut.—At Trumbull, Fairfax County, the chlorophane variety occurs with topaz; at Plymouth, Litchfield County, octahedral and dodecahedral crystals; at Willimantic, Windham County, purple, in a vein in gneiss, and also sparingly at the topaz vein; at the old Middletown lead-silver mine, and at Haddam Neck, in Middlesex County. It is found in considerable quantity at Trumbull only.

Georgia.—Beautiful purple crystals occur in the Knox dolomite formation, near Graysville, Catoosa County.

Maine.—Fluorspar occurs on Long Island, Blue Hill Bay, in veins.

Maryland.—Fluorspar is reported near Cumberland, Allegany County.

Massachusetts.—Fluorspar has been found in small quantities in Franklin County at Conway, Deerfield, and Northfield, in Hampshire County, in the Southampton lead mine near Northampton, and West Springfield.

Missouri.—Reported deposits are in Madison County, at the Einstein silver mine near Iron Mountain, and in St. Louis County, in the St. Louis limestone near St. Louis.

New Jersey.—Fluorspar occurs in small quantities mixed with the zinc ore at Franklin Furnace, Sussex County.

South Dakota.—Fluorspar occurs in mines near Portland (Trojan P. O.), Maitland district, Lawrence County, and in considerable quantity in the Ulster mine.

Vermont.—Fluorspar in green cubes is found at Putney.

West Virginia.—Fluorspar occurs at Shepherdstown, Jefferson County, in white limestone; it is not mined.

Wisconsin.—Near Appleton small crystals of fluorspar have been observed in the joints of an Ordovician limestone.

OTHER COUNTRIES OF NORTH AMERICA

CANADA

BRITISH COLUMBIA—ROCK CANDY GROUP

A deposit of fluorspar occurs on Kennedy Creek, a tributary to the North Fork of the Kettle River, near Lynch Creek station on the Kettle River Railway, 15 to 20 miles north of Grand Forks, British Columbia. This property, consisting of five claims (267.8 acres) of which the best known is the Rock Candy, belongs to the Consolidated Mining & Smelting Co., of Trail, British Columbia. The Rock

Candy group or Rock Candy mine began producing in 1918, and continued until early in 1921, when it was closed down due to low prices and lack of market. About July 1, 1922, work was again started.

The deposit [34] consists of veins and stringers occupying a fractured zone between walls of alkali-syenite and alkali-syenite porphyry. This zone is about 140 feet wide at the surface, but the fluorspar-bearing part varies from about 50 feet in width at the top level opened to 35 feet 92 feet below and 25 feet at the lowest level, which is about 190 feet below the top level. Within the fractured zone are stringers of chert, kaolin, barite, and quartz, and two veins 3 to 7 feet wide carrying fluorspar mixed with quartz, chalcopyrite, limonite, galena, chalcocite, pyrite, and covellite, with large tabular crystals of barite in the cavities.

Mining started on the side of a hill and the deposit is opened by three adit tunnels 90 to 100 feet apart vertically and mined by cross-cuts connecting the veins, by drifts along the veins, and by raises connecting the levels. On the lowest level the ore body is split up by tongues of alkali-syenite, which make mining and development more difficult and expensive. In 1919, 26 men were employed and 5,442 tons of ore mined.

Ore is hauled over an aerial tramway about 2 miles long to the mill, where it is concentrated by a special process already described under "Milling" that makes use of its property, decrepitation. In 1919, 16 men were employed and 3,372 tons of ore milled, producing 898 tons of concentrates, averaging 84 per cent CaF_2 and SiO_2; thus the recovery was about 26 per cent based on mill heads, or about 16½ per cent based on ore mined.

In 1920, 22,673 tons of ore were mined and 19,720 tons milled, yielding 7,477 tons of concentrates, with the men at mine and mill averaging 61. In 1920 the recovery was about 33 per cent based on ore mined and about 38 per cent based on ore milled.

The low recovery is due, first, to the presence of iron and copper sulphides which can not be milled out, and, second, to the intimate admixture of quartz and fluorspar. Ore carrying any large amount of copper or iron sulphides has been discarded. By the decrepitation process used to separate out the silica high tailing losses result when concentrates of a commercial grade are made. It is reported that a number of carloads of concentrates shipped to steel mills in the Chicago district were of very poor quality and were rejected, although analyses of several carload shipments in 1920 are reported to have averaged about 90 per cent CaF_2 and 7.25 per cent SiO_2.

[34] See Minister of Mines of British Columbia, Annual Report for 1919: Vancouver, 1920, pp. N 164–165.

In 1918 production from the Rock Candy mine was 89 short tons, in 1919 the production was 898 tons of concentrates, and in 1920 shipments were 7,477 tons. In 1921, 3,367 tons of concentrates, valued at $82,811 ($24.50 per ton), were shipped from the decrepitation plant. In addition, 6,291 tons of rejects from this plant were shipped to Trail, where they were treated by a flotation process. Concentrates shipped from the flotation plant amounted to 1,909 tons, valued at $49,620 ($26 per ton). Thus the total shipments from the two mills amounted to 5,276 tons. An additional small tonnage shipped for experimental purposes brought the total 1921 shipments from this district to 5,403 tons, valued at $134,523.

Part of the Rock Candy fluorspar is shipped to Trail for the manufacture of hydrofluoric acid, which is used in the lead refinery. Some shipments have been made to other Canadian points, but most of the output apparently has been shipped to steel plants in the Chicago district. In March, 1921, the freight rate on fluorspar from Archibald, British Columbia, the point of shipment, to Chicago was $15.33 per ton. The import duty was $1.50 per ton. Under present normal conditions it does not seem possible that this deposit can compete in the principal markets of the United States with gravel-grade fluorspar from domestic deposits.

ONTARIO—MADOC DISTRICT

Practically all the fluorspar production of Canada, aside from that from the Rock Candy mine in British Columbia, has come from deposits near Madoc, Ontario. Mining was started here in a small way in 1905, but serious work did not begin until the period of high prices in 1916. In 1915 there was no production, in 1916 1,283 tons, valued at $10,146, were produced. In 1918 a peak of 7,286 tons, valued at $153,190, was reached, followed by a decline to 3,704 tons, valued at $67,381, in 1920; and in 1921 there was no production, but shipments of 116 tons, valued at $1,744, came from two producers. This decline in production was apparently due to exhaustion of the larger deposits and the somewhat unsatisfactory grade of the product, as well as the decline in prices.

Deposits of the Madoc district are in the southern part of Madoc township and in the northern part of Huntington township and are nearly all within a radius of 5 or 6 miles of Madoc station, at the north end of the Belleville-Madoc branch of the Grand Trunk Railway in the central part of southeastern Ontario. The ore occurs in nearly vertical veins occupying fault fissures in a pre-Cambrian complex of crystalline limestones, dolomites, and other sedimentaries cut and intruded by gabbro, diorite, syenite, and granite, and overlaid by at least 150 feet of nearly flat Paleozoic sediments, consisting of limestones and calcareous sandstones. The mineralization occurs in both the pre-Cambrian and the Paleozoic rocks, and often near an igneous contact.

The veins range in width from a few inches to a maximum of 17 feet. The fluorspar occurs principally in steeply pitching lenses within the veins, which range from a few feet to 200 feet in length and from 2 to 17 feet in maximum width. Only a few large lenses have been found.

The chief minerals found in the veins, in order of abundance are: Fluorspar, barytes, calcite, and celestite. Minerals found occasionally or in minor quantities, in order of abundance are: Quartz, marcasite, pyrite, chalcopyrite, tetrahedrite, malachite, and elaterite. Barite is present practically always in large quantities and in parts of some deposits is more abundant than fluorspar. Visible quartz is often absent. The metallic sulphides occur only in minor quantities and have little or no effect on the grade of product.

The fluorspar occurs both in massive form and in crystals lining the walls of cavities. The color is usually white, gray, or green, but honey-yellow, blue, purple, rose, and red are common. Some very clear crystals which contain optical fluorspar are found. Two typical vein structures are noted: (1) Banded, massive, in which cavities are uncommon; and (2) cavernous, in which the vein material forms partitions between caverns [35] and cavities form a large part of the total volume. Wilson gives analyses of typical shipments of fluorspar from the Noyes mine, the largest shipper in the past, as follows:

Analyses of fluorspar shipments from Madoc district, Ontario, Canada

Analysis	1	2	3	4	5	6	7
CaF_2 (fluorspar)	80.68	84.35	74.05	80.24	73.52	81.81	76.61
$BaSO_4$ (barite)	5.10	5.34	9.34	7.54	11.88	5.30	8.13
$CaCO_3$ (calcite)	10.04	6.75	10.76	7.16	10.31	7.85	9.11
R_2O_3 (alumina, ferric oxide, etc.)	2.00	2.10	3.00	1.20	1.20	1.88	3.07
SiO_2 (silica)	2.33	1.37	3.60	3.07	2.40	2.97	2.74
Total	100.15	99.91	100.75	99.21	99.31	99.91	99.66

NOTE.—1 to 6, typical shipments; 7, average of 16 shipments. Analysis by Algoma Steel Corp.

The two largest veins, the only important producers, are the Noyes and the Perry; both are on the Noyes-Perry fault.

The Noyes mine is about one-half mile east of the Moira Lake station on the Belleville-Madoc branch of the Grand Trunk Railway. Mining was started here in 1916 and continued until the fall

[35] Wilson, M. E., "The fluorspar deposits of Madoc district, Ontario": Canadian Dept. Mines, Geol. Survey Summary Rept. for 1920, part D, 1921, pp. 41–78.

of 1920, when this mine was closed down. Over 15,000 tons of fluorspar were produced during that period. The workings consist of lateral underground openings extending over about 1,100 feet along the vein. The mine is opened by two vertical shafts and by five working levels, 50 feet apart vertically, the lowest being the 250-foot level. The largest lens developed had a maximum width of 17 feet, horizontal length of about 200 feet, and axial length (on the pitch of about 55°) of about 250 feet. From this lens, which has been practically worked out, about 10,000 tons of fluorspar were obtained. Five or six much smaller and narrower lenses were found, and they also have largely been mined out.

The Perry mine, about 1½ miles to the northwest, on the same vein and within a few hundred feet of the railroad, was first opened late in 1915. Mining operations were carried on until December, 1917, resumed in November, 1918, and again suspended in the fall of 1920. Partly connected surface and underground workings have opened up the vein for a total length of about 450 feet, but continuation of the vein for a total length of about 1,100 feet has been assumed. The principal lens mined had a maximum thickness of 6 feet and a maximum axial width of 100 feet. The axial length is undetermined, but at the 140-foot level (the lowest worked) its thickness is 5 feet. The ore in this lens has been mined out above the 140-foot level. Other minor lenses with maximum thickness of 2 to 4 feet have been mined. The ore is mostly massive and banded and contains such a high proportion of fluorspar that most of the vein material is minable.

Many other small mines and prospects are scattered over this area, but production has been unimportant. The maximum width of vein matter has usually been not over 2 feet and often less than 1 foot. Where wider veins have been found the lenses have usually been small.

Available reports indicate that the larger known lenses and pockets have been mined out for the most part. The largest lens yielded only about 10,000 tons of fluorspar. Most of the remaining known deposits are narrow stringers, usually less than 2 feet wide. Practically all veins contain a large proportion of barytes, a very objectionable impurity which can not be separated out mechanically by present known milling methods. No milling has been done in the district and most of the shipments have averaged over 8 per cent barytes and less than 77 per cent CaF_2. As the quality of the fluorspar is low, the deposits small, and other factors unfavorable, this district is not likely to produce any large tonnage of fluorspar acceptable under present standards.

OTHER LOCALITIES

Fluorspar has been reported at a number of other localities in Canada, but, so far as known, the deposits are so small they have mineralogical interest only, so remote from transportation that mining would not be feasible, or not prospected enough to prove the worth of the deposit. The deposits of this class more recently reported include the following:

Near Harcourt in Cardiff Township, Haliburton County, a deposit of fluorspar was discovered in 1918 on the Schickler farm. The fluorspar is reported as violet blue and associated with calcite and apatite in a vein of good width. Recently the United States Bureau of Mines received samples from a deposit somewhere in Haliburton County, possibly from this same deposit or one close to it. This deposit is stated to have been proved along the strike of the vein for over 1¼ miles. At the two ends the fluorspar is said to be associated with calcite but in the center it is of a higher grade and associated with crystals of feldspar and books of mica. Two samples from this deposit had the following composition: No. 1 (deep purple), CaF_2 99.02 per cent, SiO_2 0.24 per cent, and $CaCO_3$ 0.35 per cent. No. 2 (crude ore, mixture of purple fluorspar and white calcite), CaF_2 43.0 per cent, SiO_2 0.16 per cent, and $CaCO_3$ 56.23 per cent. No barytes was observed in either sample, but the No. 2 grade contained occasional prismatic crystals of apple-green apatite (a calcium phosphate containing chlorine or fluorine, or both). This dark-purple fluorspar is a somewhat lighter purple when finely ground, but most of the color disappears on slight heating. A strong odor somewhat resembling that of chloride of lime is evolved during grinding. Upon heating, an inflammable gas is driven off that suggests the presence of hydrocarbons.

In the "Matachewan gold area" in Ontario, in the southwestern part of the Timiskaming district near Fort Matachewan in Cairo and Alma Townships, fluorspar has been found in quartz veins in small quantities. It is dark purple and occurs in masses in the quartz veins or in the syenite wall rocks near the veins, and is also found in the Biederman barytes vein. The largest reported vein is about 7 inches wide. Owing to the very small size of the deposits, the mixture with quartz and barytes, and the inaccessibility of the deposits to railroads and to consuming markets, this area seems of no present commercial importance.

Fluorspar deposits are reported to occur in Pilgrims Island in the St. Lawrence River, off Kamouraska, and at St. Andre and other places in Kamouraska County, Quebec. These deposits have never been opened up, and no information is available concerning them.

GENERAL CONDITION OF CANADIAN FLUORSPAR INDUSTRY

The Canadian consumption of fluorspar for the past 10 years, except for the abnormal years of 1914 and 1921, seems to have ranged from 10,000 to 17,000 tons per year. Except for 1920 and 1921 the exports have been less than 1,000 tons annually and the imports have ranged from about 8,000 to 13,500 tons per year. During the year of Canada's greatest fluorspar production, 1918, imports amounted to nearly 63 per cent of the total consumption. These facts are shown in the following table:

Fluorspar production and consumption in Canada, 1913–1919

[Short tons]

Year	Production of open-hearth steel [1]	Fluorspar			
		Consumed [1]	Shipped [1]	Exported to United States [2]	Apparent imports
1913	864, 035	10, 687			10, 687
1914	623, 698	7, 845			7, 845
1915	990, 795	13, 520			13, 520
1916	1, 400, 883	13, 213	1, 284	556	12, 485
1917	1, 685, 715	17, 084	4, 249	93	12, 928
1918	1, 746, 334	17, 307	7, 362	913	10, 858
1919	1, 008, 540	12, 796	5, 063	902	8, 635

[1] Data compiled from reports of Canada Department of Mines, Mines Branch.
[2] Data compiled from Bureau of Foreign and Domestic Commerce, U. S. Department of Commerce.

From the nature, size, location, and quality of the known Canadian fluorspar deposits, and consideration of the statistics of production and consumption during the period of the highest fluorspar prices known, it seems very improbable that Canada can ever care for her own domestic needs under normal conditions. It appears even more certain that Canada will not supply any large part of the needs of the United States.

CUBA

There is no fluorspar production in Cuba, but fluorspar is reported to occur in the vicinity of Bueycito in Oriente Province. No information as to the extent of the deposit is available, but it is stated that it is doubtful whether it could be profitably developed.

MEXICO [36]

Fluorspar has been mined in Mexico for a number of years, but no production statistics are available. It is probable that no fluor-

[36] See Wittich, Ernesto, " La fluorita en los criadores de contacto y de cinabuo de Guadalcazar, San Luis Potosi ": Bol. Petról. vol. 13, No. 197, Apr. 17, 1920, p. 10; Pena, Manuelo, " Los criadores de fluorita en Santa Cruz, Sonora ": Bol. Minero, vol. 5, No. 546, 1918, p. 577; also brief summary in U. S. Geol. Survey Mineral Resources for 1919, part 2, pp. 365–366.

spar has been imported or exported and that all the local production has been used within the country. It was reported that from 1917 to 1923 fluorspar consumption in Mexico averaged about 600 tons per year. Although fluorspar is reported to occur in many localities it has been recognized in commercial deposits at but few places and has been mined in important quantities from only one deposit, in the State of San Luis Potosi, in Mount Realejo, near Guadalcazar. Here fluorspar is found in masses or irregular veins, associated with quartz, pyrite, and a little antimony along a contact between granite and limestone. The ore is apparently sorted by hand and hauled to the nearest railroad station at Villar, at least 10 miles away. It is used in the iron and steel industry at Monterey and in the manufacture of hydrofluoric acid. Early in 1923 this mine was reported to be producing 50 tons per month, and the average value f. o. b. mine was about $14 (United States) per ton.

Several other deposits are known in this district. About three-fifths of a mile west of Guadalcazar fluorspar occurs in a contact deposit, associated with pyrite, tetrahedrite, arsenopyrite, and stibnite. About 3 miles away fluorspar is found in a deposit of cinnabar in limestone, associated with barite and anhydrite. On the eastern slope of Mount Realejo near the La Luz mine is another extensive contact deposit containing fluorspar, garnet, calcite, pyrite, and black and white tourmalines.

A deposit of green fluorspar has been worked to a small extent in the town of Chalchihuites in the State of Zacatecas. Other localities of possible commercial interest are the Magdalena district of Sonora, in the Garandiaz mine near Taxco in the State of Guerrero, and on Santa Roas Mountain north of Guanajuato (in rhyolite associated with pyrite and bismuth minerals).

The following list of fluorspar occurrences in Mexico has been compiled by the Geological Institute of the Mexican Government:

Aguascalientes.—District de Ocampo, Mineral de Tepezala, "No Pensada" (mine).

Coahuila.—District de Monclava, Municipality Romero Rubio, La Panuco Copper Co. and Continental Copper Mining Co. (mines).

Chihuahua.—District de Arteaga, Municipality Chinipas, Mineral de Palmarejo (mine). District de Camargo, Municipality y Mineral de Naica, Naica y Siglo XX, Sierra Encinillas (mines). District de Hidalgo del Parral, Municipality y Mineral del Parral, Crestas de la Veta, El Tajo, and Cerro de la Cruz Prieta (mines).

Durango.—District de Mapimi, Mineral y Municipality de Mapimi, Ojuela, Santa Rita, Socavon de la Trinidad (mines). District Nombre de Dios, Mineral de Las Vacas (mine). District de San Juan del Rio, Bufas de Coneto (mine). District de Santiago Papasquiaro, Mineral y Municipality de Guanacevi, Socavon de San Jose (mine). District de Tamazula, Municipality de Tamazula.

Guanajuato.—District de Guanajuato, Mineral y Municipality de Guanajuato, El Nopal, El Obrero, Sierra de Santa Rosa (mines), Mineral del Calvillo, Bismute (mine).

Guerrero.—District de Alarcon, Mineral y Municipality de Taxco; Municipality de Tehuilotepec, Tehuilotepec (mine).

Jalisco.—Canton de Ahualulco, Town y Mineral de Hostotipaquillo.

Mexico.—District de Sultepec, San Pedro mine.

Puebla.—District de Tetela, Mineral y Municipality de Tetela del Oro.

Queretaro.—District de Cadereyta de Mendez, Municipality y Mineral del Doctor.

San Luis Potosi.—District de Catorce, Rancho Salado. District de Guadalcazar, Municipality y Mineral de Guadalcazar. District de Santa Maria del Rio, Municipality Reyes, Cerro de la Piedra del Molino, Hacienda, San Pedro. District de Tancanhuitz, Arroyo de las Papas.

Zacatecas.—District de Mazapil, Municipality y Mineral de Mazapil, San Jose mine. District de Sombrerete, Mineral y Municipality de Chalchihuites, Santa Maria Dolores mine. District de Zacatecas, Municipality y Mineral de Zacatecas, Las Cantera mine.

Most Mexican deposits now known are apparently in the southern or south central part of Mexico and far inland. Shipment into the United States would therefore entail a very long haul or a combination of a long land haul with a long water haul. Furthermore, most of the deposits seem to be far from a railroad and at least part of them contain barite. No information is now available to suggest that any important part of the consuming needs of the United States can be supplied from Mexican deposits.

CENTRAL AMERICA

GUATEMALA

Fluorspar has been found in Guatemala in the departments of Baja Verapaz and El Quiché and elsewhere in the Republic, but very little is known regarding the quality, composition, or extent of the deposits. There is no fluorspar production, no local consumption, no imports, and no exports.

SOUTH AMERICA

ARGENTINA [37]

Fluorspar occurs in Argentina at San Roque in the Province of Cordoba in fissure veins from 8 to 12 inches wide to lodes several yards wide in biotite gneiss and associated with pegmatites. This fluorspar occurs in the gneisses east of their contact with the granite massif of the Andes. The deposits are reported as large and pure.

[37] See Miller, B. L., and Singewald, J. T., Mineral Deposits of South America. New York, 1919, p. 54; also Beck, Richard, tr. by Weed, W. H., The Nature of Ore Deposits, New York, 1905, p. 218.

The fluorspar occurs in bands that range from colorless, light green, yellow, violet, and blue, to almost black. The associated minerals are quartz, feldspar, muscovite, pyrite, and chalcedony.

BOLIVIA

Fluorspar is reported to occur in very small quantities at several places in Bolivia, but none is mined or exported. Even if the deposits were of commercial size, high transportation costs to the coast would probably preclude profitable operation. There are no imports and no consumption of fluorspar in Bolivia.

BRAZIL

Deposits of fluorspar are reported to exist in the State of Minas Geraes, but none has been mined and no information is available on the extent of the deposits. In mining limestone near Palmyra in the southern part of Minas Geraes a small amount of fluorspar is obtained by a by-product. This small quantity seems to be enough for local needs, as there are no imports. Local fluorspar consumption is insignificant. A small amount is used in a glass plant in Rio de Janeiro.

EUROPE

ENGLAND [38]

England stands second only to the United States as a fluorspar producing country; in recent years these two countries together have produced around 80 per cent of the world's fluorspar output. Before 1901 England's fluorspar production averaged less than 1,500 long tons per year, but gradually the production increased to a maximum of over 65,000 long tons in 1917. Since 1917 it has varied from 23,000 to 55,000 long tons per year. Before 1910 much of the British production was exported to the United States. In 1910, such exports amounted to about 62 per cent of the British production; in 1911, 53 per cent; 1912, 49 per cent; 1913, 37 per cent; 1914, 27 per cent; 1915, 19 per cent; 1916, 20 per cent; 1917, 17 per cent; 1918, 20.5 per cent; 1919, 14.5 per cent; and 1920, 27 per cent; 1921, 6 per cent; 1922, 65 per cent; 1923, 40 per cent; and 1924, 58 per cent. Some fluorspar is exported to Canada and formerly a little to Russia, but the United States has always been the largest

[38] The most complete recent account of fluorspar in Great Britain is given by Carruthers, R. G., Pocock, R. W., Wray, D. A., and others, Fluorspar: Spec. Repts., Min. Res. Great Britain, Geol. Survey Mem., vol. 4, 1916, 38 pp. (2d. ed., 1917).

See also Imperial Mineral Resources Bureau (London), Fluorspar (1913–1919): 1921, 18 pp.

Wedd, C. B., and Drabble, G. C., "The fluorspar deposits of Derbyshire": Trans. Inst. Min. Eng., vol. 34, 1908, pp. 501–535.

The Engineer (London), "Fluorspar"; Aug. 21, 1908, pp. 185 and 187.

customer. Exports evidently declined steadily until about 1917, while British home consumption increased steadily. Since 1917, business conditions have been so unstable that the present trend is not clear. In 1918 British officials estimated that normal fluorspar consumption in the United Kingdom was about 35,000 long tons per year.

From 1906–7 for about 10 years, much of the British production came from the reworking of tailings and waste dumps at old lead mines, principally in Derbyshire. It was reported in 1916, however, that these dumps were nearly exhausted and could not be depended upon for any large future tonnage. From available information production from this source in the past few years seems to have been relatively small.

Fluorspar deposits in Great Britain are centered in Derbyshire, Durham (north of England) including adjacent parts of Northumberland, Yorkshire, and Cumberland, Cornwall, and North Wales (Flintshire). Of these districts only the first two have much importance. Derbyshire has usually been the larger producer, but a large part of this production for a number of years came from reworking waste piles rather than from new mining operations. The following descriptions of the principal districts in Great Britain are given by Carruthers, Pocock, and Wray.[39]

DERBYSHIRE

In Derbyshire, the oldest and best known fluorspar center in Britain, the mineral occurs in filling vein fissures and other cavities in the Carboniferous limestone. A description of the veins has been given in an earlier publication,[40] and parts of the following accounts have been reproduced from it. Fluorspar has also been recently studied by Wedd and Drabble [41] and their work with that of Egglestone is the source of much information.[42]

Fluorspar is found in comparatively few of the rake veins that traverse the Derbyshire lime. Wedd and Drabble say that it is practically confined to the limestone and does not pass up into the overlying grits and shales; moreover, it is restricted to the uppermost 600 feet of the limestone, mainly in the uppermost 300 or 400 feet. This restriction confines the occurrences to the margin of the limestone massif; inward from the margin and at depth the spar is

[39] See footnote 37.

[40] Green, A. H., Foster, C. Le N., and Dakyns, J. R., The Geology of the Carboniferous Limestone, Yoredale Rocks, and Millstone Grit of North Derbyshire: Mem. Geol. Survey Great Britain, 2d ed., 1887, 228 pp.

[41] Wedd, C. B., and Drabble, G. Cooper., "The fluorspar deposits of Derbyshire": Trans. Inst. Min. Eng., vol. 35, 1908, pp. 501–535.

[42] Egglestone, W. M., "The occurrence and commercial uses of fluorspar": Trans. Inst. Min. Eng., vol. 35, 1908, p. 236.

replaced by barytes and calcite. They noticed, moreover, that practically all the fluorspar comes from the eastern margin of the massif, and from the Crich and Ashover inliers beyond; little is found along the western fringe.

The massive commercial Derbyshire fluorspar is usually opaque white or faintly tinted; the well-grown cubes found in cavities are more highly colored, ranging from amber yellow to deep violet. Green, pink, and pure blue tints are noticeably absent, although "ruby-colored fluor in perfect cubes" has been recorded. A variety peculiar to the county is known as "blue John"; it is strictly local and is used solely for ornamental work. The spar is associated with barytes, calcite, and galena, and sometimes with blende, but only locally with copper ores; the metallic minerals are often concentrated in the center of the vein. The rarity of quartz is noteworthy.

Most fluorspar, both lump and gravel, is used for fluxing in iron and steel foundries. Fluorspar from Ashover is said to be in demand for refining silver and gold. Fine-ground spar is used for making hydrofluoric acid; the finest quality makes a pure white enamel glaze for pottery, especially for lavatory ware. The product of Stubbin Low or Smith's mine near Bonsall caters to this demand.

Derbyshire fluorspar is usually put on the market in two grades—lump spar, which is the mine-run product, and gravel spar, or tailings from the old ore dressings, which contains from 55 to 75 per cent CaF_2. The lump spar has some impurities, including calcite and barytes, and when dressed for market averages from 90 to 95 per cent of CaF_2.

Near Matlock and at Ashover a third grade, fine-ground fluorspar is now being produced by grinding good lump spar in a ball mill.

All mines were originally worked for lead, the fluorspar being a by-product of no commercial value, but its increasing use in smelting and other industries has caused reopening of certain mines where much fluorspar had been stored in the "gob" of the old workings.

As both fluorspar and lead can now be marketed and as the price of the latter has advanced over its former low level, prospects for the profitable working of the Derbyshire mines are promising.

Wedd and Drabble believe that the available supply of fluorspar is almost intact and can bear the strain of greatly increased annual output for many years. The surface waste heaps which have been the mainstay of the Derbyshire output for the last six years have now been well picked over, and are no longer an important source of supplies.

The fluorspar deposits of Derbyshire are found in the Castleton, Bradwell, Eyam, Calver, Matlock, Ashover, and Crich districts.

DURHAM

Although fluorspar is common in the metalliferous veins of the north of England, the commercially productive area is restricted, and the whole supply now comes from the upper part of Weardale.

Upper Weardale, from Stanhope to the western watershed, covers 80 to 90 square miles. All this ground is occupied by Carboniferous strata, mostly Yoredale rocks, composed of numerous alternations of sandstone, shale, and limestone in beds up to 100 feet thick. The dip is gentle and the outcrops wind in and out of the valleys regularly.

The district is an old lead-mining center, although the industry is not conducted on the old-time scale. Fluorspar mining is a comparatively new feature, having been started in earnest less than 20 years ago. The first record for Durham in the home office "Returns of Mines," was in 1883, when the Weardale Iron and Coal Co. (Ltd.) produced 13 tons of spar from the Red vein (probably the Crawley mine). The next year that company mined 109 tons; and from 1898 the output increased rapidly. The veins are abundant, of the normal fissure type, mostly filling small faults, and oriented in two groups, one trending southwest, the other between east and southeast. When traversing beds of limestone the veins frequently give off horizontal stringers or "flats" similar in content to the veins themselves.

In this district fluorspar is the chief constituent of veins and "flats" alike; sometimes it fills the whole vein, and spar bodies measuring as much as 20 feet across have been found. Galena, although often scattered in small quantities through the spar, is generally concentrated in the center of the vein. Some veins carry chalybite instead of galena; then the fluor not infrequently occupies the center of the vein, the iron minerals being in the walls and impregnating the country rock.

Weardale fluor is generally pale, usually an amethyst tint, although white or clear varieties are also common; green or yellow spar is rare, and red quite absent. The fluorspar is well crystallized and rarely granular, and the crystals are large.

Quartz, the commonest accessory mineral, is found in relatively small quantities, often lining geodes or cavities. Chalybite and isolated crystals of galena are not uncommon and are usually concentrated in the center of the vein. Pyrites is rare, and in contrast with the Derbyshire and Kentucky deposits there is an entire absence of barytes. The only other accessory mineral of any importance is calcite, which is never abundant, and in most of the veins is quite a rarity.

Although most of the veins carry fluorspar steadily for long distances, occasionally as much as several miles, they are sometimes subject to abrupt changes, as in the Slit vein on Peat Hill above Eastgate.

Variations in the type of country rock have not been shown to affect the quality of the spar; the largest bodies generally occur in the limestones, but sandstone strata often yield well, in contrast with the Kentucky deposits, where brecciation and poor yields are the rule at sandstone levels. Shale or " plate " generally has an adverse effect.

Most spar is exported to America and Russia in lumps or gravel form for steel smelting, and the demand for other purposes seems to be quite small. Any grinding is done to extract galena, rather than to produce fluor "sands."

In contrast with Derbyshire, little fluor has ever been recovered from old surface dumps, and now none is so obtained. At one or two mines the vein worked has not been opened before, but access to the spar is facilitated greatly by the work of the old lead miners, who have cut out the central part of the veins where the galena was concentrated and stowed their " gob " or waste, with such fluorspar as they had to remove in their search for lead. Their adits have also unwatered large tracts of ground which can still be worked for fluorspar.

For even an approximate estimate of reserves, abundant data on the rapid variations in the veins would be necessary, but the number of still untouched veins and the relatively small amount of work done on the others create a strong impression that the industry is still in its infancy and that the present output could be greatly increased without danger of exhaustion for a prolonged term of years.

The three centers for fluor production in Upper Weardale are now St. John's Chapel, Rookhope, and Stanhope.

NORTHUMBERLAND

Fluorspar is an abundant constituent of the gangue in the old galena mines round Allenheads, a few miles north of the Upper Weardale watershed. Apparently it has never been specially mined there, but there are large quantities on the waste heaps at the mine heads. About 1910 George Blackwell, Sons & Co. had several of these waste heaps hand picked for lump spar, and many thousand tons were taken away and used for fluxing, but a much greater amount remains untouched. The spar is mostly in small blue lump and gravel, and is hard and clear.

Certain layers in these waste heaps consist almost wholly of fluor gravel, evidently taken out when the vein was broad; the upper layers of the heaps, representing the material last thrown out of the mine, usually consist of "plate" and country rock, possibly indicating that the veins pinch in depth.

Spar was hauled 4 miles on a hilly road to Wearfold mine near Surrender. An east-and-west fault has stopped any spar working in the Allenheads district.

YORKSHIRE

In the higher parts of Swaledale and Wensleydale certain veins occasionally carry fluorspar, but nowhere in workable quantity. The spar occurs as nests in the lead veins at Old Rake and South Arngill mines near Muker, where they traverse the Carboniferous limestone. Purple spar has been observed in the Friarfold mine near Surrender, and in an east-and-west fault which follows the course of a fault at Marble Scar near Gunnerside.

In Upper Wensleydale small quantities of yellow fluorspar have been observed at Mossdale Gill.

CUMBERLAND

The Rotherhope mine is operated by the Veille Montague Zinc Co., Nenthead, Alston, and is on each bank of the river opposite Blackburn Bank, 2½ miles south by west from Alston.

The Rotherhope Fell vein, worked from this mine, is a fissure vein trending southwest through Yoredale rocks. It is unusually broad, averaging 15 feet, with 30 feet the maximum, but much of it is shattered country rock set in a matrix of fluorspar, quartz, and calcite, with galena and a little blende. On the northwest flank of Rotherhope Fell the vein can be traced for at least 2 miles, and to the northeast runs across the South Tyne River to join the Dowpot vein. The fluor is of good quality, but is closely intergrown with the other minerals so that pure lump is an exception. The best level for spar is at the Whin Sill under the Single Post limestone at this point; the Scar limestone is also a good producer.

The main adit, opposite Blackburn Bank, is driven 1,200 yards southeast to cut the vein; only 1,500 yards have been proved so far, the intersecting Sir John's vein to the northeast not having yet been reached. The amount of water is not serious, as the average for the whole mine is only about 20 gallons per minute.

A small amount of lump spar is obtained by hand picking after washing, but by far the greatest quantity of fluorspar is produced as a gravel residue from the galena jigs after crushing. It has been impossible to effect complete separation of the small quantities of quartz, calcite, and blende in the spar.

CORNWALL

No fluorspar was being mined for sale in Cornwall in 1916, but the mineral is recognized sparingly in the mining parts of the county, in association mainly with copper ores. According to Rudler,[43] fluorspar is a notable accessory in the lead veins also, especially those near Liskeard. The copper ore is usually replaced in depth by tin ore and wolfram, and the fluorspar usually dies out. Most of the important copper lodes are worked out and the mines abandoned, but fluorspar may be found on many old dumps; near the towns, such as Redruth, it has been picked out and sold to local assayers. All mines are now making wet assays for themselves, and there is therefore no sale for small lots of fluorspar.

At one mine only has any appreciable amount of fluorspar been obtained in recent years. On Hingston Downs near Gunnislake a 20-foot vein of fluorspar was struck in 1906.

Cornwall fluorspar occurs in the following districts: St. Agnes, Lostwithiel, Redruth, Camborne, and Callington (Hingston Downs).

NORTH WALES (FLINTSHIRE)

Fluorspar occasionally accompanies the ores of lead and zinc in the veins that traverse the Carboniferous limestone and Millstone grit of Flintshire, but is nowhere abundant or pure enough to repay extraction.

The Bryngwiog lode at the Halkyn mine yields zinc blende, which, after concentration, contains 10 per cent of fluorspar, but would not repay mining for that spar. The Rhosesmor veins, some east-and-west veins at Pen-y-bryn, and the Coed Cynric vein, about 2 miles southwest of Mold, contain some fluorspar but not in paying quantity.[44]

SUMMARY

It is interesting to note that in the Derbyshire district the fluorspar is mainly concentrated in the upper 300 or 400 feet of the limestone and that "inward from the margin or in depth the fluorspar is replaced by barytes and calcite." The situation apparently somewhat resembles that in Illinois and western Kentucky.

Much English fluorspar which has been exported to the United States in the past has been of low grade (55 to 75 per cent CaF_2) and

[43] Rudler, F. N., Handbook to the Collection of Minerals of the British Isles: Mem. Geol. Survey, Great Britain, 1905, p. 86.

[44] Strahan, Aubrey, The Geology of the Neighborhoods of Flint, Mold, and Ruthin: Mem. Geol. Survey, Great Britain, 1890, 242 pp.

high in silica. This grade of material evidently came from the waste piles of Derbyshire. As these dumps are largely exhausted, as the Derbyshire vein material in place is of higher grade, and as quartz is a rarity in the Durham deposits, it is expected that future exports will be of higher grade.

Imported English fluorspar has always sold in the United States at prices much lower than those of domestic spar. In 1914 Burchard [45] stated:

> Large quantities of gravel spar produced at a low cost from the tailings of lead mines and from the gob in abandoned mines in England have been shipped to this country as ballast at a very low freight rate. * * * According to American producers spar from England at present competes with American fluorspar as far west as Pittsburgh and practically fixes the market price at that point, while in the Lehigh and Susquehanna Valleys of Pennsylvania and other localities near the Atlantic seaboard English fluorspar can be purchased advantageously. * * * In the latter part of 1913 the cost of imported material, including the duty of $1.50 per ton, was $4.65 as compared with $5.87 for domestic gravel spar. The freight charges on domestic spar to points where it is consumed are generally higher than on foreign spar from the docks to eastern steel plants, so that the differences in cost to the consumer are relatively higher than are indicated.

This price differential in the past was partly offset by the lower average grade of the imported product. In future the grade will probably be somewhat improved, but the cost will increase, as the product must be obtained by actual mining.

FRANCE

Fluorspar is found in France associated with barytes in the Haute-Loire district, near Langeac, Paulhauget, and Briode. In the Rhone district a vein is known at Vaux-Rebard. Fluorspar is also reported in manganese deposits at Romaniche.

GERMANY [46]

Commercial production of fluorspar in Germany has come chiefly from the South Harz district in Prussia, the upper Palatinate of Bavaria, the Black Forest of Baden, the Thuringian Forest of Thuringia, and Saxony. Statistics of production are available only for Bavaria and Saxony and these are not completely available for all recent years. From 1902 to 1910 it is stated that the annual exports from Germany averaged about 15,000 long tons, and that the total production was probably more than twice this amount.

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[45] Burchard, E. F., Fluorspar: U. S. Geol. Survey Mineral Resources of the United States for 1913, part 2, 1914, p. 379.

[46] Imperial Mining Research Bureau, Great Britain, Fluorspar (1913–1919): 1921, 99 pp. Von Heimrich, Über den Flusspat von Wolsenborg; Ztschr. angew. Chem., Jan. 20, 1920, pp. 20–22. Isser, M. von, Mitteilinger über neu-erschlossene Erzvorkommen in den Alpenlanden: Bergbau u. Hütte, Mar. 15, 1919, pp. 91–98.

In the South Harz district, Prussia, the principal mine is near Stolberg, not far from Nordhausen. The fluorspar occurs in thick veins associated with very small amounts of chalcopyrite, galena, barite, siderite, quartz, and other minerals. There has been a large production from this district, but most of it seems to have been used locally for iron smelting and, to a lesser extent, copper smelting. Formerly it was mostly used in smelting the Mansfield copper ores. No recent production statistics are available.

In the upper Palatinate of Bavaria, fluorspar has been mined in several places, but the most important deposits seem to have been near Wolsendorf between Nabburg and Schwartzenfeld, in northeast Bavaria, east of Amberg. Much of the fluorspar in this district is reported to be low in silica and to contain 95 to 98 per cent CaF_2.

Fluorspar mixed with barytes occurs in the Thuringian Forest, particularly in the barytes mines of Herges-Voigtei. There are similar occurrences in the Black Forest of Baden.

The distribution of German production by States from 1896 to 1901 is given below. This table is of interest, as it shows the relative importance of the different districts in the past, as well as indicating the total German production.

Production of fluorspar in Germany,[1] 1896–1901, in metric tons

Year	Anhalt	Bavaria	Prussia	Saxony	Schwartz-burg	Saxe-Weimar
1896	5, 600	5, 218	----------	805	1, 218	330
1897	7, 000	4, 904	10, 095	592	641	----------
1898	6, 415	4, 440	11, 863	775	294	----------
1899	5, 815	3, 631	12, 932	1, 335	573	----------
1900	6, 028	7, 456	13, 820	1, 462	987	557
1901	5, 707	5, 220	14, 973	1, 624	1, 016	201

[1] Mineral Industry, for 1898–1902.

Most of the German consumption of fluorspar is in the iron and steel industries, but the glass, enamel, and chemical industries are important consumers. In 1921 [47] it was stated that, due to the cheapness of extraction and milling and to the condition of German exchange, Germany could export fluorspar with profit at lower prices than any other country could offer. During 1920 Germany exported to the United States 407 short tons of fluorspar, valued at $9,450; in 1924 exports to the United States were 9,924 short tons, valued at $104,189 ($10.50 per ton). Values given are declared values at point of shipment in Germany.

[47] Commerce Reports, "Fluorspar industry active in Germany": U. S. Bureau of For. and Dom. Commerce, Feb. 9, 1921, p. 788.

ITALY

Italy has never been an important producer of fluorspar in the past because the local demand is small and production costs have been high enough to discourage exports. The period of greatest productive activity at the largest developed deposit was between 1915 and 1918, when about 6,000 tons of fluorspar were mined by the military authorities from a deposit 34 kilometers north of Bolzano. From 1918 to 1922 there was practically no production at this deposit, but the total reported Italian fluorspar production in 1921 was 1,600 metric tons, and in 1922, 1,700 metric tons.

The Venetia deposit occurs at an elevation of 1,240 meters (4,067 feet). The mine is on a hillside and is opened by a series of tunnels. The vein is opened for a depth of 1,000 meters (3,280 feet) and has an average width of 2 meters (6½ feet), with a fluorspar contact of about 80 per cent. The ore is free from barite and pyrite, but contains small amounts of silica, calcite, galena, and sphalerite.

The high-grade fluorspar is sorted from a picking belt in the mill, which, when in operation, should yield daily 50 tons of lump spar analyzing at least 95 per cent CaF_2 and under 3 per cent SiO_2. Acid-grade spar is made by grinding high-grade lump to 60 mesh in a Hardinge mill and treating on concentrating tables. A product containing 98 per cent CaF_2 is made. The glass and enamel grade spar (95 per cent CaF_2) is ground to 30 mesh.

This deposit contains an estimated tonnage of positive ore (fluorspar) of 200,000 tons with another 200,000 tons probable. The cost of production (mining and milling) early in 1923 was estimated at 50 to 100 lire per ton ($2.50 to $5, with 20 lire to the dollar), depending upon the grade of the ore mined and the product made. Transportation is rather a serious problem. The ore is hauled by rail from Bolzano to Trieste (the nearest port). The total transportation cost from mines to Trieste is about 150 lire ($7.50) per ton, making a total cost of about 250 lire ($12.50) for mining, milling, and delivering to Trieste.

A few other deposits are reported in Italy; some have been mined unsystematically on a small scale. Little information is available on these deposits, but they seem to have little present importance.

The consumption of fluorspar in Italy is very small, and under normal conditions may be between 1,000 and 1,700 metric tons per year. There are no large steel plants and most local consumption is taken by iron foundries, and small amounts by glass and enamel plants. Local needs are adequately supplied from local deposits. Little or no fluorspar has been imported into or exported from Italy. Early in 1923 the possibility of export to the United States was considered, but conditions do not seem favorable. If an export market is created it is reported that 10,000 to 12,000 tons could be exported annually from the Bolzano deposit.

Fluorite deposits at the Rabenstein mine.—The Rabenstein mine is 13 kilometers north of Sarentino on the west slope of a canyonlike valley, here fairly flat and open; its adit level is 1,240 meters above sea level. The mine property consists of four Government concessions and 73 mining permissions, 51 of which extend for 3 kilometers along the fluorite veins; the others are scattered over the region nearby where ore veins occur which have not been developed in Essen, Kesselberg, Kandelsberg, Seeberg, and Durnholzerthal. At Rabenstein there are 20 acres of forests and lands, office buildings, and many workmen's houses, in addition to the mine plants, representing a value of over 2,000,000 lire. The mine also owns the water rights.

This mine was worked continuously from 1883 to 1893, and the annual output was 200 to 800 tons of galena, averaging 73 per cent lead and 630 grams of silver per ton. In 1893 the mill was destroyed by fire and the mine closed. During the war it was reopened by the military authorities and several thousand tons of fluorite were produced.

Ore deposits.—The Rabenstein vein has been developed by five levels over a total length of 1,000 meters and a height of about 200 meters. Along its surface exposure it shows an average width of 0.5 meter while at the adit or Rosa level this average increases to 1 meter and at the shaft level, 30 meters below the Rosa, to 1.50 meters in width.

The vein, although well-defined, shows the effect of considerable movement along the fissure plane, which is about parallel to the strike of the inclosing schists. A series of pinches and openings between the walls form shoots which extend from the upper to the lower mine levels, following a pitch of 60° northeast. These shoots are 3 to 4 meters wide and 20 to 60 meters long.

Two faults cut the vein at right angles and dip 40° to the southwest. These faults have caused a displacement of the vein to the left, this displacement being several meters at the upper level and only a few meters at the lower level. At the end of the Rosa level, which is 1,100 meters long, another fault cuts off the vein.

The composition of the vein varies with width. Where the fissure pinches, the vein is usually rich in zinc blende with only small amounts of galena, and the gangue is of fluorite, banded with schist and some quartz seams, the vein walls being less defined and the sulphides more disseminated. In the shoots or wide parts of the vein the center is almost entirely very pure pale blue fluorite, resembling glacier ice. Toward the sides of these shoots lumps of galena weighing from a fraction to many kilograms are included in the fluorite and along the vein walls occur fragment of schist, often quite large, surrounded by fluorite, with blende and some galena. As to the average composition, about three-fourths of the vein material is fluorite, and the remainder principally schist fragments, galena, and blende. Some quartz and calcite minerals occur in the gangue but no other minerals are present. Vugs or druses are common, and in these clear fluorite crystals are found which are valuable as optical fluorite.

Analyses of a number of average samples gave 3 per cent lead and 3 per cent zinc for metal contents, a finding confirmed by the mill results, which show 1 ton of galena for every 40 tons treated and about the same amount of blende; as it is mixed with fluorite, this blende product is being stored for the present.

Ore reserves.—The ore reserves have been estimated at 200,000 to 300,000 tons of positive ore. As probable ore one can assume a depth of 100 meters below the adit level, a length of 1,000 meters and an average width of 1.25 meters, a total of 375,000 tons. The vein may extend 1,000 meters or more below the adit level and there is no apparent reason why mining can not be extended to this depth.

Plants.—The water-power plant includes a 500-horsepower turbine fed by a pipe line. Electric light and power for the electric mine pump at the shaft are supplied by a 30-horsepower turbine with dynamo. The mine plant consists of an 80-horsepower compressor connected with the large turbine and a 20-horsepower compressor connected with the small turbine, a compressed-air hoist at the shaft, and a small electric pump, pipe lines, and tracks to the various workings, besides rolling stock and drilling equipment. The high-grade fluorite, which is mined separately, is sent to a sorting floor equipped with a grizzly, with bars spaced at 25 millimeters; oversize is sorted by hand, and undersize down to 10 millimeters is treated in five hand jigs, the fines going direct to the mill. Ore which does not go direct to the sorting floor and rejects from the sorting floor are delivered to two 100-ton storage bins at the ore-dressing plant or mill.

At the ore-dressing plant the ore is fed from the bins by automatic feeders which deliver the material over 20 millimeters to a sorting belt; the undersize goes direct to the ball mill. From the belt high-grade lumps are picked by one sorter and those of second-grade fluorite by another sorter; lumps of galena and large pieces of waste are also picked off the belt, which discharges the ore into a 16 by 19-inch crusher from which it is fed into a ball mill with peripheral discharge through steel bars 6 millimeters apart. A bucket elevator lifts the discharge from the ball mill to a trommel with 1½, 3, and 5 millimeter screens. The fines go to six hydraulic classifiers and thence to eight tables, the 1½ to 3 millimeter size to one jig, the 3 to 5 millimeter size to another jig, and the oversize to a third. Four products are made from the jigs and tables, galena, blende with some galena, blende with some fluorite, and fluorite with some blende. The galena-blende middling goes to a small bucket elevator which delivers it into a 4½-foot Hardinge mill and to the four tables through eight hydraulic classifiers. The blende product, with some fluorite, and the fluorite, with some blende, are now being stored. A small flotation unit will probably be installed to separate the blend from the fluorite and thus make a cleaner fluorite and, if possible, a marketable blende.

Transportation.—To permit transportation of 50 tons or more a day and to reduce the present cost, a ropeway project from Rabenstein to Sarentino, a distance of 14 kilometers, was made last year. From Sarentino the product is transported by trucks or teams to the railway station at Bolzano. The present cost of transport by teams from Rabenstein to Bolzano is 54 lire per ton, while with the ropeway in operation this cost should be reduced to 35 lire per ton.

Venice is the nearest port to Bolzano and the cost of railroad transport, including loading charges at this port, amounts to about 69 lire a ton. Shipping rates from Venice to New York or other Atlantic ports are now about 17 shillings on 200-ton lots. A flat rate of 160 lire per ton from Bolzano to New York via Genoa has also been obtained.

Production.—At present 10 to 12 tons of fluorite are mined daily and sent to the sorting floor; 4 tons of acid-grade lump spar are sorted from this. Arrangements are being made to handle 30 tons per day of this material, which should yield 10 to 12 tons of the acid grade.

The ore-dressing plant is still in the experimental stage. From 40 to 50 tons of ore are now being treated per shift, with about 1 ton of galena and 1 ton of blende. A few tons of lump fluorite are picked from the sorting belt and several tons from the jigs, but these products have to be re-treated to bring the fluorite up to the enamel (95 per cent) grade. A large tonnage of fluorite comes from the tables, but it contains some blende and too much silica for the enamel or glass grade and is too finely ground for the fluxing grade. Experiments are being made to bring this up to the enamel grade by re-treatment on tables and by flotation. Experiments are also to be made to briquet these fines so that they may be used for fluxing.

Mining and treatment of at least 100 tons of ore daily are planned; this ore should yield 2 tons of galena (70 to 75 per cent Pb, 650 gr. Ag); 2 tons of blende (45 to 50 per cent Zn); 10 tons of acid-grade fluorite (98 per cent CaF_2); 10 tons of enamel-grade fluorite (95 per cent CaF_2); and 20 tons of fluxing-grade fluorite (85 to 90 per cent CaF_2).

NORWAY

Fluorspar production in Norway had no importance until 1915, when imports were cut off by the war and local consumption had to be satisfied by Norwegian production. In 1915 the production was 180 tons; 1916, 140 tons; 1917, none; 1918, 155 tons; and 1919, 560 tons. Since 1919 the production has been very small. Under normal conditions most of the fluorspar used in Norway is imported from Germany, as German fluorspar can be obtained cheaper than that from local deposits. The annual consumption of fluorspar in Norway averages about 500 tons per year, and probably has not exceeded 1,500 tons in any year. The principal use is in the steel industry.

Most of the fluorspar deposits in Norway are near Kongsberg. The most important deposits are as follows: (1) Lassedalen Flusspatbrudd, Ovre Sandsvaer, Buskerud County, eastern district of Norway; and (2) Tveitstaa Flusspatgrube, Barsgaard, Skafsaa Parish, near Dalem, Telemarken County, western district of Norway.

No information is available on ore reserves. At Lassedalen the fluorspar content is said to be 65 per cent. At Tveitstaa the veins are 3 to 3.5 meters (10 to 11.5 feet) wide, and the fluorspar content is 75 to 85 per cent.

These deposits are some distance inland and the cost of delivering fluorspar to the coast seems rather high.

SPAIN

Fluorspar is reported to occur in Spain in several localities, principally in the Provinces of Barcelona, Gerona, Cordoba and Guipuzcoa, but the only production now comes from the last. Fluorspar consumption in Spain is very small and there are apparently no imports. Domestic needs are supplied by domestic production, which is 250 to 400 tons per year.

In Guipuzcoa there are three known fluorspar deposits, but in recent years only one has been worked, the San Maximiliano mine, at Renteria, near the French frontier. It is owned by a Spanish company which is principally engaged in the mining and smelting of lead and zinc ores and in the manufacture of lead and zinc products. No information is available regarding the nature and size of the deposit and mining methods, but the fluorspar shipped is said to contain 90 per cent or more CaF_2. Samples of the ore examined by the writer resemble coarsely crystalline grayish-white limestone and contain some galena and pyrite.

In January, 1923, the operating company was said to be able to deliver 100 metric tons of high-grade lump ore monthly at 60 pesetas per metric ton, f. o. b. port of Pasajes, Spain, a price equivalent to about $9.30 per ton at the rate of exchange then prevailing. It is reported that in 1922 the average value of the ore at the mine was 38 pesetas per metric ton.

SWITZERLAND [48]

Fluorspar was discovered a few years ago near Sembrancher, in Vallais Canton, on the Martigny-Orsiires Railway. The deposits, which were worked in the sixteenth century for lead, occur on the right bank of the Dranse below Sembrancher, and the main vein crosses Mont Chemin. In the principal or Trappist mine, so called from the time of Napoleon, when the Trappist monks took refuge in the valley, the average vein width is about 1 meter, but locally it widens to 3 meters. The vein apparently occurs between layers essentially of a mixture of argentiferous galena, quartz, and fluorspar. An analysis of one sample showed 89.6 per cent CaF_2 and 10.35 per cent SiO_2. Less common accessory minerals are calcite, sphalerite, pyrite, and chalcopyrite.

No fluorspar has been mined from this deposit, as the consumption of fluorspar in Switzerland is very small (probably between 30 and 70 metric tons per year). Past Swiss needs have been supplied from Grenoble, France, and the Thuringen district of Germany, chiefly the latter.

ASIA

CHINA

The information on China is abstracted from unpublished reports of United States consuls. Very little is known of the fluorspar resources of China, but several occurrences have been noted and probably there has been a small production for local use.

In Shantung about 23 miles south of Kiaohsien near a hill called Ch'i Pao Shan at Chin Liu Lan considerable fluorspar is reported as occurring in a lead mine. A glass company formerly produced both quartz sand (from sandstone) and fluorspar from deposits in Heishan and Hsishan near Poshan.

Several small deposits of fluorspar are reported in South Manchuria along the line of the South Manchuria Railway. These

[48] Abstracted from a communication from Fletcher Dexter, United States vice consul, Lausanne, Switzerland, Mar. 4, 1919, reprinted in U. S. Geol. Survey Mineral Resources for 1918, part 2, p. 326; also from unpublished consular report by U. S. Consul Philip Holland, Basel, Switzerland, Jan. 25, 1923.

deposits are owned and worked in a small way by Chinese who dispose of their output to Japanese at Dairen. These deposits are said to be at the following places:

Luchiatun (5 miles south-southeast of Luchiatun in Kaiping prefecture); of fine quality, found in meager quantity; concession held by a Chinese; Shimakyu, druggists, Dairen, acting as sales agent.

Tsuichiatun (3⅓ miles west of Luchiatun); of fine quality, found in meager quantity; concession held by a Chinese; Shimakyu, Dairen, acting as sales agent.

Laomukou (6⅔ miles south of Haicheng station on main line); of fine quality, found in small quantity; concession held by Kungy Kungsu, Haicheng; work under suspension.

There is also said to be a small deposit of fluorspar near Kaiyuan, north of Mukden on the South Manchuria Railroad. The output, about 30 tons per year, is used by the central laboratory of the South Manchuria Railway at Dairen in the manufacture of glass.

INDIA

Fluorspar is not produced in India in commercial quantities and no important deposits are known. Several small deposits are reported, for example, at Sleemanbad in the Jubbulpore district and at Chicholi in the Drug district in the Central Provinces. The former deposit consists of small crystals in a quartz porphyry dike, and in the latter deposit fluorspar, galena, and copper carbonate are found in a quartz vein. It is reported that a steel company at Jamshedpur investigated a deposit of fluorspar in Rajputana, but decided that the cost of working it would be higher than that of purchasing fluorspar from Europe.

The mineral deposits of India have not been explored enough, particularly for such minerals as fluorspar, to determine the presence or absence of commercial deposits. Apparently local needs are supplied by imports from Europe, probably through Calcutta.

PERSIA

Small amounts of fluorspar associated with barytes and argentiferous galena are reported to occur about 15 kilometers from Takht-i-Souleyman in the Arghown foothills of Persia. The deposits are not considered of commercial importance.

AFRICA

UNION OF SOUTH AFRICA [49]

The fluorspar consumption of the Union of South Africa is estimated to be about 30 tons per month; 25 tons is used in electric steel

[49] See Wagner, P. A., "Fluorspar": South African Jour. Ind., vol. 1, No. 16, December, 1918, pp. 1516–1520. Part of the material for this section was taken from Wagner's report and part from unpublished reports of United States consuls in South Africa.

furnaces and 5 tons at the Witwatersrand gold mines, probably as a flux. All domestic needs are supplied from local sources. Although the fluorspar industry has not had great local importance its coming is of increasing interest due to the export trade. Since 1917 exports have amounted to about 8,000 tons, 5,000 of which were taken by the Broken Hill Proprietary Co. of Australia; the rest was shipped to the United States. These shipments are reported to be remarkably free from impurities, averaging 99.6 per cent calcium fluoride. In February, 1923, a 2,000-ton order for the United States and a 200-ton order for the steel works at Newcastle, Australia, were being filled.

Fluorspar is reported to occur in deposits of possible commercial interest in several localities in South Africa. The most important known deposits, and the only ones worked on a fairly large scale, are in the Transvaal, where there are two deposits in the Zeerust district, southeast of Ottoshoop, which have been mined commercially. The largest of these deposits is on the farm Malman, Oog No. 101. It consists of a large, funnel-shaped pipe or chimney in rather disturbed dolomite and chert belonging to the dolomite series of the Transvaal system. One description states that the chimney measures 120 by 120 feet at the surface and 80 by 160 feet at a depth of 40 feet. The owner of the deposit states: "Fluorspar occurs as a pipe 60 feet in diameter, and this should give about 330 tons per foot down (fluorspar 10 cubic feet to ton). Doctor Wagner suggested to me that it is probably a true fissure vein which will contract and expand alternately as it goes down. My workings have reached 50 feet where the best stuff is."

The periphery of the pipe is occupied by grayish and purple fluorspar containing a little pyrite in places. The interior is occupied by very pure white spar which is occasionally of optical grade. Some of the latter has been sold to makers of optical instruments in London at 10 shillings per ounce. Optical fluorspar is also found in the Stavoren tin-scheelite mine in the Waterberg district of the Transvaal. No additional information on probable reserves is available.

The ore is now broken by simple quarrying methods and hauled up an incline to the surface by oxen. Practically no water has yet been encountered in the pit. The ore is hand cobbed and the larger lumps hand loaded into wagons. The fines are screened through a half-inch screen to remove dust. The shipping product is hauled in wagons to the railroad, about 8 miles away, over bad roads.

Early in 1923 the cost of production was estimated at about 12 shillings per ton, f. o. b. cars, including 5 shillings for production and 7 shillings for sorting and wagon haul to railroad. Production costs will increase with depth. Rail freight to Cape Town was 20 shillings per ton and the price f. o. b. cars at Table Bay docks (ocean shipping point) was 55 shillings per ton, about $13.20 at normal rate of exchange. This price is too low for regular production, but contracts at that figure were accepted to pay for development work.

Another deposit in the Zeerust district is situated on the adjoining farms, Nauuwpoort No. 228 and Buffelshock No. 284. Fluorspar also occurs here as a pipe or chimney in dolomite, but the fluorspar is associated with sphalerite, galena, pyrite, and calcite. In another deposit in this district, worked by a Johannesburg syndicate, fluorspar is said to occur in commercial quantities associated with galena.

Fluorspar associated with tin ores is reported at a number of localities. In the Waterberg tin district, fluorspar occurs in red granite at the following tin mines: Zaaiplaats, Groenforstein, Groenvlei, Appingadam, Rooiberg, and Leeuwpoort. A persistent vein of colored fluorspar, 18 inches to 3 feet wide, was said to have been opened up some years ago on the farm Vlakfonstein No. 2235, about 4 miles northeast of the Leeuwpoort mine. In the Olifant River tin fields it is reported in considerable quantities at the Stavoren and Mutue Fides mines. Deep bluish-violet fluorspar in a pegmatite associated with monazite and molybdenite occurs on the farm Houtenbeck No. 392. Dark violet fluorspar is reported to be a common accessory mineral of the elæolite-syenites and allied alkali rocks of the Bushveld complex, and of the alkali felsites of the Pilandsberg.

AUSTRALIA [50]

The production of fluorspar in Australia began in 1915, when the production was about 400 long tons; in 1916 and 1917 it was about 1,370 long tons annually; in 1918 and 1919 it was 2,300 to 2,400 long tons annually. This production all came from New South Wales except 71 tons in 1917 from Queensland and 100 tons and 314 tons in 1918 and 1919, respectively, from Victoria.

The principal output has come from the old Woolgarlo silver-lead mine in the Yass division and from Carboona in the Tumbatumba division of New South Wales. Most of this material was shipped to the steel works of the Broken Hill Proprietary Co. at Newcastle.

Very pure fluorspar associated with wolfram and copper ores occurs in the vicinity of "The Gulf" in the Emmaville division of

[50] New South Wales Department of Mines, Annual Report for the Year 1919: Sydney, 1920, p. 4. Smith, George, "Occurrence of pure fluorspar in New South Wales"; New South Wales Department of Mines, Annual Report for 1918: Sydney, 1919, p. 76. Annual Reports of Secretary of Mines, Melbourne, Victoria. Annual Reports Under-Secretary of Mines, Brisbane, Queensland: Geological Survey of Queensland, Publication No. 248, pp. 22 and 29.

Queensland. Although in the aggregate a large tonnage of fluorspar exists here it occurs in small irregular deposits, and as the district is at least 30 miles from the nearest railroad (at Deepwater), the deposits have no present interest for low-grade uses. However, for higher-grade uses, for which a higher price may be paid, mining may be profitable. An enameling industry is said to have been established at Sydney and more than 100 tons of fluorspar have been mined for this use. In 1920, 11 tons of high-grade fluorspar were exported from Australia to the United States for chemical use, probably from this district, but none has since been sent here.

In 1917, for export, the Herbertson district of Queensland mined 71 long tons of fluorspar, but no production was reported in 1918 and 1919. This material probably came from near Bamford or Bamford Hill. In the Bamford area fluorspar occurs in association with wolfram, molybdenite, bismuth, and quartz, particularly in the vugs cementing quartz and the various sulphides, as at the Northern United mines. At the Petford Spring mine, 4 miles southeast of Bamford Hill, fluorspar occurs as veins in granite.

Fluorspar is reported to occur at Beechworth and Woolshed in Victoria.

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CRYOLITE

Cryolite is the only fluorine mineral besides fluorspar which occurs in large enough quantities to have commercial interest. A brief description of cryolite is therefore included in this work. The following material is taken from a book on the nonmetallic mineral industries,[51] by the author.

Composition.—Cryolite sodium aluminum fluoride, Na_3AlF_6 contains: Na 32.8 per cent, Al 12.8 per cent, and F 54.4 per cent.

General description.—Cryolite or kryolith, sometimes called " ice stone " or, in German, " Eisstein," usually occurs in compact, granular or cleavable masses, but may occur in groups of triclinic crystals resembling cubes. It is soft, waxy, translucent, and when white often resembles paraffin.

Hardness: 2.5 to 3. Specific gravity: 2.9 to 3. Melting point: 2 in scale of fusibility. Index of refraction: 1.364. Color: Colorless, white, black, brown, and reddish. Streak: White. Luster: Pearly on basal pinacoid but vitreous to greasy or waxlike elsewhere. Cleavage: Basal and prismatic at nearly right angles. Fracture: Uneven. Transparency: Translucent to transparent. Tenacity: Brittle.

PRODUCTION AND CONSUMPTION

Cryolite is produced at only one locality in the world, Ivigtut, south Greenland. Annual shipments in recent years have been as follows, according to Mineral Industry for 1925, page 274:

Shipments of cryolite from Greenland

[Long tons]

Year	Tons	Year	Tons
1913	10,415	1920	13,928
1914	11,512	1921	11,318
1915	9,562	1922	8,692
1916	13,585	1923	18,582
1917	9,637	1924	23,791
1918	10,118	1925	31,612
1919	6,367		

[51] Ladoo, Raymond B., The Nonmetallic Mineral Industries. New York, 1925, 686 pp.

Imports into the United States, as given by the Bureau of Foreign and Domestic Commerce, are as follows:

Cryolite imports into the United States

Year	Quantity long tons	Value	Average price per ton	Year	Quantity long tons	Value	Average price per ton
1894 [1]	12,756	$170,215	$13.34	1910	36	$2,343	$65.08
1895	8,685	116,273	13.39	1911	2,007	47,093	23.46
1896	7,024	93,198	13.27	1912	2,126	48,293	22.72
1897	3,009	40,056	13.31	1913	2,559	52,557	20.54
1898	10,788	114,178	10.58	1914	4,612	94,424	20.47
1899	5,529	79,455	14.37	1915	3,940	82,750	21.00
1900	5,878	78,658	13.38	1916	3,857	165,222	42.84
1901	6,167	82,533	13.38	1917	4,383	218,500	49.86
1902	4,653	61,116	13.13	1918	1,950	97,500	50.00
1903 [2]	7,708	102,879	13.34	1919	2,131	106,956	50.19
1904	959	13,708	14.29	1920	3,864	193,638	50.11
1905	1,600	22,482	14.05	1921	3,460	295,186	85.31
1906	1,505	29,583	19.66	1922	3,899	196,302	50.35
1907	1,438	38,902	20.10	1923	6,375	319,959	50.19
1908	1,124	16,445	14.63	1924	6,320	320,670	50.74
1909	1,278	18,427	14.42	1925	9,844	690,651	70.16

[1] Fiscal years, 1894-1902. [2] Calendar years, 1903-1921.

It is reported that in recent years at least 25 per cent of these imports have been reexported to Canada. The values given above are the declared values at the Greenland point of shipment. The entire output is marketed through two sales agents, the Pennsylvania Salt Manufacturing Co., of Philadelphia, for North America, and a company in Copenhagen, Denmark, for the rest of the world.

According to various reports, the two grades which are mined and shipped are known as "black" and "white." The white grade, which contains 90 to 95 per cent of fluorite with a small amount of a mixture of pyrite, galena, and siderite, is shipped to Copenhagen. The black grade, which contains a large quantity of fluorspar in addition to cryolite, is exported to the United States. Use of the term "black" grade is not clearly understood, for the material imported is surely not black. It is a mixture of white cryolite and chiefly siderite, galena, fluorspar, and pyrite.

In 1918 black cryolite had a value of about $20 per ton. When pure or freed of impurities it was worth $100 per ton or more. In September, 1922, purified cryolite sold for 9¼ to 9¾ cents per pound, f. o. b. cars. Selected pure white lumps sold for about 15 cents per pound.

The normal European consumption of natural cryolite in the aluminum industry is probably about 1,500 tons per year. Of the average world consumption of about 12,000 tons per year probably not over 3,000 tons is used in the aluminum industry. The remainder is used in the manufacture of enamels, opaque glass, etc. The foreign consumption for the latter uses seems to be about twice that of the United States.

OCCURRENCE, MINING, AND MILLING

Minerals containing cryolite have been found near Pikes Peak, Colo., though not in commercial quantities. As stated, the only commercial deposit of cryolite known is at Ivigtut, an Eskimo hamlet on the southern coast of Greenland in latitude 61° N. It is owned by Denmark and operated under a State concession by the Kryolith-Mine of Handelsselskab (the Cryolite Mining & Trading Co. (Ltd.), of Copenhagen.

The cryolite occurs as an irregular mass in a small area of granite porphyry inclosed in an older granite gneiss. On one side of the cryolite mass is a pegmatite dike and it is believed that the cryolite is of pegmatitic origin. At the surface the deposit had an elongated outcrop about 100 feet wide and 500 feet long, but the size has increased notably with depth. In 1916 the deposit had already been worked to a depth of nearly 200 feet, with the total depth unknown.

Until 8 or 10 years ago all mining was done by very primitive open-cut methods with hand drills and black powder, but now drilling is done by compressed-air drills and dynamite is used in blasting. The ore is hoisted in cages through a shaft at one side of the open cut by a modern double-drum hoist.

Apparently no milling is done at the mine, but the ore is sorted into the two grades, white and black. Apparently the relative proportions of the white and black grades vary greatly or the shipments to the United States and Denmark are not separated strictly by grades as reported.

Shipments from Ivigtut can be made only from April to November, as no ship can reach Greenland during the rest of the year, due to ice. The steady labor employed numbers 40 to 50 men, and 50 or 60 more are brought in temporarily during the shipping season.

No information is available as to reserves, but the deposit is reported to be very large and production could be largely and rapidly increased. If the deposit continued downward, even at the dimensions of the outcrop, allowing for 50 per cent loss in mining and sorting, each hundred feet in depth would yield over 200,000 tons of cryolite. As production has averaged 10,000 to 13,000 tons per year, resources seem ample for many years at the present rate of consumption.

Before the cryolite can be used for most purposes it must be purified. Purification plants [52] are located in the United States and in Denmark. Darlington describes the method of purification used in this country as follows:

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[52] Darlington, H. T., "Boiling-over concentration"; Min. and Sci. Press, vol. 124, No. 7, Feb. 18, 1922, pp. 217 and 218.

The crude cryolite is first crushed and treated by Wetherill magnetic separators to remove siderite, then by Wilfley tables which remove galena, sphalerite, chalcopyrite, pyrite, and the residual galena. The slimes, too fine to be treated on tables, were formerly wasted, but eventually a process was devised for their treatment:

Several thousand tons of accumulated slime from the Wilfley tables presented a difficult problem. If purified by subsequent treatment it had a value as high as $260 per ton. "Boiling-over" concentration solved the problem, all impurities being removed, leaving a pure and white product, whereas the material charged to the plant was dark and valueless. By boiling in the presence of acid and without the use of additional agents, the coal, coke, pyrite, sphalerite, chalcopyrite, galena, and miscellaneous dêbris come to the top and are removed. The siderite often dissolves before removal, as does the galena; this action depends on the acidity maintained.

The screened fine cryolite, passing 80 mesh, with about 1 part of water to 2 or 3 parts of cryolite, is delivered to a boiling vat heated by a coil of extra-heavy lead piping. The vats are of cypress, 6 feet in diameter by 7 feet high. The unlined wood lasts several years; it is then lined with lead. Simple boiling brings to the surface a large quantity of organic dirt, which is skimmed. Then several buckets of acid are added and the tanks boil over. The foam, 2 to 3 feet thick, is skimmed by means of 20-inch scoops of Monel metal fly screen; it is then accumulated in settling vats, smelted for lead, copper, and silver, or discarded. Boiling is repeated in a lower tank, to insure a good extraction; the product is sent to a vacuum filter; after washing it is dried in shelf driers.

In starting a plant of the above character it is impossible to get foam for the first few days, unless kryolith "dope" is used. This counteracts the oils present, particularly the linseed oil from paint and the antifoam effect of new wood. An ounce of kryolith "dope" produces a wonderful foam; it is made by boiling together 8 parts of old oil from pipe-cutting machines (where old acid pipes are threaded), 1 part of fels-naphtha, and 1 part of water. The oil used is presumably neat's-foot oil; new oil or other oils may be used, but generally are not satisfactory. A few drops of linseed-oil paint added to the contents of a large tank with a heavy foam will kill the foam; a little "dope" will restore it.

The siderite product from the table concentration is saved and marketed as a finely ground powder.

UTILIZATION

Originally cryolite was the only aluminum ore, but with the introduction of bauxite its use as a source of that metal ended; however, cryolite is still very important in the manufacture of aluminum, for it is employed as a solvent for alumina in the bath used in the electrolytic manufacture of aluminum. In this country now and probably in other countries part of the natural cryolite for this use is replaced by an artificial cryolite made from fluorspar. It is reported, however, that the artificial product is not as efficient, due to an excess of water and that some natural cryolite (possibly 20 to 25 per cent) must be used.

Other important though less essential uses are in the manufacture of opalescent and other opaque white glass and of enamels for iron and steel and as a flux in white Portland cement.

Formerly it was used to produce sodium salts and alum, but other and cheaper sources of these materials have practically displaced cryolite in this field.

Sodium silicofluoride or sodium fluorsilicate (Na_2SiF_6) is manufactured in Europe and imported into the United States as a substitute for cryolite and for oxalic acid used for bleaching purposes. Competition with both of these materials is on a price basis only; that is, when sodium silicofluoride may be obtained more cheaply than cryolite or oxalic acid there is a tendency toward substitution. In September, 1922, sodium silicofluoride sold in United States markets for 2 or 3 cents a pound below the price of cryolite. Importers of this material try to sell it as a substitute for cryolite in the glass and enamel industries. It is not really a substitute, for it has a different chemical composition and different physical properties. Although it may be a few cents cheaper per pound, it is reported to be rather unsatisfactory and nearly twice as much sodium silicofluoride as cryolite is required to produce a given effect.

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