Younger, P. L. (2003): Frazer's Grove: the life and death of the last great Weardale fluorspar mine. – In: Fairbairn, R. A. (ed) Fluorspar in the North Pennines. – p. 47-72, 6 Abb., 3 Tab.; Durham (Friends of Killhope).

FRAZER'S GROVE: THE LIFE AND DEATH OF THE LAST GREAT WEARDALE FLUORSPAR MINE

Paul L Younger
School of Civil Engineering and Geosciences
University of Newcastle
Newcastle Upon Tyne NE1 7RU

SUMMARY

"Frazer's Grove Mine" was the compound name given to a cluster of largely separate fluorspar workings at the head of the Rookhope valley, Weardale. The individual sets of mine workings which made up "Frazer's Grove" were as follows: Grove Rake Mine; Rake Level; Firestone Dib; Frazer's Hush Dib; and the Greencleugh Dib. ("Dib" is a local term for a decline i.e. an inclined drift). In latter years, active working of fluorspar was restricted to the last three of these sets of workings, but access to the other two sets was maintained in order to provide complete ventilation circuits and secondary means of egress for the working areas. The history of mining in the ground most recently commanded by Frazer's Grove Mine is long and only partially documented. In common with most other Weardale fluorspar mines (a notable exception being the former Red-burn Mine nearby), most of the Frazer's Grove complex was formerly worked primarily for lead (1819 - 1916), with fluorspar being produced only as a gangue mineral until the late 19th Century. Indeed, long after the primary focus of mining at this site switched to fluorspar, lead remained a minor economic by-product. When the Frazer's Grove complex was put up for sale by the receivers of Minworth Group in 1991, the mine entered its ultimate phase of activity (barring the unlikely circumstance of future re-opening). The new owners of the mine, Sherburn Minerals Ltd, focused all development and extraction activity in the Greencleugh Vein. The portions of the vein which cut the Firestone Sill and overlying strata were worked (up to December 1995) from the Greencleugh Dib, with the remainder of the vein being worked from the Frazer's Hush Dib. Both of these dibs were relatively recent sinkings (early to mid 1980s), albeit the very place name of Frazer's Hush betrays the presence of former, shallow workings on the Greencleugh Vein (the uncertainty over which necessitated considerable precautionary drilling ahead of lode drives in the shallower workings). The recent history of sinking and working of the Frazer's Hush workings provides an interesting study in the pros and cons of various types of run-of-mine haulage (essentially, rail-mounted versus free-steered vehicles) in North Pennine strata. While ventilation of the workings was successfully achieved without undue difficulty, experiments demonstrated that the workings lacked any capacity for self-ventilation (an important safety consideration post-closure). The maintenance of secondary egress routes via 19th Century workings to modern

and Metallurgy specialised in mine water management (see Younger *et al.*, 2002). The reader should be aware that I am a mining environmental engineer rather than a production-oriented mining engineer. Hence, although I have done my best to record aspects of mine development and operation, these aspects were not the particular focus of my own work at the mine. Having said that, I was very familiar with the mine, perhaps more familiar with it than any other professional not in the direct employment of Sherburn Minerals Ltd. I was involved with the mine over five years from 1995 to 2000, and at certain stages in that time I worked underground one day per week over periods of up to several months. During my visits to the mine I always took a keen interest in all aspects of the life of the mine, so that hopefully this paper contains trustworthy primary material which will give the reader considerable insight into this last great Weardale mine.

1. GEOLOGY AND MINING HISTORY OF THE UPPER ROOKHOPE VALLEY

The geology of the Frazer's Grove area has been described in detail by the late, great Sir Kingsley Dunham, principally in his classic memoir (Dunham, 1990), but also in engaging personal recollections of a lifetime of involvement with the mines of the Rookhope Valley (Dunham, 1997). Important additional geological information is provided by Carruthers and Straughan (1923), Dunham *et al.* (1952), Greenwood and Smith (1977) and Smith (1995); these authors provide thorough listings of the key primary references concerning the geology of the district. The mining history of the district has also been documented by Carruthers and Straughan (1923), Dunham *et al.* (1952), Dunham (1990, 1997), and Fairbairn (1996).

As is the case throughout the North Pennine Orefield, the mineral veins of the Frazer's Grove district are hosted by fairly flat-lying sedimentary rocks (principally shales, sandstones and limestones) of Lower Carboniferous (Dinantian-Namurian) age. Although full details of the regional stratigraphy are given by Dunham (1990), the sequence local to Frazer's Grove Mine is perhaps best appreciated by reference to Table 1, which has been collated by the author from site specific shaft and exploration borehole records held by Sherburn Minerals Ltd. Stratigraphic units marked in bold typeface in Table 1 are the predominant, thick, competent horizons (either sandstones or limestones), which were of economic importance for two reasons:

(i) the veins tended to reach maximum thickness where they cut these competent horizons, and
(ii) roof support was easiest, and therefore least expensive, where mine roadways traversed these competent horizons.

regulatory standards was more of a struggle. In the later years of working, the management of mine water quality became an increasing challenge, but one to which the company responded with innovative strategies, which (had the mine survived) would at one stroke have solved the problems of both secondary egress and environmental management. Closure finally came after years of struggle on the part of the owners in a declining world market, in which unsubsidised British fluorspar production was expected to compete pound-for-pound with fluorspar which is dumped on the European market by countries such as China, which operate highly subsidised production and shipment systems. The period of closure of the mine necessitated evaluation of the inter-connectedness of the Frazer's Grove workings with those of other long-abandoned mines nearby. Important lessons were learned, which not only proved crucial to the final closure strategy for the mine, but raise other intriguing questions over the mining history of Rookhope

INTRODUCTION

This paper is an attempt to record for posterity some of the most important facts and figures concerning (what now seems likely for the foreseeable future to have been) the final phase of industrial-scale mining in the Rookhope valley, and therefore in all of Weardale, and indeed in the North Pennine Orefield as a whole. This valedictory episode in the long mining history of Weardale was played out in the complex of old and new workings which were latterly collectively labelled "Frazer's Grove Mine". Frazer's Grove was a die-hard soldier of a mine, which alone survived the many vicissitudes of the international fluorspar market which gradually claimed as victims all the other 20th Century mines of the Rookhope valley: Boltsburn (closed in 1932), Stotfield Burn (closed 1970) and Redburn (1964 - 1981). The survival of Frazer's Grove to the threshold of the new Millennium surprised many outside observers. After all, it was one of the most remote working mines in Britain, and it raised its ore to bank 15 kilometres from its beneficiation plant at Broadwood. How did Frazer's Grove outlive all of its near neighbours, and indeed all other comparable 20th Century mines of the North Pennines (White Heaps, Cambokeels, Blackdene and Settlingstones)? As this article will hopefully make clear, the extraordinary staying-power of Frazer's Grove was testament both to its natural riches as a record-breaking nexus of highly-productive veins, and to the skills and determination of its owners and workforce: if Sherburn Minerals Ltd could not extend the life-support system of Frazer's Grove Mine beyond July 1999, then no-one else could have done so.

It is important to note here that the information presented in this paper was acquired in the line of my professional involvement with the mine, as a Chartered Geologist and as a Chartered Engineer of the Institution of Mining

Table 1 – Simplified geological succession for the Frazer's Grove Mine site, based upon borehole, shaft and mine plan records of Sherburn Minerals Ltd (after Younger, 1998).

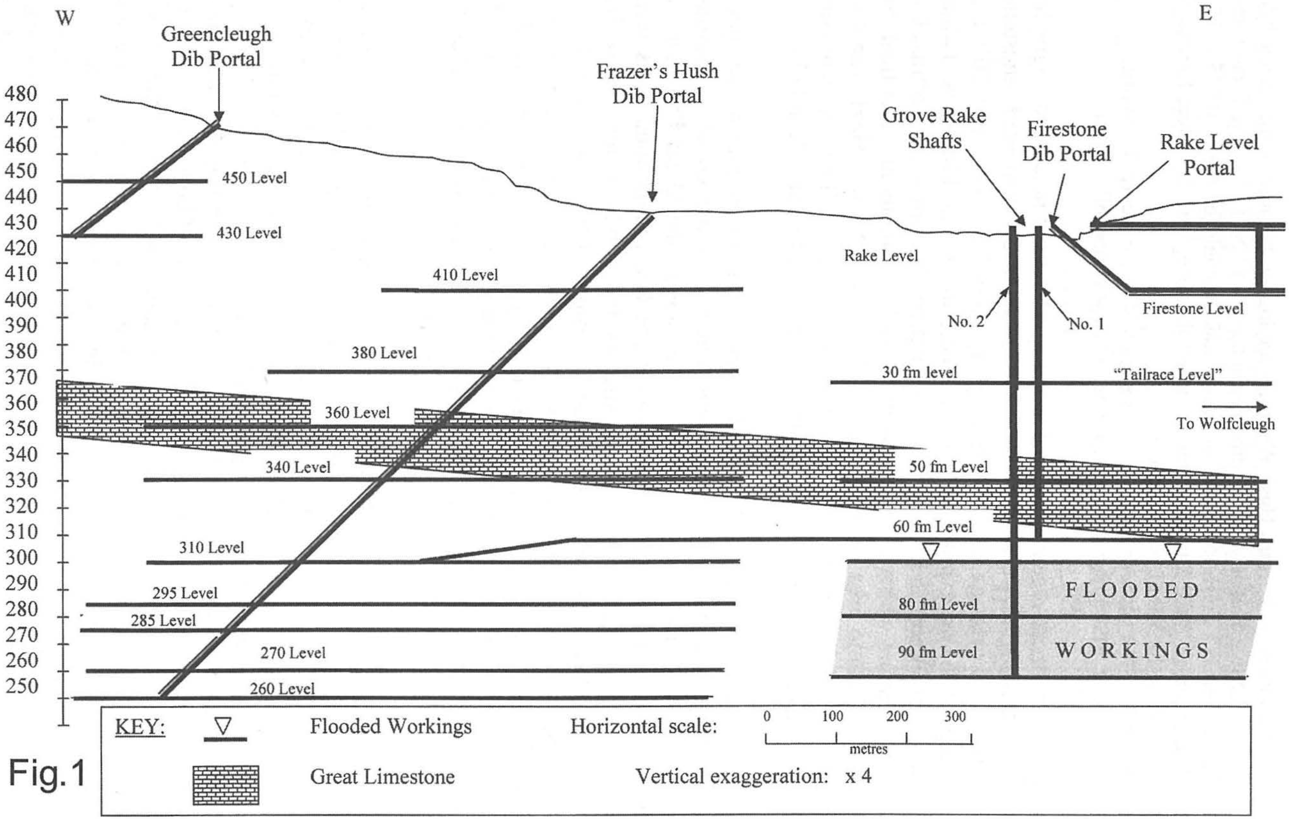
Unit Name (key units in bold typeface)	**Approx. elevation of base (mAOD) at Grove**	**Lithology[2]**	**Thickness (m)**	**Hydrogeological Classification[3]**
Low Slate Sill	434.6	Sst (silty)	11.3	C
Knuckton Shell Beds	423.3	Slt/Mdst	19.8	C
Crag Limestone	403.5	Lst	0.15	C
Plate beds	403.4	Mdst/Sst	1.4	C
Firestone Sill	402	Sst	8.2	M
Plate beds	397.3	Mdst	4.7	C
White Sill	391.3	Sst	6	M
Plate beds	381.9	Mdst	9.4	C
Girdle Beds	377.5	Sst/Mdst	4.4	C
Pattinson's Sill	373.2	Sst	4.3	M
Plate beds	367.9	Mdst	5.3	C
Little Limestone	364.5	Lst	3.4	M
Sandstone bed	359.9	Sst	4.6	M
Plate bed	357.2	Mdst	2.7	C
High Coal Sill	355.6	Sst	1.6	M
Coal	355.45	Coal	0.15	C
Plate beds	350.05	Mdst	5.4	C
Coal	350	Coal	0.06	C
Low Coal Sill	349	Sst	1	C
Plate beds	346.2	Mdst	3.8	C
Great Limestone	325.8	Lst	20.4	A
Tuft	323.7	Sst/Slt	2.1	M
Plate beds	322	Mdst (py)	3.5	C
Iron Post Limestone	320.3	Lst/Mdst	1.7	C
Quarry Hazle	308.9	Sst	11.4	M
Plate beds	297.3	Mdst	11.6	C
FourFathomsLimes'	291.7	Lst	5.6	M
Plate parting	291.1	Mdst	0.6	C
Nattrass Gill Hazle	278.8	Sst	12.3	M
Grey beds	265.6	Slt/Sst	13.2	C
Three Yard Limestone	263	Lst	2.6	M
Six Fathoms Hazle	254	Sst	9.0	M
Plate beds	245.9	Mdst	8.1	C
Five Yard Limestone	243.3	Lst	2.6	M
Grey beds	223.8	Slt/Sst	19.5	C
Scar Limestone	213	Lst/Mdst	10.5	M

[1]Note: OD Elevations in Frazer's Hush Workings are higher, because of the regional dip of around 1.5° ENE (i.e. about 0.025m drop per m travelled ENE). e.g., the Great Limestone Base at Frazer's Hush (600m W of Grove Rake) should be 600 x 0.025 = 15m higher than at Grove Rake Shafts. This is indeed the case, with the Great Limestone base being seen at the 340 Level in Frazer's.
[1]Sst = sandstone; Slt = siltstone; Mdst = mudstone; Lst = limestone; (py) = pyritic.
[1]A = major aquifer; M = minor aquifer; C = aquitard (low-permeability layer)

Throughout the most recent period of working, the most notable stratigraphic horizons in this regard were; the Firestone Sill (a densely-cemented sandstone, in which the workings of both the eponymous Firestone Sill Dib and Greencleugh Dib were principally developed); the Great Limestone (which maintained a thickness in excess of 20m throughout the mine); the Nattrass Gill Hazle (a sandstone which afforded excellent roof conditions in the critical 295 landing / 285 ramp area of the mine); and the Six Fathoms Hazle (another sandstone, which performed a similar role to the Nattrass Gill Hazle, facilitating safe working of the 260 Level at the very bottom of the Frazer's Hush Dib).

As in other parts of the North Pennine Orefield, the most productive ore-shoots in the Frazer's Grove district were encountered in the Great Limestone. However, in contrast to the conditions obtaining in the Great Limestone at Nenthead and in Boltsburn Mine, in which the Great Limestone hosts well-developed 'flats' (i.e. stratiform and stratabound sub-horizontal orebodies flanking the sub-vertical veins), the Great Limestone at Frazer's Grove showed no signs of flat development. However, the Lower Felltop Limestone (which outcrops in the hills above the mine yard) hosted very productive iron-rich flats, which were worked by the Weardale Iron Company in the late 19th Century, by means of surface excavations and shallow adits (such as Wallace's Level, the portal of which lies at 488 m AOD around NY 8989 4416).

In the vicinity of the Grove Rake shafts, several major ore shoots coalesce, resulting in one of the most highly-mineralised pieces of ground in the entire North Pennines (Dunham, 1990). Interpretation of isotopic and fluid-inclusion data suggests that the Grove Rake intersection actually represents one of the principal 'root zones' for rising hydrothermal solutions in the orefield. If this is indeed the case, it perhaps helps to explain (when taken together with local tectonic predisposition; see Smith, 1995) why Frazer's Grove Mine holds the distinction for both maximum height and maximum width amongst the veins of the orefield. Individual ore-shoots (productive sections of veins) can extend vertically over as much as 200m, and vary in width from a few centimetres to more than 10m. As occurs elsewhere in the orefield, ore-shoots are widest and most richly mineralised where they cut through competent strata (particularly limestones, and to a lesser degree sandstones). Where the great width of



W
E
Greencleugh Dib Portal
Frazer's Hush Dib Portal
Grove Rake Shafts
Firestone Dib Portal
Rake Level Portal
480
470
460
450
440
430
420
410
400
390
380
370
360
350
340
330
320
310
300
290
280
270
260
250
450 Level
430 Level
410 Level
380 Level
360 Level
340 Level
310 Level
295 Level
285 Level
270 Level
260 Level
Rake Level
Firestone Level
No. 2
No. 1
30 fm level
"Tailrace Level"
To Wolfcleugh
50 fm Level
60 fm Level
80 fm Level
90 fm Level
FLOODED WORKINGS
KEY:
Flooded Workings
Great Limestone
Horizontal scale:
0
100
200
300
metres
Vertical exaggeration: x 4

Fig.1

individual veins is compounded by juxtaposition of veins in the Grove Rake intersection zone, the apparent total width of spar in some of the workings near to the shafts can exceed 20m.

Although three distinct veins are identified on mine plans in the Frazer's Grove workings, all three are considered by Dunham *et al.* (1952) and Dunham (1990) to be splits of the Red Vein, which is thus the "mother lode" of this reach of the Rookhope Valley. The three 'veins' distinguished by the fluorspar miners are:

- Grove Rake Vein (strike: 80°N)
- the Red Vein (strike: 102°N west of Grove Rake shafts, swinging to around 108°N to the east of them)
- Greencleugh Vein (strike: ~ 102°N - i.e. continuing the trend of the Red Vein). A southerly split off the Greencleugh Vein, colloquially named the "Sun Vein" (following common North Pennine usage for such souterly off-shoot veins) trends approximately 60°N.

The trend of the Greencleugh "Sun Vein" closely parallels that of the Burtree Pasture Vein 2 km to the east. Although there are no living memories of this vein having been worked from Grove Rake shafts, during exploration of the 30 fathom level of the Grove Rake workings for environmental management purposes in 1998, a cross-cut in shale was discovered leaving the Grove Rake Vein workings on a trend of about 160°N. Stale air precluded full exploration of this cross-cut, but it seems highly that it was originally driven to allow lead-bearing bouse from the Burtree Pasture Vein to be hauled to bank at Grove Rake, in the Frazer's Grove area. Furthermore, surface features such as old shafts (some of which are stone-lined and still open), mounds of spoil, crown holes and small open-cuts trace the 62°N strike of this vein across the fellside of Wolfcleugh Common, whence it eventually merges with the features known to be associated with the working of this vein from the Burtree Pasture Mine itself (Dunham *et al.*, 1952), the run-in adit portal of which can still be seen in the Sedling Burn valley, about one kilometre north of Cowshill.

2. PREDECESSORS OF FRAZER'S GROVE MINE

The modern Frazer's Grove Mine (Figure 1) is essentially a conglomeration of four largely distinct mining operations (albeit they are in close proximity and interconnected to varying degrees). The four operations (and the veins they worked) are as follows:

Mining Operation	Veins Worked
Grove Rake shafts	Grove Rake Vein, Red Vein
Rake Level / Firestone Dib Workings	Grove Rake Vein, Red Vein
Frazer's Hush 1-in-4 Dib	Greencleugh Vein

(It should be noted that the term "dib" was the term invariably used by local miners working in Frazer's Grove to refer to the type of feature that would elsewhere be termed a decline i.e. an inclined drift). The mineral rights of all of these workings are owned by the Church Commissioners, and have been worked under lease agreements by both private companies and by the public sector (British Steel, 1948-1985). A summary of ownership and working prior to 1990 is given below for each of the mining operations, synthesising previously unpublished information with historical information previously unearthed by Dunham (1990) and Fairbairn (1996). (The post-1990 history of the Frazer's Grove complex is described in detail in sections 3 - 5 below).

Photo 1. **P. L. Younger**

The Grove Rake Shafts. General View looking west, showing the No 1 Shaft headframe on the right and No 2 headframe on the left.

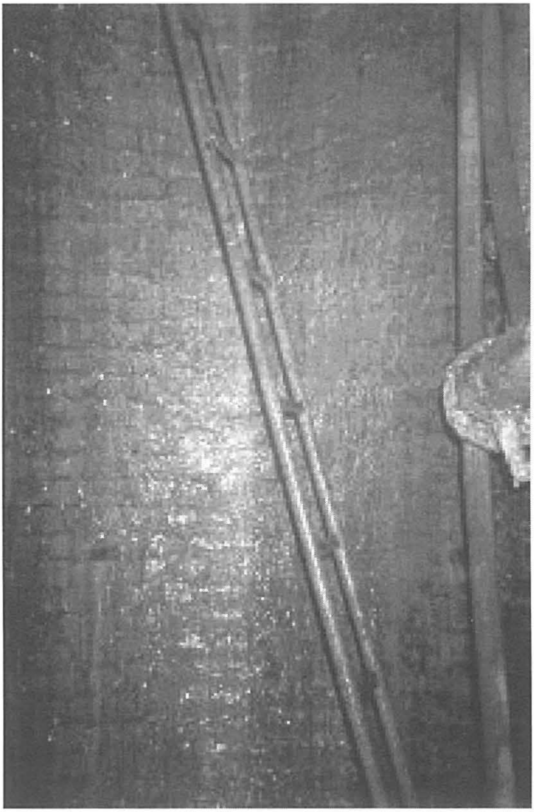


Photo 2. **P. L. Younger**
Inside Grove Rake No 1 shaft on 24-9-1998: View of ladderway installed to provide secondary means of egress.

Grove Rake Mine is the body of workings accessed by the two shafts in the main mine yard (Photo 1). Grove Rake is an old mine, in which the Grove Rake Vein and the Red Vein were originally worked for lead. By North Pennine standards, Grove Rake was never a great lead mine, as it yielded only 24,900 tonnes in nearly a century of lead mining. The first intensive working for lead was undertaken by the Beaumont Co. between 1819 and 1883. The two Grove Rake shafts (Table 2; Figure 1.) were sunk during this period, and remained in use right up to the closure of the Frazer's Grove combine. Lead was also worked by the Weardale Lead Co. between 1884 and 1916. While disappointing as a lead mine, Grove Rake has been the top producer of fluorspar in the entire orefield, with a total yield of fluorspar concentrates amounting to little less than one million tonnes. Fluorspar began to be recovered from around the beginning of the 20th Century, but large-scale production of the mineral commenced during World War II, when the mine was briefly operated by Blanchland Fluor Mines Ltd, prior to nationalisation under the British Steel Corporation in the early post-war period. Fluorspar was won from both the Grove Rake Vein and the Red Vein, both east and west of the shafts.

Table 2 Grove Rake shafts: summary details (adapted after Younger, 1998)

Shaft Name	No 1 Shaft	No 2 Shaft
Name given in Dunham (1990)	Old Drawing Shaft	Old Whimsey Shaft
Grid Reference	NY 8950 4410	NY 8949 4410
Diameter (approx) (m)	2.5	4m
Lining	Stone blockwork to 20m; brick-lined from 20m to 93.7m	Brick-lined full depth
Shaft Collar Elevation (mAOD)	430.7	429.9
Total Depth (m)	93.7	164.6
Shaft Foot Elevation (m AOD)	337	265.3
Insets to workings (level names and elevations in m AOD)	a. 30 Fathom Level (= Tail-race Level) @ 371m AOD b. 50 Fathom Level (at Shaft Foot) @ 337m AOD	a. 30 Fathom Level (= Tailrace Level) @ 371m AOD b. 40 Fathom Level @ 354mAOD c. 50 Fathom Level @ 337m AOD d. 60 Fathom Level @ 318.9m AOD e. 80 Fathom Level @ 288.12m AOD f. 90 Fathom Level (Shaft Foot) @ 265.3m AOD
Condition in 1999	Excellent	Excellent
Most recent use	Ventilation downcast; ladderway (19 ladders and platforms, installed winter 1994-95 by Paul Allison and Tony Hallam) for main secondary egress route; route for pipe range.	Occasional materials winding; emergency egress route by cage to winder; sump for submersible pump (pipe range routed via 30 fm level into No 1 shaft); water level monitoring and water sampling post-closure.

Rake Level / Firestone Dib Workings: although always administered as part of Grove Rake Mine, these workings are not accessible via the Grove Rake shafts, and were always worked via two drift-type drivages from surface:

1. Rake Level, with its portal at 430 m AOD [grid reference NY 8956 4413], just north of the No 2 Shaft headframe, runs into the hillside to the north of the mine yard for more than a kilometre, giving access to the higher portions of the Grove Rake and Red Veins.
2. The Firestone Dib, a 1-in-4 inclined drift, commencing in the eastern part of the mine yard, 40m east of the No 1 Shaft. The portal of the Firestone Incline lies at 425.9 mAOD, and it sustains its 1-in-4 gradient for an inbye run of around 140m length, before flattening to almost-horizontal at around 402 m AOD, in the Firestone Sill horizon. This roadway provides access to stoped ground beneath the Rake Level, to which it is connected by a ladderway staple shaft which provided both a complete ventilation circuit and a secondary means of egress.

Most of the Rake Level / Firestone Incline workings were excavated during the period of nationalisation under British Steel (1948 to 1985), with only brief later working .

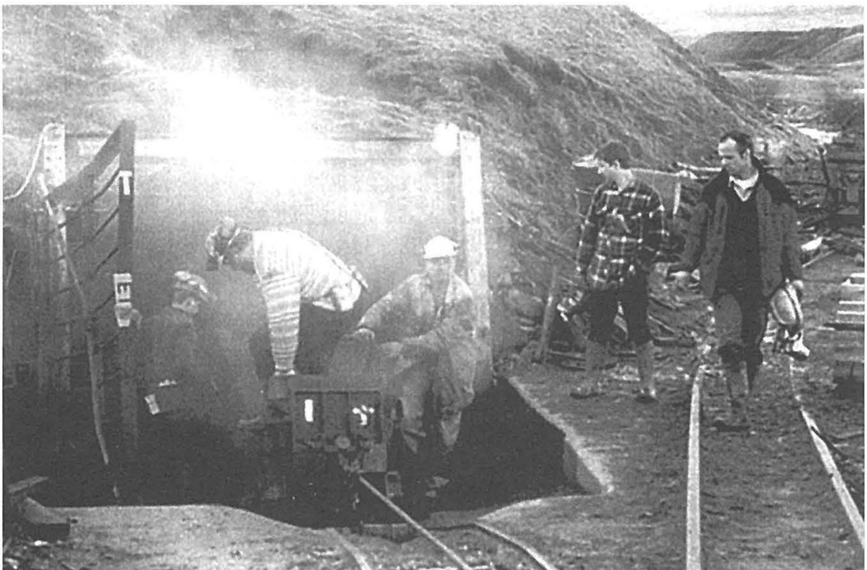


Photo 3. **Aidan Doyle**

Frazer's Hush 1-in-4 Dib portal on 23-2-1988. Notice the "steam" due to the relatively warm upcast ventilation meeting the cool North Pennine air. Paul Younger is climbing from the man-riding set.

Frazer's Hush Dib was the main area of recent working (see Sections 3 - 5 below). The mine was accessed by a 1-in-4 dib (decline), the portal of which lies at 433m AOD, on the south bank of the Rookhope Burn at NY 8900 4435, some 600m west of the Grove Rake shafts (Photo 3.). The 1-in-4 Dib descends approximately parallel to (and a few metres to the north of) the Greencleugh Vein, and was originally sunk to the 340mAOD Level by Swiss Aluminium Mining UK (SAMUK) in the early 1980s. (It should be noted that the old level numbering system used at Grove Rake i.e. fathoms below the No 1 Shaft collar, was not used in Frazer's Hush; rather the working levels accessed by the 1-in-4 dib are all numbered in terms of their elevation relative to Ordnance Datum).

The Frazer's Hush workings are connected directly to the Grove Rake shafts via the old 60 Fathom Level of Grove Rake Mine, which was deliberately extended westwards into the Frazer's Hush workings to facilitate ventilation, dewatering and secondary egress. The 60 Fathom Level meets the No. 2 Shaft at Grove Rake at 318.9 m AOD, and is at about the same elevation where it is joined by a ramp to the 310 Level in the Frazer's Hush workings. There are no other engineered direct connections between Frazer's Hush and Grove Rake, for the Greencleugh Vein does not extend as a separate, workable ore body into the Grove Rake workings. However, since the Greencleugh Vein is thought to be a westerly off-shoot of the Red Vein, which was extensively worked from both the Grove Rake shafts and the Rake Level, it is possible that a shear zone extends from the Greencleugh workings to the Red Vein workings.

Greencleugh Dib worked higher portions of the Greencleugh Vein, principally in the Firestone Sill and overlying strata, commencing at surface at a point some 600 m WNW of Frazer's Hush portal. The Greencleugh Dib portal lay in the Green Cleugh itself, a small side valley on the south side of the Rookhope Burn. The workings here were accessed by a 1-in-4 incline (portal at @ 470m AOD; NY 8843 4451; Photo 4), which was very similar in appearance and structure to the Frazer's Hush Dib. The portal of Greencleugh Mine is in a part of the vein directly above the 285 landing of the Frazer's Hush workings (Figure 1), and the dib descends to extraction roadways at 450m and 430m AOD. Greencleugh Mine was worked intermittently until December 1995, after which it was maintained for dewatering purposes, to avoid dangerous accumulations of water above active workings in Frazer's Hush. The westernmost workings in Greencleugh Mine are very close to the Corbet Mea Shaft (NY 8772 4443), which intersects a barren stretch of the Greencleugh Vein. Inspection of the Corbet Mea Shaft revealed that it remains open and in relatively good condition (Paul Allison, personal communication); however, it has no mined connection to the Greencleugh Vein, but from its foot (at about 423 m AOD) the Fawside

Level stands open and presumably still provides a direct connection to the Allenheads Mine, as indicated by Dunham (1990).

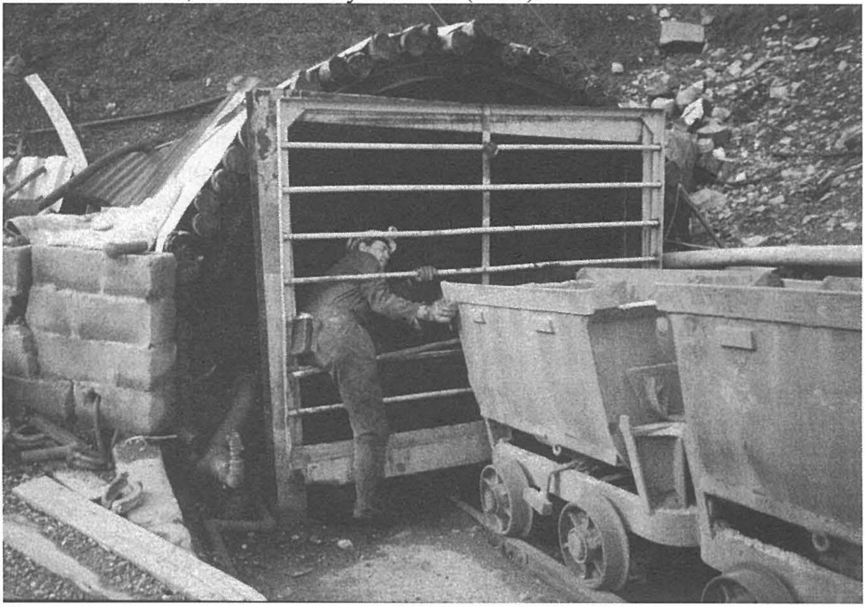


Photo 4 **P. L. Younger**

Frank Stephenson entering the Greencleugh 1-in-4 Dib portal on 26-9-1995

3. SHERBURN MINERALS LTD

Dunham (1990) describes the development of the mine up to the time when it was in the ownership of SAMUK. In 1985, Minworth Ltd acquired the North Pennine interests of both SAMUK and British Steel around 1985. The former SAMUK operations were subsequently operated by Minworth under the name Weardale Minerals. A brief 'bubble' of expansion was subsequently stimulated by Minworth, who were also actively re-developing the old barytes mines at Strontian in Scotland, as well as other mines in Newfoundland. However, despite the optimism generated in mining and geological circles by Minworth's development activities, the economic basis for their activities proved ill-founded, and the company was forced into receivership in 1991. As a wholly-owned subsidiary of Minworth, Weardale Minerals Ltd also went into receivership. It was at this point that Sherburn Minerals Ltd stepped in,

[1]It is important to note that Sherburn Minerals Ltd, and its established subsidiaries, wholly owned and operated the Frazer's Grove / Broadwood operation from 1991 onwards. From the mid-1990s, the wholly-owned subsidiary operations at Frazer's Grove / Broadwood were managed in the form of a separately-named subsidiary, Durham Industrial Minerals Ltd.

purchasing the assets of Weardale Minerals Ltd (with the exception of the Blackdene site, which was sold off separately, essentially for scrap). The assets acquired by Sherburn Minerals Ltd included all of the mine workings listed in Section 2, along with the Broadwood fluorspar flotation plant at Frosterley, and mining lease rights for most of the mines in the North Pennines with the exception of those of Alston Moor. Most importantly for residents of Weardale, Sherburn Minerals Ltd provided continuity of employment for around twenty mining and mineral processing workers. At its peak in the mid-1990s the total workforce rose to around fifty, thus establishing the operation as one of the most important employers in the Dale.

Although Sherburn Minerals Ltd focused all development and extractive in the Greencleugh Vein (accessed by the Frazer's Hush and Greencleugh Dibs), the Grove Rake Shafts were maintained for purposes of ventilation, dewatering and secondary egress. The heapstead buildings beside the shafts were also retained for the use of their workshops, office and pithead showers (fed by water pumped from the Rake Level) throughout the life of the mine, albeit this entailed a minimum 500m walk between the heapstead and the Dib portal before and after every shift.

The westernmost portions of the vein (within the Firestone Sill and overlying strata) were worked (up to December 1995) from the Greencleugh Dib, with the remainder of the vein further east (and from the Firestone Sill downwards) being worked from the Frazer's Hush Dib. Both of these dibs were relatively recent sinkings (by SAMUK in the 1980s), albeit the very place name of Frazer's Hush betrays the presence of former, shallow workings on the Greencleugh Vein (the uncertainty over which necessitated considerable precautionary drilling ahead of lode drives in the shallower workings).

Run-of-mine ore produced from these workings averaged 30% fluorspar, 3% lead sulphide (galena, present as nodular aggregates of large crystals) and 0.3% zinc sulphide (usually aphanitic and disseminated within galena masses). The gangue typically comprised:

- white iron (i.e. siderite), which was most abundant near the cheeks of the vein, and often functioned as a cement for brecciated masses of country rock material
- coarsely-crystalline quartz, especially abundant as cavity linings, and
- traces of pyrite (most frequently fine-grained, and associated with the nodular masses of galena) and chalcopyrite (found as discrete stringers within siderite masses, near the cheeks of the vein).

All ore was hauled to bank by means of rakes of four tubs at a time, and tipped in stockpiles below the winding house platforms. Thence it was loaded by tractor shovels into 30 tonne lorries, which transported it 15 km down-dale to the Broadwood mineral processing plant. The basic process at Broadwood (as it was operating under the ownership of Minworth in 1987) has been described by Pickin (2002). The current configuration of the plant has changed little since 1991, and may be summarised as follows:

- two stage crushing, with the < 20mm fraction passing to the ball mill for grinding
- the ball mill product is then subjected to density separation, liberating the < 250 μm fraction
- this fraction is then passed to two-stage froth flotation:
  - the first stage (which uses xanthates) recovers lead and zinc
  - the second stage (which uses lipids) recovers the fluorspar
- thickeners and roughers are then applied to achieve the final result: powdered fluorspar, grading 98% CaF_2, of which 80 - 90% is less than 150 μm in grain diameter.

The innovative focus of Sherburn Minerals Ltd activities at Broadwood has been in two principal areas (for which the ingenuity of the plant manager, Bob Bennett, merits special mention):

(i) Optimising recovery using the existing infrastructure, but with subtle changes in flotation agents and operational parameters, and
Final processing of the fluorpsar product to suit the changing demands of customers.

Typically, around 80% of the fluorspar present in the run-of-mine ore from Frazer's Grove Mine has been recovered at the Broadwood plant (with recovery rates reaching 90% when ore properties were favourable). Lead (co-mixed with zinc) has also been consistently recovered as a saleable by-product. The remaining gangue (principally quartz, siderite and country-rock fragments) is disposed of into a tailings pond.

The peak production rate of the Broadwood plant is around 8 tonnes per hour, so that in a week of intense operation as much as 1000 tonnes of fluorspar product could be produced. However, it was rare for the plant to remain in production for more than one or two weeks at a time, so that annual production rates ranged between 10,000 and 20,000 tonnes throughout the 1990s. Table 3 summarises production figures from the plant from 1991 to 2001 (sporadic production having continued after the closure of the mine, working from stockpiled run-of-mine ores).

Table 3 - Summary production figures (tonnes), Broadwood Plant, 1991 - 2001

Financial year	Fluorspar production	Lead-zinc concentrates production
1991	10118	841
1992	15176	1618
1993	18187	2474
1994	11588	1600
1995	10372	1736
1996	9735	1695
1997	9923	1089
1998	6119	480
1999	4282	108
2000	1659	0
2001	1170	0

4. TECHNOLOGICAL CHANGE AND THE EVOLUTION OF FRAZER'S HUSH

The recent history of sinking and working of the Frazer's Hush workings provides an interesting study in the pros and cons of various types of run-of-mine haulage under North Pennine conditions. Developments in mine layout and working techniques were jointly designed by Jeffrey Allison (a director of Sherburn Minerals Ltd), Percy Simpson and the various other mine managers who held day-to-day responsibility for production, safety and other aspects of mine operation. The managers of Frazer's Grove Mine during the period of ownership of Sherburn Minerals Ltd were:

1. 1991 - 1992: Jim Sherwin, the former British Steel mine surveyor, who was one of the beneficiaries of continuity of employment when Sherburn acquired the mine.
2. 1992 - 1995: Percy Simpson of West Auckland, former manager of Kellingley Colliery, West Yorkshire (which, at the time, was in its production heyday and employed 200 men) and a cousin of Jeffrey Allison. As manager, and subsequently as advisor, Percy was responsible for many improvements in working methods, such as routine long hole boring as protection against inrushes.
3. 1995 - 1996: Frank Stephenson, former mechanical engineer of the mine, who later went on to work at Blair's foundry in Stanhope.
4. 1996 - 1997: Rod Haigh, a former under-manager of Kellingley Colliery.
5. 1997 - 1999: John Evans, also a former under-manager of Kellingley Colliery.

Throughout the working of the Frazer's Hush Dib, all spar was hauled to bank by means of a static engine and cable drum located at surface. This haulage system was capable of raising rakes of four rail-mounted tubs at a time. For all levels down to the 295 Level, these rakes of four tubs were hauled from the appropriate dib cableway landing to the working face by means of battery-powered locomotives. At the face, spar which had been previously broken by conventional drill-and-blast techniques was "mucked" into the tubs, one at a time, using an Eimco air-powered rocker shovel. When all four tubs of a given rake were full, they were hauled back by loco to the 1-in-4 dib cableway, and thence to bank.

Working in this manner, levels were driven within the vein at approximately 10m depth intervals, via short cross-cut landings (Figure 1). From these landings, the levels were driven east and west within the vein until the fluorspar became too thin for working. (This usually occurred within 200m - 300m of the landing in either direction). Advance was achieved by a two-shift production cycle, with drilling and blasting in the first shift, followed by mucking-out and support-setting in the second shift. During advance, the level was typically supported by NCB-type steel-arch girders at conventional four-feet spacing, with timber packing. In the retreat from each working level, the girders were systematically removed, and stoping of the vein above the roadway ceiling was pursued as appropriate by a simple overhand / shrinkage technique, using ladders for access to the blasting positions. In the mid-1990s, it was usual practice for four faces (i.e. four roadway headings) to be in production at any one time. For instance, an inspection by the author on 26-9-1995 observed faces in production on the 410 Level (where the hassles of precautionary drilling ahead of advancing roadways had previously deterred completion of drivage), through the 340 Level in the Great Limestone, the 310 Level in the Four Fathom Limestone and the 285 Level in the Nattrass Gill Hazle. By the late 1990s, production had declined so that only two faces would be working at any one time, with east and west faces of the 270 Level working synchronously, then east and west faces of the final, 260 Level.

The mode of production using rail-mounted tubs and rocker-shovels was undertaken for all levels down to the 295. For the working of the 285 and 270 levels, significant variations in technique were introduced in an attempt to improve the long-term prospects of the mine. In time for the working of the 285 and 270 levels, diesel-powered free-steered vehicles (FSVs) were introduced to the mine. Bearing in mind that the single standing engine at bank would reach its technical limits by the time the 1-in-4 Dib reached the 250m Level, the introduction of FSVs had the potential to facilitate future mine development to greater depth without either:

(i) the expense and difficulty of installing and using a secondary, under ground haulage engine from a secondary 1-in-4 dib which would have had to commence at the 250m Level, or
(ii) introducing conveyor belt technology to the mine, at even greater cost.

With these considerations in mind, a corkscrew drivage with a relatively gentle downward gradient was commenced from the 295 landing. A straight drivage similar to the 1-in-4 Dib could not be used, because FSVs require relatively gentle gradients (ideally less than 1-in-6). This corkscrew drivage was optimistically named the "Whin Sill Dib" (Photo 5), for it was hoped that it would eventually provide access to the zone in which the Greencleugh Vein cuts the Whin Sill. Elsewhere in the orefield (most notably at Cambokeels), ore-shoots in the Whin Sill proved to be amongst the widest and most well-paying ever encountered, notwithstanding a tendency to high silica contents due to metasomatic interactions with the dolerite of the sill. As the Whin Sill had been proven by drilling to lie about 110m below the 285 Level in Frazer's Hush, up to a kilometre of spiral drivage would have been needed for the "Whin Sill Dib" to attain its patronymic horizon. Sadly, this project was never completed.

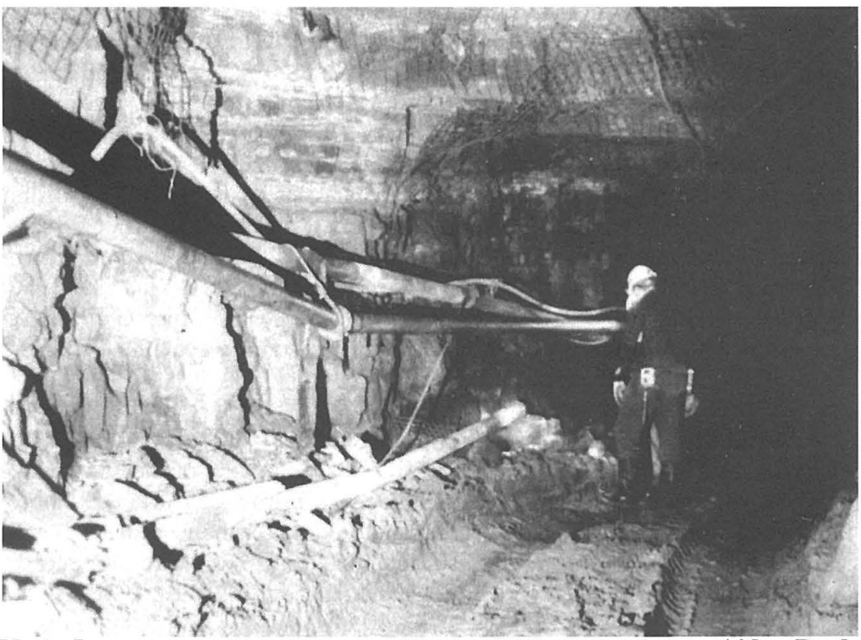


Photo 5 **Aidan Doyle**
In the Whin Sill Dib, good roof conditions in the Nattrass Gill Hazle

Because the FSVs could not negotiate the 1-in-4 Dib, they could not provide non-stop haulage from face to bank, as occurs in more modern mines (such as the Foss Barytes Mine in Perthshire, Scotland). The best that could be achieved using the FSVs in Frazer's Hush was to haul run-of-mine product to an ore pass at the 285 level. This ore pass fed a hopper which was controlled below by a 'cousin jack chute' on the 1-in-4 Dib, where the conventional rakes of 4 tubs could be loaded with ore for haulage to bank.

A number of problems beset the introduction of FSVs to the Frazer's Hush workings. High maintenance requirements soon became apparent, and these were not too easy to handle in a situation in which the FSVs could only be brought to bank in pieces. Furthermore, the introduction of FSVs to Frazer's Hush workings also required a change in roof support strategies, because the conventional NCB steel arches available at the mine were too narrow to allow for reliable manoeuvring of FSVs. At first, this problem was readily overcome by the introduction of rock bolts and mesh, which were effective in the vicinity of the 295 landing and the uppermost stretches of the Whin Sill Dib (Photo 5), in which the country rock was the competent Nattrass Gill Hazle. However, where the Whin Sill Dib descended towards the 270 Level, and at the point where the 285E roadway settled to horizontality, poorer roof conditions were encountered (Photo 6), associated with the platy siltstones which lie between the Nattrass Gill Hazle and the Three Yard Limestone (Table 1). At the easternmost end of the 285E Level, the 'plate beds' which underlie the Quarry Hazle also gave rise to difficult roof conditions. If the 285E Level could have simply been abandoned (as was the 295) after spar extraction ceased, these roof conditions would not have been such a problem.

However, as luck would have it, the forehead of the 285E Level was the locus of a considerable water make, which necessitated sustained access for localised pumping to avoid dangerous accumulations of water above active workings on the 270 and 260 Levels.

The problems of FSV maintenance and roof support became sufficiently substantial by the time the 270 Level was worked out that the driving and retreat of the last working level (260 Level) were undertaken by the traditional technique, with Eimco rocker-shovels filling rakes of four tubs in each mucking cycle. (A mucking-out cycle on the 260 Level was filmed by the BBC's "Close-Up North" programme in 1998, and a copy of the raw footage has been deposited on video in the Friends of Killhope archive).


Photo 6. **P. L. Younger**
In the Whin Sill Dib, poor roof conditions in the shales below the Quarry Hazle

Ventilation of the workings was achieved by operation of a major fan (capacity approximately 10 m^3/s) on the 310 Level, approximately 100m from the 1-in-4 dib. This drew a fresh air current from the Grove Rake end of the workings, where ventilation doors around the Number 2 shaft ensured that the Number 1 shaft was the principal downcast (Table 1). (The down-casting properties of the No 1 shaft gave rise to the spectacle of snow falling 70m below ground in 1994, during the installation of the secondary egress ladderway). The air passed along the 60 fathom level of Grove Rake to meet the fan in the Frazer's Hush 310 Level (Figure 1). Brattice partitions were used to divert the air into the 295, 285, 270 and 260 Levels, with local booster fans to ensure adequate currents in critical areas. Given that so many mine workings in the North Pennine uplands are slef-ventilating, an experiment was undertaken by mine manager John Evans on a weekend in 1997. With staff ready to measure the air current at the routine ventilation monitoring stations, the 310 fan was halted. The result: the ventilation current stopped altogether within minutes.

Secondary egress routes were a constant headache in Frazer's Grove Mine. Greencleugh was a single-entry decline, so that compliance with mine safety regulations meant that only a small number of miners could work in it at any one time. As has already been mentioned, the Frazer's Hush workings are connected directly to the Grove Rake shafts via the old 60 Fathom Level of Grove Rake Mine, which was deliberately extended westwards into the Frazer's Hush workings to facilitate ventilation, dewatering and secondary egress. The 60 Fathom Level meets the No. 2 Shaft at Grove Rake at 318.9 m AOD, and is at about the same elevation about 100m east of the Frazer's 1-in-4 Dib, where it is joined by a ramp from the Frazer's 310 Level. There are no other engineered direct connections between Frazer's Hush and Grove Rake. Secondary egress necessitated walking along the 310 - 60 fm levels to the No 1 shaft, whence the surface could be attained by climbing a ladderway (which was installed in the winter of 1994 - 95, after the cage haulage in the No 2 shaft ceased to be certifiable for man-riding). This route was difficult to travel, due to deep accumulations of water in the 60 fm Level. Roof maintenance was also expensive and awkward to arrange. In view of these difficulties, a plan was developed to solve the secondary egress problem by installing a 1-in-1 raise from the 285 landing (next to the ore pass mentioned previously), which would intersect the Greencleugh Dib a few tens of metres in-bye from the portal. At the time the mine closed this raise had been developed to a position about half way to the Greencleugh Dib.

5. THE TWILIGHT YEARS

The overall state of the fluorspar market is discussed elsewhere in this volume, and will not be rehearsed in detail here. Suffice it to say that global demand for fluorspar peaked in the mid-1980s (around the time of sinking of the Frazer's and Greencleugh 1-in-4 dibs), but by the mid 1990s a number of factors were combining to lower global demand for fluorine. Chief amongst these factors was the advent of the international ban on the production and use of chlorofluorocarbons (CFCs). The decline of metal-finishing and fibreglass production in Europe also contributed to marked decreases in demand for hydrofluoric acid, and thus for reagent-grade fluorspar. These factors affected all fluorspar producers equally. In the particular case of the Frazer's Grove operation, specific difficulties in marketing fluorspar arose from two principal causes:

(i) the well-established trading relationship between ICI and Laporte (producers of Derbyshire fluorspar), which included elements of reciprocal interests in relation to hydrofluoric acid production which were beyond the scope of the Frazer's / Broadwood operation to influence.

(ii) A switch within British Steel (later Corus) from using filter cake (dried, bagged powder) to using fluorspar gravel. While a number of foreign producers could produce suitable gravel-sized material by controlled blasting and screening of run-of-mine ore, the content of white iron in gravel-size blast fragments from Frazer's Grove Mine was always too high to facilitate such an easy route to market. To maintain custom in the face of the switch in demand from powder to gravel, the Broadwood plant was forced to develop a pelletisation process for the previously milled < 150 μm fluorspar powder, to produce gravel-sized fragments free of white iron. While Corus were happy to purchase this product, they were not willing to pay more than the going rate for powder, so that Sherburn were having to absorb the extra cost of producing re-constituted gravel.

Whilst the European Union does have an "anti-dumping tariff" in force, which is supposed to protect EU fluorspar producers from unfair foreign competition, it has been clear for some time that this tariff is set at too low a rate (currently around €113.50 / tonne, or about £68 / tonne at present exchange rates). Throughout the 1990s, most UK producers (with Sherburn no exception) have struggled to break even at prices any lower than about £110 / tonne. While mining was ever a game of hoping for an upturn in demand and in price, there is only so long a small to medium-sized private sector operator can sustain the imbalances inherent in such a hostile market. Sherburn Minerals Ltd sustained their position far longer than most observers would have predicted.

On top of these fundamental economic issues, management of mine water quality became an increasing challenge as the mine deepened past the 295 Level. The dewatering strategy and mine water quality during working have been presented by Younger (2000a). The principal issue from a regulatory perspective was the elevated quantities of zinc in the pumped mine discharge (which averaged 12 mg/l and sometimes reached 30 mg/l). Since conventional, active treatment of the mine waters was beyond the resources of the company, innovative strategies were called for. In association with the University of Newcastle and another small mining company in Spain (Río Narcea Gold Mines Ltd), Sherburn Minerals obtained funding from the EU's BRITE-EURAM programme to investigate low-cost options for pollution abatement. The strategy finally identified (Younger, *et al.*, 1998) envisaged isolation of the most zinc-rich sources of water in the mine (on the 285 Level), and pumping of these via the new 1-in-1 raise to Greencleugh, where they could be passively treated using a combination of innovative carbonate-based reactors (Nuttall and Younger, 2000) and an existing *Juncus* wetland which had grown up around the existing pumped discharge from the Greencleugh workings. In the event, the mine closed before these plans could be implemented at full scale.

Once it was clear that the mine could no longer resist the market pressures which had for so long borne down upon it, closure became inevitable. As it happened, closure was announced soon after the introduction of new legislation, in the form of the Mines (Notice of Abandonment) Regulations 1998. To comply with the terms of these regulations, a hydrogeological investigation was required, to determine the inter-connectedness of Frazer's Grove Mine with other long-abandoned mines nearby. The ultimate goal was to predict the range of possibilities for post-closure discharges of poor quality water after flooding of the workings. The pre-closure survey is described by Younger (1998), and the subsequent evolution of mine water levels and quality are documented by Johnson (2002) and Younger and Johnson (2002), and no further details will be given here, save to note that the eventual decant for the Frazer's Grove mine waters was via the Tailrace Level (portal at 364m AOD at NY 916427). While the pre-closure survey had successfully identified "trigger" water levels in the shaft that would indicate whether this eventuality would arise. The emergency measures taken by the Environment Agency to prevent the short-term pollution of the stream by turbid, zinc-rich waters were unfortunately beset by a breakdown of communications with (and within) Durham County Council, which led to the unwitting partial destruction of the site of the Old Rookhope Ore Hearth (Hammond, 2000; Younger, 2000b).

The last production shift in the Frazer's Hush workings (at which the author was privileged to be in attendance, while undertaking hydrogeological work) was worked by Bob Forster and Joe Forster on the 260 East Level, on 11-12-1998. Limited salvage work continued until the final withdrawal of pumps on 5-3-1999, after which the only activities in the workings related to observations of water-level rise. The lack of a capacity for natural ventilation in these workings (which was mentioned in Section 4 above) came to have important safety consequences during the closure phase. First indications of the problem were found in the Greencleugh 1-in-4 Dib in March 1998, when an inspection by mine staff following breakdown of the fan in those workings led to the discovery of a dangerous accumulation of stythe (oxygen-deficient air). This foreshadowed the similar stythe problem which developed in the Frazer's 1-in-4 Dib shortly after the rising water levels necessitated withdrawal of the fan from the 310 Level. A novel water-level monitoring system was installed in the Dib (Johnson, 2002) to allow levels to be observed without the need for staff to enter the poorly ventilated workings. Eventually, the risk to trespassing mine explorers from the likely stythe accumulations necessitated complete sealing of the portals of the Greencleugh and Frazer's Hush Dibs, somewhat earlier than would normally have been the case.

After the final withdrawal of production teams from the Frazer's Hush workings in December 1998, a brief "Indian summer" of production centred on the shallow workings accessed via the Firestone Dib. Between January and July

1999, several thousand tonnes of impressive green spar were raised from these workings. However, by the end of July 1999, production here had also ceased. At the time of writing (August 2002), all mine workings at the site have been formally abandoned, though the mine site itself is mothballed. While it currently seems unlikely that mining will re-commence in the foreseeable future, it must be remembered that Frazer's Grove has always been a mine of surprises.

EPILOGUE: "RIDING TO BANK: FRAZER'S 1-IN-4 DIB, FEBRUARY 1998"

(The following poem has an unusual metre, written to mimic in 12 syllabic beats the rhythmic noise made by a rake of four tubs plus the man-riding being hauled to bank up the 1-in-4 Dib).

A rake of tubs to muck, to shunt to couple-on
The silent tugs that ring the message bell at bank
Away below the answer rings: you'd best hop on
And squeeze into the riding-set, then off we clank

The roof here at two-sixty is a solid one
Finest Durham hazle, like cathedral walls
Doesn't need arch girders, bolts wi' faceplates on
Are quite enough to keep wi' safe from minor spalls

The platy shale above's another matter though
Arched with timber packing there, the roadway walls,
And even then best keep an eye out as you go
In case the way is blocked with unexpected falls

Mind-out as the set comes by two-seventy
The old ore chute there sticks out just a bit too far
As long as ye take care the roadway width is plenty
But keep ya arms tucked well inside the car

Tha's someone waiting up at two-nine-five to catch a ride
Why aye, there's space for one more lad to squeeze in here
If ye'll jus' shift ya rescuer to the other side
And he can use the final tub to stow his gear

It's up about three-sixty is the dodgy bit
A block of limestone's on and made the girder bend
When I say "down!" then bend as low as ye can get
We'll have to sort that girder out come next weekend

At last we see the daylight far away ahead
A growin' spot of brilliance marks wa' journey's end
Afore we make it there ye knaa we'll all get wet
Those drippers by four-twenty, man, they never end

Time to lowp out now before the tubs are tipped
Make sure ye grab your gear before ye leave the set
Take it steady now, mind on, last time ye tripped!
Now tramp back to the heapstead through the cold and wet.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the generous provision of information by Directors and staff (past and present) of Sherburn Minerals Ltd, especially Jeffrey Allison, Paul Allison, Rod Haigh and John Evans. While Sherburn Minerals Ltd kindly permitted the information herein to be published, none of the statements made in this paper are to be taken as representing the views of Sherburn Minerals Ltd, its Directors, or any of its subsidiary companies. All errors and opinions are the responsibility of the author alone.

SELECTED BIBLIOGRAPHY

Carruthers, R.G., and Strahan, A., 1923, Lead and Zinc ores of Durham, Yorkshire and Derbyshire, with notes on the Isle of Man. *Memoirs of the Geological Survey, Special Reports on the Mineral Resources of Great Britain, Vol. XXVI. HMSO, London.* 110 pp.

Dunham, K.C., 1990, Geology of the Northern Pennine Orefield. Volume I – Tyne to Stainmore. (2nd Edition). *Economic Memoir of the British Geological Survey, sheets 19 and 25, and parts of 13, 24, 26, 31, 32 (England and Wales). HMSO, London.* 299pp.

Dunham, K.C., 1997, Rookhope in retrospect. In Chambers, B., (editor), *Out of the Pennines.* Friends of Killhope, Durham. pp. 1 - 12.

Dunham, K.C., Dines, H.G., Whitehead, T.H., Earp, J.R., Stephens, J.V., Harvey, C.O., and Wilson, H.E., 1952, Fluorspar. *Memoirs of the Geological Survey, Special Reports on the Mineral Resources of Great Britain, Vol. IV. HMSO, London.* 145pp.

Fairbairn, R.A., 1996, Weardale Mines. *British Mining* No. 56. A Monograph of the Northern Mine Research Society. Keighley, Yorkshire. 151pp.

Greenwood, D., and Smith, F.W., 1977, Fluorspar mining in the northern Pennines. *Transactions of the Institution of Mining and Metallurgy (Section B: Applied Earth Sciences),* 86, pp. B181 - B190.

Hammond, N., 2000, Old Rookhope Ore Hearth, trouble in the hills. *Friends of Killhope Newsletter,* 50, pp. 7 - 12.

Johnson, K.L., 2002, *Manganese in mine water and its removal by passive treatment.* PhD Thesis, Department of Civil Engineering, University of Newcastle. 260pp.

Johnson, K.L. and Younger, P.L., 2002, Hydrogeological and geochemical consequences of the abandonment of Frazer's Grove carbonate hosted Pb/Zn fluorspar mine, North Pennines, UK. In Younger, P.L., and Robins, N.S., (eds) *Mine Water Hydrogeology and Geochemistry*. Geological Society, London, Special Publication 198, pp. 347 - 363.

Nuttall, C.A., and Younger, P.L., 2000, Zinc removal from hard circum-neutral mine waters using a novel closed-bed limestone reactor. *Water Research*, 34, pp 1262-1268.

Pickin, G., 2002, Visit to the Broadwood fluorspar plant of Weardale Minerals Ltd / Minworth Group - May 1987. In Chambers, B., (editor), *Friends on the Northern Lead Dales. An Anthology of the Friends of Killhope..* Friends of Killhope, Durham. pp. 21 - 25.

Smith, F.W., 1995, The mineralization of the Alston Block. In Johnson, G.A.L., (editor) *Robson's Geology of North East England.* (Published as Transactions of the Natural History Society of Northumbria, vol 56, part 5). Natural History Society of Northumbria, Newcastle Upon Tyne. pp. 344 - 352.

Younger, P.L., 1998, *Environmental Implications of the Closure of Frazèr's Grove Fluorspar Mine, County Durham.* Report to the Environment Agency, Northumbria Area. Department of Civil Engineering, University of Newcastle, October 1998. 52pp.

Younger, P.L., 2000a, Nature and practical implications of heterogeneities in the geochemistry of zinc-rich, alkaline mine waters in an underground F-Pb mine in the *UK. Applied Geochemistry,* 15, pp 1383 - 1397.

Younger, P.L., 2000b, Old Rookhope Ore Hearth. *Friends of Killhope Newsletter,* 51, pp 10 - 11.

Younger, P.L., Banwart, S.A., and Hedin, R.S., 2002, *Mine Water: Hydrology, Pollution, Remediation.* Kluwer Academic Publishers, Dordrecht. (ISBN 1-4020-0137-1). 464pp.

Younger, P.L., Nuttall, C.A., Jarvis, A.P., and Fernández Albarrán, C.J., 1998, *Novel methods for controlling zinc in mine waters.* Research Feasibility Report. Prepared for Durham Industrial Minerals Ltd under European Commission BRITE-EURAM Contract BEST-3274. Department of Civil Engineering, University of Newcastle. 69pp plus appendices.