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NOTES ON MINING LEATS

R.H. Bird

“.... the means of putting to work many mines that would otherwise remain unworked, or if worked, could not be worked with profitable results.”

Absalom Francis. 1874.

SYNOPSIS

Watercourses supplying mining works have been in use for centuries but their complexity increased during the 19th century, particularly in mining districts which were remote from coal supplies used for steam engines but which had sufficient river systems (or streams) of a dependable nature. Their role in Britain’s mining areas is discussed, with examples from overseas locations. An attempt is made to outline their construction methods and costs.

In an age when water power reigned supreme and, indeed, for some time thereafter, mills and manufacturing industries were dependant on a steady supply of water to drive that prime mover, the water wheel. Flour mills, fulling mills and the early ferrous metal industries were sited next to reliable river or stream courses and could thus utilise this water source with little difficulty. Sometimes, the configuration of the stream was inconveniently placed for the mill site and the miller was forced to construct a ditch, from a dam upstream of his mill, and by this, lead the water to his wheel. After driving the wheel, the water was returned to the stream directly or through another ditch, the tailrace. This arrangement of upstream abstraction was also instrumental in providing the wheel with a ‘head’, a very necessary consideration when overshot wheels were employed.

Water power, as applied to mining, was fraught with problems since metalliferous lodes do not usually align themselves conveniently to local rivers and streams, which were necessary to drive wheels for pumping and crushing machinery. Certainly, there are many instances where mines had a usable source of water close at hand but, when applied, power from the wheels required transmission through long lines of flat rods to the shaft collar, or through an adit, to reach the pumps. For fear of flooding the workings in time of high rainfall, shafts had to be sited some distance from the water supply and few are the instances where one would find a waterwheel adjacent to a mine shaft.

We may cite, as an exception, the wheel which drove the pitwork at Sedling Mine, Cowshill in Weardale. A photograph of its pit and the adjacent shaft can be found in *Life & Work of the Northern Lead Miner.* (Raistrick and Roberts. 1984). Just what became of the tail water is uncertain but it may have been used for ventilation purposes through a water blast machine, but this is very unlikely and defeats the purpose of the wheel and pumps!

Long lines of reciprocating flat rods, at a mine sunk upon the banks of a river, are nowhere better exemplified than at the 19th century enterprise of Devon Great Consols Mine. Drawing water from the Tamar, which flowed in convenient proximity, recourse was made to ditches or canals, these taking water from upstream of the massive wheels, which, in turn, drove pumps in the shafts on the hill top some half mile distant. Flat rods connecting the wheels to the pumps were carried uphill on a multitude of timber stands surmounted by iron dolly wheels.[1]

Ditches, leats, watercourses or la des are an ancient contrivance and have been with us for centuries. Drower[2] tells us that in 691 B.C., Sennacherib constructed a watercourse upwards of 50 miles long to augment the water supply to his capital, Nineveh.

This colossal leat was as wide as an arterial road and paved with masonry, it being the most impressive work of hydraulic engineering until Roman times. The Romans· of course, were well known for their abilities as hydraulic engineers and they applied this knowledge to bring water long distances via leats, both for public utility and mining purposes.

Fine leat systems, which served their gold mining operations in north west Spain, deserve special mention, if only to illustrate the technical excellence which was achieved by these people. In particular, the arrangements at Montefurado have been justifiably termed the most outstanding examples of hydrological engineering known to the Roman world.

Briefly stated, the system involved leats tapping the headwaters of the Rio Del Oro, which lay across a watershed from the Puerto Del Palo Mine, and running just below the 3000 feet contour for some 4½ miles, plunging through a tunnel at the ridge of Montefurado. A further mile of leat delivered water to a tank above a huge opencast. Further high level leats brought water from the headwaters of the Rio Pumarin, lying to the north.

The opencast at Puerto Del Palo is on a massive scale – some 658 feet vertically – and was produced almost exclusively by hushing operations. The hushing tank at the end of the Montefurado leat, and above the opencast, is some 181 feet long by 17 feet wide, with walls standing over 11½ feet high. It is set back from the lip of the opencast by some 50 feet and its outfall illustrates two phases of operations. Initially, water was channelled through a 'V' shaped sluice but later this channel was blocked. Another, later sluice was cut in an arc at the edge of the pit.[3]

In Britain, perhaps the best example of the Romans' use of a leat is to be found in Wales at the well known gold mines of Dolaucothi. It is analogous in virtually all respects to the type of waterways used in Spain for hushing although, of course, not on such a grand scale. Leat systems are described by Pliny the Elder and a translation of his remarks are, in essence, as follows. He tells us ...

'equally laborious and more expensive is the associated problem of running aqueducts mile after mile along mountain ridges to wash away mining debris. *(hushing).* The aqueduct channels are called corrugi, a term derived from the word conrivatis or confluence. The problems are innumerable; the incline must be steep to produce a surge rather than a trickle of water; consequently, high level sources are required. Gorges and crevasses are bridged by viaducts. Elsewhere protruding rocks are cut away to allow the placing of flumes'.[4]

In broad terms however, Roman mining in Britain did not require extensive use of water power. Mines were shallow and usually opencast and whilst water

Plate 1. *Set in sylvan surroundings, the course of Tavy Consols leat runs parallel to the river from its vanished weirhead above Virtuous Lady Mine (SX 475695).*

may have been spasmodically used in a form of hushing operation (as at Dolaucothi, for example), power for wheels applied to pumping, crushing and the working of bellows in smelting hearths were uncommon[A]. What were slaves for anyway! Crushing would have been undertaken manually, as would most other such operations.

Much later, in Medieval times, we find references to a leat in Devonshire which possibly brought water from the River Lumburn to mines near the Tavy. Traces of this leat still show on the ground in Shillamill Wood, where it runs along the 400 feet contour and tunnels through rock outcrops en route. It is dated circa 1461.[5]

We can be fairly certain that short leats were being cut to the Dartmoor tinners' blowing houses around this time. Water brought through these artificial cuts drove a small wheel powering the bellows. Later, leat cutting on a massive scale would be centred upon these Dartmoor hills, supplying distant mining wheels and conducting public supplies to Devonport and Plymouth. In spite of waterwheels being used for mining purposes long before 1700, they had limited application, primarily due to inadequate pumps and since deep mining had not become necessary, there being ample and easily worked shallow deposits close to surface. Moreover, adits could be driven where the topography allowed, so that long lifts of pumps were not then needed. Horse gins were used for baling and rag and chain pumps would suffice in these conditions, the latter often worked by teams of men.[6]

That is not to say that leats were uncommon at this time. Tonkin[7] tells us that in 1696, an expensive instance of leat construction – which included some tunnelling – was necessary as a result of the drying up of the Trevaunance stream, in St. Agnes, Cornwall. This seems to have occurred due to the driving of an adit beneath – so lowering the local water table, one supposes – and, consequently, the stamping and grist mills in the valley were critically short of water to turn their wheels. Water from the adit mouth was led back into the valley via a leat and tunnel which ultimately only left the upper mill high and dry!

The 18th century was a time when deeper mining necessitated more complex arrangements to provide adequate water supplies, a factor evident both at home and abroad. Hamilton Jenkin notes[8] a complex system of watercourses which ran around the Redruth district and which involved, not only leats but the passage of water through the mine workings themselves and the subsequent capture of adit waters. This, to power mines' machinery many miles away. Pryce,[9] writing in 1778 observed ....

> 'By the superior address of our miners, the rivulets are often extended many miles to drive an engine; and are then returned as far back again as possible to serve other mines and stamping mills'.

As a consequence of local topography, the rock type, presence of reliable streams, depth of mining operations and carriage costs from the nearest coalfields, water engines, and thus the leats which fed them, were somewhat regionalised. To amplify these observations, let us briefly look at different metal mining areas within Britain.

Starting in the south west, Cornwall, for example, was latterly a deep mining area, was distant from any cheap coal supplies with no indigenous supplies of this fuel whatsoever. Whilst we have seen that water-powered machinery was no stranger to the mining field, Cornwall was disadvantaged by the lack of reliable rivers and streams on which it could depend. The run-off from the central granite 'spine' was short and notwithstanding the ingenious applications of the 18th century, water supply was totally inadequate for the multitude of mines and dressing floors clustered within the county's narrow confines. This lack of water was even a problem in the 19th century, not for driving water engines but simply to provide enough clean boiler feed and condensing water for the steam pumps. Barton[10] notes, for instance, that sea water was resorted to on rare occasions for boiler feed, so scarce was the supply of clean, usable water. Where large numbers of big engines were operating – at the Consolidated Mines in Gwennap, for example – water was lifted to surface

Plate II.
Devon United mines, Near :Wary Tavy. Three mines here, North, Central, and South, were worked for tin and arsenic until final closure in 1922. *A short leat from the adjacent river 'passed beneath the dumps of Central mine* in *a 'modern' culvert. The concrete portal bore the inscription ((C.S. Ltd.* 1918" – *referring to the Contin Syndicate. The site has now been obliterated. (SX 516790). See also front cover illustration.*

by a small engine put down specially for the purpose, this water being obtained from workings which did not produce such acidified and contaminated water which was so detrimental to boiler plates. This was Eldon's engine, the modified house of which is still extant.

It is true that water did remain to power many small stamping mills until relatively recently, these often sited in valleys carrying an insignificant streamway, but viewed overall, these operations were very small beer indeed.

To all instances one can point to the exception and here we may note the use of a truly massive wheel of 65 feet diameter used for pumping the Boswedden Mine, near St. Just. The huge wheel case remains as does the short leat which served it; it was working in 1837 and was the largest wheel in the area.

A deviation from the general trend in west and mid Cornwall, where steam prevailed, was in the east of the county. Here, water power was used to great advantage at the Fowey Consols and Lanescot mines, to drive no less than thirteen wheels and this, at an elevation well above ordnance datum. In addition to these wheels – ranging in diameters from 16 to 40 feet – there was a need for a constant water supply for two water pressure engines and, whilst steam was employed on the site (Austin's engine being a notable example), extensive use of water power resulted in a massive saving on coal consumption. The leats which served this assemblage of water engines, began on the moors to the east of Molinnis, distant about four miles. They delivered an estimated 25,000 gallons a minute onto the mine in winter[11] and their waters crossed the Luxulyan valley on a magnificent granite aqueduct, which also doubled up as a viaduct carrying a tramway.

However, these arrangements were the brainchild of the owner of the mines, Thomas Treffry, and such schemes as his were not repeated in the east, with steam power remaining dominant at virtually all mines here.

Across the Tamar, the scene was completely the reverse, with water power holding sway almost exclusively. The catchment area for this water was Dartmoor which is, in great measure, covered by peat, a medium allowing the gradual release of rainwater over a long period. Consequently, it provided supplies for much of the year to a multitude of big wheels used for pumping and crushing; this power source remained the prime mover until, to all intents and purposes, mining came to an end.

Of the many mining leats constructed upon the moor, we may highlight one specific example where the miners were forced to go to great lengths – literally and metaphorically – to obtain a dependable supply. Twisting and turning around the contours and commencing below Fox Tor Mires, the Wheal Emma leat can perhaps lay claim to be one of the best known and boldest schemes upon the moor. A little under ten miles in length, it was cut in the mid 1800s to feed a huge 50' x 5' pumping wheel[12] sited near Brookwood Mine at Buckfastleigh. Notwithstanding the trouble and expense involved in cutting the leat, experience showed that it leaked badly and presumably suffered in great measure from excessive evaporation in summer. As a result, the big wheel was often short of water and was frequently brought to a stand in dry spells.[B]

Most mines of any consequence on Dartmoor relied on leats to bring water to their wheels, so that we find, for example, a network of channels which supplied Whiteworks, Birch Tor and Vitifer, Sortridge, Wheal Jewel and Wheal Friendship, the last named incidentally, still being operational but feeding water to hydroelectric generating sets near Mary Tavy. Most tapped tributaries of the Dart or Tavy and other, lesser streams, these being dammed with a diversionary weir at the tap-off point.

Before leaving the area, one further notable le at should be mentioned and this was to be found on the steeply wooded slopes on the Devon side of the Tamar Valley. It linked the Bedford United mine at Gunnislake to the Tavistock Canal, from which the mine drew its water. Its sinuous course hugged the 200 feet contour and, as its route lay over very difficult terrain, short tunnels and launders (hung on chains) were provided. It last saw running water in the 1930s. Within the British Isles, an area which surely has the greatest concentration of leats in a given district, is mid Wales. Like Cornwall, local sources of coal

Plate III. The inscription "D.G. C. 1819" on the keystone of an arch which straddles the Devon Great Consols leat, near to the site of one of the huge pumping wheels. As Jar as is known, this remains the only extant field reference to this huge Victorian enterprise. (SX 427725).

were absent and, although steam was tried at the more productive mines – notably those run by Taylor – this was soon abandoned due to high carriage costs.

The Plynlimmon Dome, which has a high rainfall and a profusion of fairly reliable streams and rivers, was an ideal area for water power and long leat systems came into being. These ingenious systems often included holding reservoirs and a glance at a large scale map will reveal the twisting blue watercourses which both feed and radiate from them. Often clinging to steep mountain sides, they finger out towards the coastline from the headwaters of the rivers.

As Bick[13] points out, John Taylor was the foremost architect of the Cardiganshire leat systems, this, since his Lisburne Mines were some of the largest amalgamations within the mining field. His long leat, tapping the Afon Lluestgota below Esgair Fraith mine (this, also served by a comprehensive layout of watercourses), is quite remarkable both in conception and execution. Its waters could be split and diverted to a number of mines at a point below Pond Syfydrin and, in places, they course across near-vertical mountain crags;

Plate IV. Tucked away in a rocky gorge, Temple Mine, mid Wales, required a considerable 'head' of water for its crusher wheel (and pumping wheel, out of sight beyond), so a leat tapped the river some considerable distance upstream. Long stretches of launder carried the channel parallel to the gorge and down to the mine. Parson's Bridge in the foreground.

the installation of launders slung on chains here being essential. Similarly, the leat which supplied the wheels at Temple Mine at Ponterwyd had to be laundered for a greater part of its length due to the awkward terrain it traversed.[14]

Unlike foreign mining fields, such as the Harz in Germany, tunnelling on leats was avoided wherever possible and their courses went round an obstacle rather than through it. There are instances where tunnels were unavoidable but these bores were kept as short as possible. Examples of leat tunnels can be found on the Dyfngwm leat in Montgomeryshire but this is akin to a rock arch and can hardly be referred to as a tunnel proper; on the high level leat above Drwsycoed Copper Mine in Caernarfonshire; in north Wales on the Talargoch leat, the portal of which still exhibits fine masonry work[15] and, in the south west, we find a long 500 yard tunnel on the leat which supplied Wheal Lopes. This latter is cut through solid granite. In any event, with few exceptions, water supplies were channelled to distant points upon the flank of watersheds and not across them (as in the Harz), so large scale burrowing was unnecessary.

In Cardiganshire, and like many districts dependant on water supplies for pumping, dressing and, for that matter, condensing water for steam engines, there were many instances of squabbling over water rights. These latter were a fruitful source of income for those who held them.[16]

Moreover, water coming down a le at was frequently made to turn wheels at more than one mine and should these mines be run by separate companies, such arrangements could be a recipe for friction between the differing parties. In such cases, the water from dressing floors upstream was essentially an effluent, containing poisonous detritus and Lewis[17] tells us that, in the 19th century, leats often overflowed and poisoned the land beneath. One is led to the inevitable conclusion that deposition of slimes from upstream dressing floors was the primary cause of such overspills. In Cornwall, be it noted, water used at successive streaming works became so laden with suspended matter that it had difficulty in passing over wheels at the downstream extremities of the group! In the high mountains of central Wales, leats were often frozen up in winter and work underground could be jeopardized. Conversely, in summer, droughts were not unknown and, again, unless a holding dam was incorporated into the system to augment supplies during the day, work could come to a standstill. Such were the drawbacks of water power, wherever used.

Plate V.
Opposite Castle Rock, the Dyfngwm leat, mid Wales, contours the steep hillside, through an arch of rock. Just beyond, the channel was possibly laundered over the outcrop of the lode.

Plate VI. Water for the Cwmbyr Mine, mid Wales, was obtained from two impressive leats. Designed to intercept many of the small streams and running below steep crags, their dried up beds provide a splendid approach to this remote working. (SN 786946).

To a lesser degree, north Wales has its quota of leat systems but these were fewer in number by virtue of the greater use of steam power. In Flintshire particularly, a coalfield was close at hand to provide fuel, free from the crippling carriage costs experienced in the hinterland of Aberystwyth.

Leats of the Alyn Valley, serving Taylor's Mold Mines are perhaps best known, more especially 'The Leete', construction of which was started in 1824.[18]

The Leete does duty as a public footpath today, as it claws its way along the steep hillside from its tap-off point below Loggerheads, and nearly three miles away from the mines it once served. It was larger than the Cardigans hire examples, being about 7 feet wide by 5 feet deep and it also exhibits short tunnels along its course where it passes beneath public roads. In the same area were other, shorter, leats connected with the Mold Mines.

Also in North Wales, a concentration of leats and dams were laid out high above the Conway Valley, serving mines in the Llanwrst district. Like the Mendips region of Somerset, the high limestone mining field of the Peak District has few water courses. The reasons are not hard to find.

The limestone strata soaks up water like a sponge, leaving a dearth of rivers and streams which could be easily utilised. In any event, the construction of a watercourse here can be likened to running it across blotting paper and any route would require a thick lining of impervious clay (similar to the construction of our inland waterways) to obviate leakage. An extensive systems of drainage soughs further depressed the local water table, in turn, lessening surface supplies. In addition, mining was generally conducted on a small scale and, where companies with sufficient capital existed, large scale drainage tended to be directed to sough easement or steam-powered pumps. These latter were supplied with coal from a coalfield quite close at hand. When water-powered pumps found use, the water pressure engine tended to be favoured, the greatest assemblage of which were installed in the Alport Mines. Here, water was conveyed from the River Lathkill through a tunnel.

We find, therefore, that the water wheel was of much less significance in Derbyshire mining than other areas, although it was put to work at scattered sites. The Mandale mines near Bakewell had, for instance, a 35' wheel driven by the adjacent River Lathkill, whose waters were more or less dependable except in dry summers. The leat which fed this wheel – and one of no less than 52' x 9' at the Lathkilldale Mine itself – was more analogous to that of a corn mill water race, displaying no bold contour engineering features as were found in Wales. It did, however, possess a fine aqueduct on its course, which carried its waters from the south to the north side of the valley, the piers of which still stand. The Lathkill’s waters were fickle in times of low rainfall and a steam pump was later erected at the Mandale Mine.

Leats do not figure significantly in the Shropshire mining field due to its reliance on steam power.

Further north, we come upon a remarkable system of water conduits on the Grassington Moor mining field. These have been described at some length by recent authorities[19] and suffice it to point out that this ingenious system made full use of the scant water resources on this high moor to the maximum and, incidentally, bear all the hallmarks of John Taylor’s management, a man whose water-powered systems have been touched upon already.

The mines of Lakeland have a sprinkling of mining leats, particularly associated with the Coniston area and above Greenside Mine in Patterdale. Leats which crisscrossed the fells above Coniston Mine cumulatively amounted to some 2½ miles and, here again, we find evidence of minor tunnelling operations in the course of one of these water races. Also, a rather interesting stretch of leat (part of which is now obliterated) and its tunnel can be located above Tilberthwaite Gill. Lakeland leats were relatively simple affairs of limited extent. Abundance of streams were generally close to the mine sites and short diversionary waterways were often all that was required to bring them to a point where either waterwheels or, later, turbines could make use of their waters. The latter, of course, needed a high head which was achieved by pipe lines laid down the fellsides.

In the north Pennines, with its high rainfall and capital intensive mining working large grants, one would expect to find ample evidence of wheels supplied with a complex feed network. Rather surprisingly this is not the case.

Plate VII. One of the tunnels on the leat high above the workings of Drwsycoed copper mine, North Wales. There is almost a sheer drop on the left into the valley below. (SH 543533).

Here, productive ore horizons were shallower, could be approached and worked through lengthy, self-draining horse levels and the waterwheel, where used, tended to be sited on the dressing floors at these level portals, there to drive crushers and other dressing machinery. Because of the requirement to begin these levels at the lowest practical horizons to work the orebody, the level mouths and the concomitant dressing areas tended to be close to rivers and streams which could drive the wheels without unnecessarily complex channels. Deep, sub-level pumping was, of course, carried out at a number of places and here the water pressure engine also tended to be favoured.

For a microcosm of this system, we can instance the Sir Francis mine in Swaledale. Here, a hydraulic engine was installed underground for pumping below the adit level and was fed through cast iron pipes which reached the engine down a shaft.

Water was taken from a dam on the moor above. At the dressing floor at the adit mouth there was sited a large waterwheel, this fed by a relatively short leat from the nearby streamway, and this wheel drove both dressing equipment and formerly an air compressor.

Around Nenthead and Allenheads, we find similar evidence of large reservoirs which supplied water to the nearby mines for pumping sub-levels and dressing. Indeed, the Allenheads Mine had three underground waterwheels for the former purpose.

Further north still, at the Leadhills and Wanlockhead mines, the use of leats was quite widespread. At the former location, for instance, water was brought from a consistent source in the high hills to the south, at Shortiecleugh, to feed various pumping wheels. Over the years, these leats were extended around Leadhills whilst in 1768, Sherrif, the Factor to the Earl of Hopetoun built a wheel to drain mines on Wool Law which involved a long feeder leat; this was extended considerably in later years by the Scots Mines Company.[20] It is of interest to note that defects of open leats, with their tendency to lose water through evaporation in summer, was recognised in the mid 1800s by the Leadhills Silver and Lead Mining Company. When installing water pressure engines here in about 1862, they not only incorporated a large reservoir into the supply system but substituted fired clay pipes for the latter.[21]

Finally, water power – shared with the Cornish engine – was of significance in the Isle of Man and used by wheels and turbines at many mines. Indeed, who has not heard of the Lady Isabella wheel at Laxey? To feed this colossus (still the largest water wheel extant in Europe) water had to be collected from as far away as Glen Roy, some three miles distant. The cutting of this waterway was accomplished by 'contouring' the many hillsides en route via the usual open channel.[22]

Having very briefly looked at the regional distribution of British mining leats, let us now compare these with some systems overseas. A mining field which immediately springs to mind is that of the Harz in Germany (Saxony) and this very deep mining area was entirely dependant on water power for its operation. In consequence, a massive building and investment programme, to supply the innumerable wheels with water throughout the year, was carried out. Most of the system was in place by the mid 1800s, having its origin in the 16th century. This network was made possible to a great extent by a vast amalgamation within the mining interest, the State having a major influence in this, so that an integrated system of a very complex nature was the outcome.

The Harz is a mountainous region, deeply cut by river valleys, which caused difficulties in relation to the collection and storage of rainwater, which tended to run off rapidly and be lost to the mines. To combat this phenomena, work was carried out to construct large and numerous holding dams, these being in turn, fed by intricate collection leats which intercepted as many streams as possible. To entrap the absolute maximum water available, frequently entailed driving channels in tunnels through hillside spurs and ridges. Thus, water was often collected from opposite watersheds. Moreover, as the dams were often built some distance from the mines they supplied, it was necessary to cut lengthy distribution channels, controlled by sluices.

As an example, one long system is taken over an impressive embankment which would not have disgraced the later boldness exhibited by the railway builders. This embankment was constructed between 1732 and 1734, is 60 feet in height and over half a mile in length; the leat it carried still functions but is nowadays led over the top in pipes.[23]

At another place upstream, this same watercourse emerges from a hillside to be immediately carried over the foot of an impressive waterfall by an iron aqueduct, only to vanish underground at the opposite end.

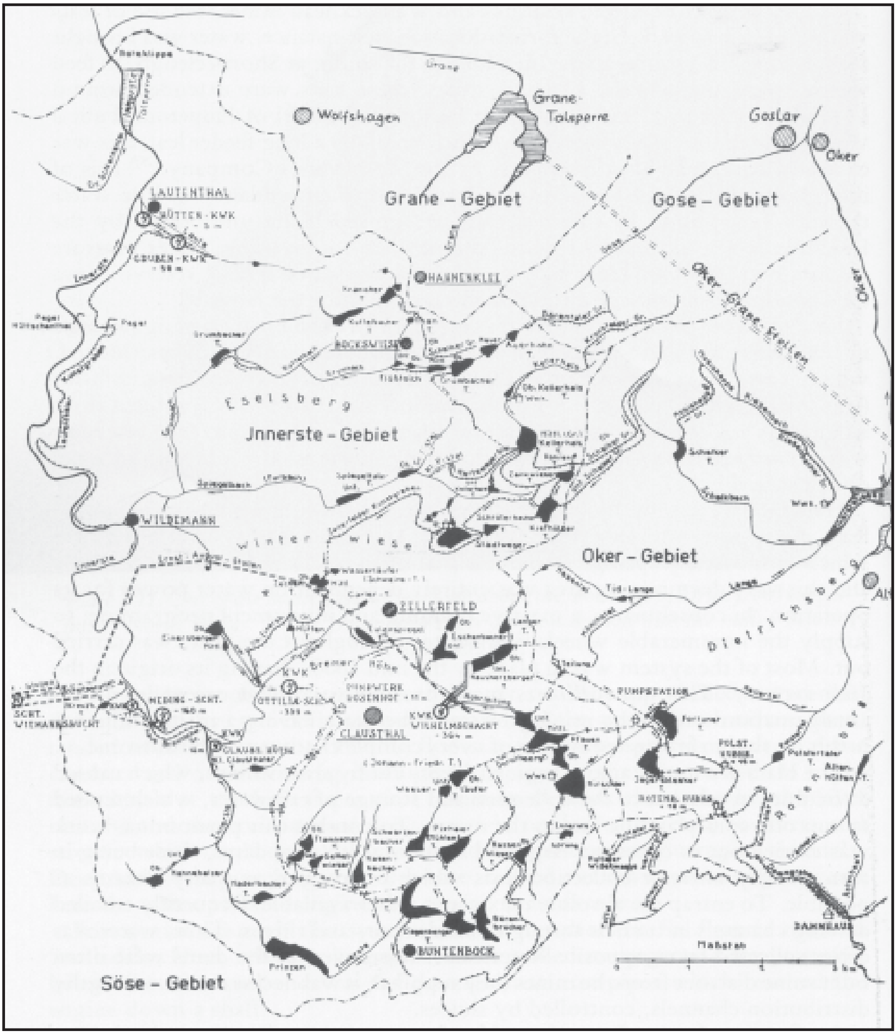

Fig. 1. *The main network of leats, dams and tunnels* in *the Clausthal Zellerfeld district, Harz. (after* H. *Haase).*

The aqueduct is provided with a sluice in its side, to drain the section when necessary, whilst the portals of the tunnels – like so many in the district – display inscribed keystones, replete with the ubiquitous crossed hammers mining symbols. Teutonic attention to detail which comes as no surprise!

The Harz mines used great quantities of timber, not only for ground support in the workings but at surface also; this went into the construction of machinery and buildings. To have such a ready-made network of water channels to hand meant that these could provide highways for the transportation of this wood from the forests where it was felled to the mines themselves, so offering a reduction in carriage charges.[24] We might suppose, however, that the timber was cut into small enough lengths to negotiate the many bends on the system! Timber was also floated down leats in the States but the writer has been unable to find any reference to this practice in Britain. Shallow, narrow, slow flowing watercourses – allied to a scarcity of timber – probably meant that such operations were impossible in this country.

To gain an insight into the complexity and size of these hydraulic masterpieces, we may note that, in the single district of Clausthal there were, in the 1890s, 63 dams and ponds; 125 miles of leat supplying 46 overshot wheels at surface; 21 wheels and 3 water pressure engines underground; 50 wheels applied to dressing operations and 39 to the smelting furnaces working bellows.[25]

Nowadays, many of the leats here continue to carry water but this is conveyed to deep shafts to drive hydroelectric generating sets.

Plate VIII.
One of the countless tunnels (wasserlaufs) on the Harz system. This example, which is about ¼ mile in length, was constructed in 1864 for the Dammgraben leat. Many channels are still in use – having ring arching in their tunnels – necessary since they are an integral part of a hydro electric generating system

(left)
Plate IX.
Complete with rails supported above water, the Schulte Wasserlauf conveys a rapid stream through a hillside to modern turbines near Bad Grund, Harz.

(right)
Plate X.
The Dammgraben emerges from the 1/2 mile long Rotenberger Wasserlauf, driven in 1868. Here are some of the many sluiceways incorporated into the system, necessary for control of such an extensive layout

Other foreign mining fields, particularly the Americas where gold was obtained by washing huge quantities of gravels by ‘hydraulicking’, great lengths of leat were built to bring the large volumes of water needed at the mining sites.

Moreover, since the gold workings were sited in very mountainous regions, often very precipitous in nature, considerable use was made of the wooden launder. These, not only suspended on chains across vertical faces but also supported on timber trestles across defiles, the well-known ‘flumes’. Often, these flumes were so high as to require anchoring with wire rope as a safeguard against swaying in the wind and they were generally very expensive to maintain. Subject to destruction by fire in the summers and freezing solid in winters, they later gave place to pipelines which could be buried underground and could, additionally, be led down into valleys and up the other side in the form of an inverted syphon. Such a layout was used in a 60 mile long waterway supplying North Bloomfield mine. Here, four miles of 30 inch pipework was incorporated at a point where a branch valley had to be crossed; this pipe was laid as an inverted syphon 2½ miles long with a vertical depression of 856 feet.[26]

Having frozen solid (the high altitudes did not help) box launders and flumes needed expensive remedial work to bring them into service again. Considerable lengths needed cutting out and replacing so that maintenance costs frequently exceeded the original construction price.

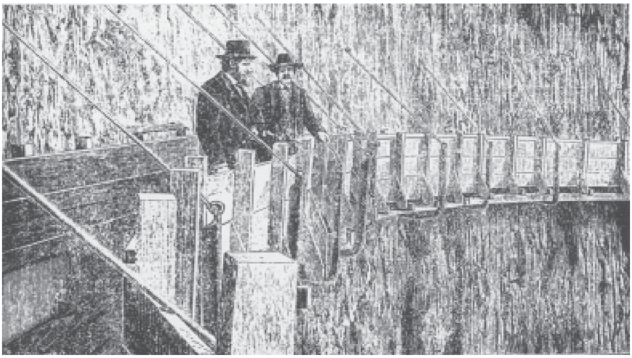

Fig. 2.
An example from the States of a watercourse crossing precipitous terrain. The launders are suspended from iron rods let into the rock face.
(After C. *Le Neve Foster).*

Leat and flume construction in California was used on an unprecedented scale and many of the long watercourses were beyond the means of the gold mining companies, since lengthy tunnelling was often required. Such tunnelling was, in itself, on some considerable scale, a case in point being a bore started in 1855 and driven for twelve hundred feet in length and not completed for seven years. It cost a tremendous one hundred thousand dollars!

Such were costs like these that separate ‘fluming or ditch companies’ were formed (obtaining royalties from their customers, the mines) and these concerns often dammed rivers and made extensive reservoirs to augment supplies. Like the watercourses in the Harz, the leats were used for floating logs and other such materials down to the mines. The fluming companies often charged exorbitant rates for their services but without the precious fluid they supplied,

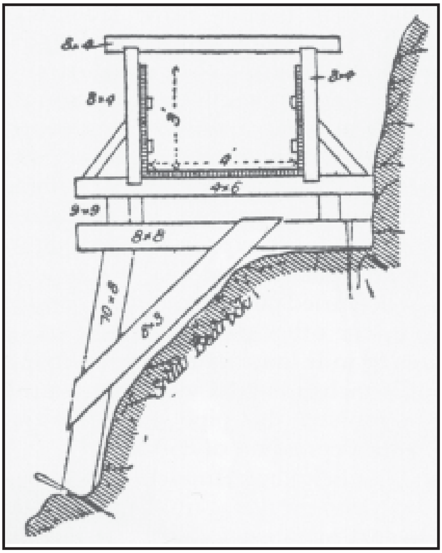

Fig. 3.
As all alternative to the arrangement shown in the previous figure, launders could be supported on trestles, if the rock face to be traversed was not truly vertical (after Lock).

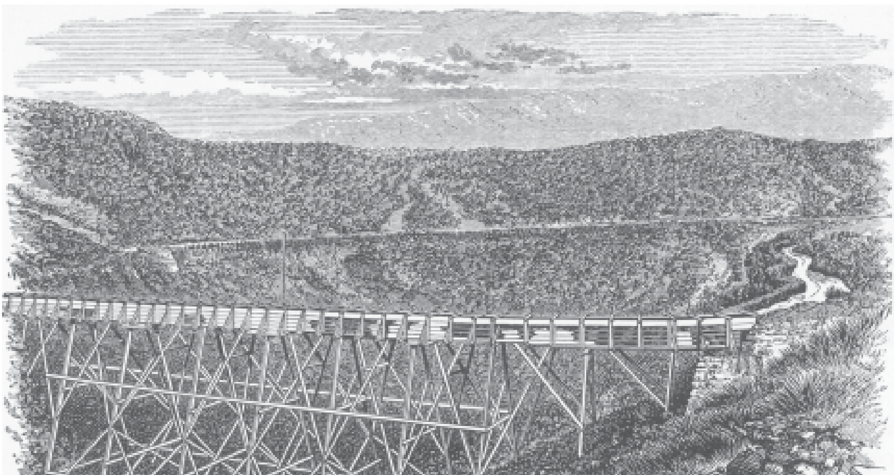

Fig. 4. *A typical flume carrying a leat across a moderate valley. However, some flumes in the States were considerably grander than this example from New Zealand.* (after Lock).

the mines were helpless. As can be seen, such ventures were highly monopolistic and could virtually dictate their own terms.[27]

Often, it should be noted, gold mining concerns turned themselves into so called ‘ditch companies’ with the prospect of greater financial returns than from gold mining proper. Water was generally sold to the mining companies at prices between 5d (2½p) and 10d (5p) per ‘miners’ inch’ per day. The miners’ inch was a purely arbitary measure of the quantity of water which will flow through a given orifice – sometimes a notched weir – in a given time. Although, since there was no universal scale between mining camps, this term makes computation difficult. A mean average was the amount of water passing through a one inch square opening in a plank two inches thick with a ‘head’ of six inches, or seven inches from the bottom of the hole to the water surface. This produced approximately 94.7 cubic feet per hour, some 590 gallons.

Space does not allow detailed discussion on water flow measurements involving miners’ inches (which would be very tedious anyway) but the interested reader is directed to numerous contemporary mining textbooks in which the subject is presented in detail, i.e. see E.H. Davies *Machinery for metalliferous mines* (1894).

Lock cites an interesting example of the profit considerations when changing from “gold to water”. One company expended about £9000 on preliminary mining operations from which they received about £10,800 in gold, leaving £1,800 as profit. If it had sold its water at some 8d per inch per 24 hours it would have reaped a profit of about £8,000![C]

Construction and Costs

In its simplest form, a leat is merely a shallow ditch cut on a gentle gradient over ground amenable to pick and shovel. Wandering their winding courses, one marvels at the surveying work necessary and the ingenuity of their builders, whose tools were of the simplest kind. Frequently cut along the sides of valleys from headwaters of rivers, their outer margin comprised an earthen embankment which was sometimes faced with random stonework. To obtain a flow, careful levelling was needed, without too much loss of level between the source and delivery point. To quote Pryce again[28]

> ‘The miners, instead of the true levelling instruments (being used) called the air level or spirit level, commonly substitute a water level of their own construction; which is generally a clumsy instrument in the form of a narrow trough, an inch wide and three feet long planed very exact and true. To find the declination of the ground, they lay this levelling instrument on the highest part of the ground they are about to level or measure, and by pouring water into the trough they easily perceive when it lies horizontal’.

No doubt a tedious operation, except where difficult rock cutting was involved.

In easy ground, it is probable that a pilot trench was cut in short lengths ahead of the main leat, this trench filled with water and subsequently dug out to the correct gradient and dimensions. As an alternative, Roberts[29] describes a construction method using pegs, stakes and level.

In this operation, large stakes were driven at about 100 feet intervals to establish the desired route and intermediate pegs driven in at, say 20 feet intervals between the larger ones. The pegs were marked with the required depth and hammered home with a prefabricated timber baulk about 20 feet long having, at both ends, legs of differing length, calculated for the desired gradient. Should a grade of, say, 5 in 1000 be chosen then over the 20 feet span this would equate to 1.2". Consequently, if one leg was 24" long at the end of the baulk, the other would be 25.2" and so on. The baulk was placed with the legs resting on the intermediate pegs, the shorter of the legs on the upstream peg. The peg downstream was then hammered into the ground until the baulk was level and the channel dug out to the depth indicated on the pegs.

To create a flow from the inlet point (usually a weir) the gradient had to be chosen with care so as to arrive at the discharge end without causing too rapid a flow, which could have deleterious effects on the outer banking – particularly at bends – due to erosion by the fast flowing current. Generally, a fine gradient of about 1 in 720 was chosen in Cardiganshire[30] but in California, steeper falls of some 1 in 350 were occasionally found.

The 100 mile long leat supplying the Milton Mine for instance, had an average fall of 1 in 364.[31]

Exceedingly fine gradients occasionally prevailed, these being much less than the British examples. This was in order to maintain a sufficient retention of level between two points which, although close as the crow flies, required an immense distance for the leat channel due to difficult topography.

Thus, in the rugged Sangre de Cristo mountains of New Mexico, such a watercourse was commenced in 1868, bringing water from the Red River to placer mines at Elizabethtown. The linear distance between the inlet and discharge point was a mere 11 miles but so circuitous was the leat that, in following the contours, the length of the waterway was no less than 42 miles. This perhaps explains why the chosen gradient was a fall of only 12 feet in the first 12½ miles, followed by a fall of 4 feet per mile thereafter. (i.e. 1 in 5,500 and 1 in 1320). The construction cost of 210,000 dollars was high, as there were no less than 3½ miles of launders and flumes on the route – one flume extending half a mile across a valley, 79 feet high at the centre of the span – and, for five miles, its course needed blasting out of solid bedrock.

It took a year to cut and as many as 420 men were employed at the peak of its construction. Designed to deliver about 1050 gallons a minute at the mines, such was the scale of evaporation, seepage and leaking flumes that, at best it only managed about 175 gallons a minute. It comes as no surprise to learn that the company operating the leat soon failed and, after passing through several hands it fell into disuse.[32]

Sudden loss of level was now and then unavoidable, *vis a vis* the Devonport leat on Dartmoor – although this was not a mining leat – where it tumbles down Raddick Hill, and on the Dammgraben leat in Harz. Erosion could be very

Fig. 5. *The colossal thirst for water, occasioned by 'hydraulicking', required leats of large capacity, never equalled in Britain. Some idea of water consumption can be gained from this illustration of a section of North Bloomfield mine, Nevada.* (after Lock).

fierce at these points. This was countered on the latter by laying larch poles parallel to the flow, so creating a 'water slide'.

In the goldfields, waterways were generally of more generous proportions because of the large amount of water needed for gravel washing whereas in Britain, there was great reliance on the overshot waterwheel which could work on relatively modest flows.

Very narrow but deep cross section of channel was the exception, for whilst there is an advantage in this, such as a reduction of evaporation due to smaller surface area (and, for the record, a swift current through a narrow channel can be made to deliver as much water as a slow current through a wide one), the drawback of narrow waterways was that the very steep sides needed protection from slumping. This added requirement of lining with masonry increased costs many fold unless the channel happened to be driven through solid rock, which automatically protected the edges.

The writer has seen leats in Germany which are both narrow and deep which, it is supposed, was in order to counter the problems of blockage from ice and fallen leaves, but examples like these are few and far between.

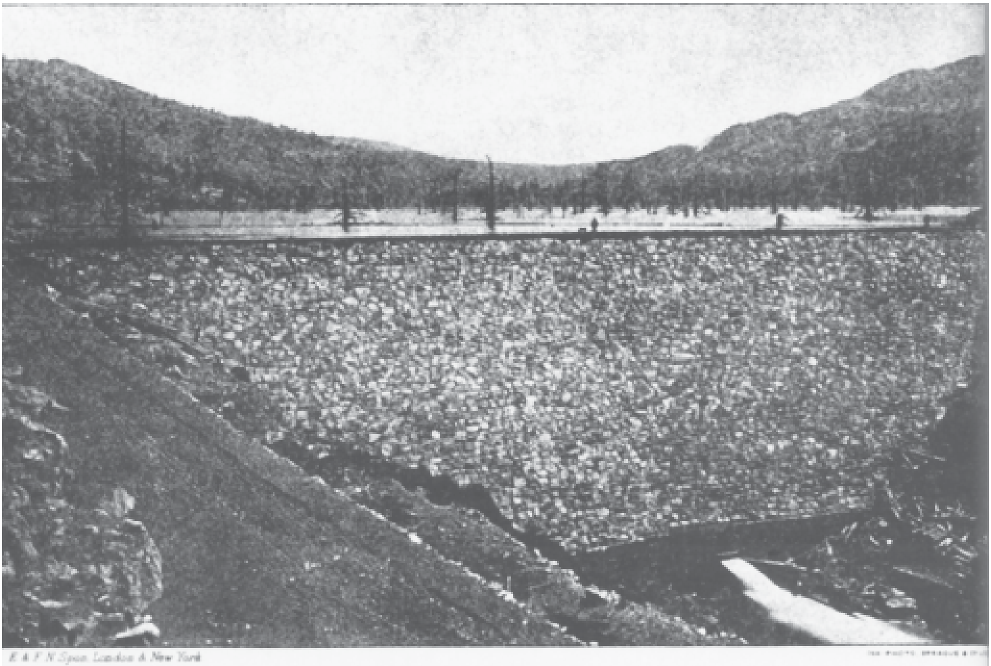

Fig. 6. The Bowman dam, a 100 feet high reservoir which provided most of the water for North Bloomfield mine, Nevada. Note remains of trees rising above the water; scale is provided by the figure in the centre of the dam. (after Lock).

Evaporation apart, leats were always subject to leakage (we have already seen that Wheal Emma leat suffered in this way) and were often lined with an impervious clay for this reason. A good example of this practise is to be found amongst the documents relating to the Lathkilldale leat in Derbyshire where, in the 1830s we are told that 474 man days were spent coating the bottom with 509 loads of clay puddle.[33]

In climates which were very hot, evaporation along the course of a leat frequently reduced it to a trickle at the point of discharge. The Mexican silver mines, which used the Cornish engine on some scale, experienced problems of this nature with the leats supplying ‘house water’ for these machines. As a countermeasure, water was run through stone pipes in places and the leat covered over where possible.[34]

The loss of water occasioned by holes left by decayed tree roots and the filtration of water beside roots left in the ground was another problem. This, however, became less so as the ground became consolidated with time but, even later, burrowing animals and ‘free range’ livestock could cause problems. In areas where supplies were drawn from numerous sources (necessary in summer, when one stream or river was insufficient for the mining needs) sluices and spill weirs were sometimes incorporated into the network, particularly an extensive one, to counter over-supply in wet seasons (see Plate X). Such measures were needed to obviate undermining of the embankments, or an overspill breach, by a surfeit of flood water. These 'freshets' could bring down increased detritus which would speedily impede flow causing a blockage. An ingenious but simple arrangement has been seen by the writer on the course of the Dammgraben system (Harz) where a feeder crossed the main channel on an aqueduct, angled at about 30 degrees. Made from larch poles tightly clamped together, the aqueduct has a slot cut horizontally in its base over the main channel. Thus, during seasons of moderate flow, water falls through the slot to feed the system below but in times of flood, excess flow, together with any detritus it carries, is sufficiently heavy to overshoot the slot and continue into the river valley beyond.

Nearer home, we find an arrangement peculiar to the Dartmoor area, at points where water was tapped from the main channel of a le at into that of an auxiliary one. These so called 'bull's eyes' are in effect, primitive sluices (or miners' inches, for that matter!) and comprise granite slabs through which are bored a one inch diameter hole – or slightly larger depending on circumstances. The slabs are set up on the side of the leat at 'T' junctions and the hole in the granite allowed a permitted quantity of water to be abstracted. Examples of bull's eyes can be located on the Sortridge leat, where about half a dozen such abstraction points exist within a short distance of each other.[35]

In situations where the topography did not allow the excavation of a trench with pick and shovel, i.e. when rock cutting was unavoidable, launders or flumes were often substituted. Both launders and, more especially flumes, were an expensive item to construct although the former possibly less costly than having to blast a channel across a cliff face. Flumes were used only for crossing defiles but on occasions a box launder was supported on flume-type trestles where a precipitous cliff face had to be crossed and there was enough purchase for trestle footings (see fig 3).

Flumes were very widespread in the States since timber was often cheap and close to the works but, even so, with the introduction of pipes they rapidly fell from favour. Keeping launders water tight could be troublesome, more especially when flows diminished – or even ceased – in times of drought. On drying out, these timber channels would contract and crack or, in winter, could be swept away by avalanches or collapse under superencumbent masses of ice.

In Britain until quite recently, there remained a fine length of box launder leat at the Great Rock Micaceous hematite mine, Devon. This brought water from the Beadon Brook to power machinery on the dressing floors. Built on short timber piers, it was about 3/4 mile in length and, being in a sheltered situation it probably did not suffer the usual tribulations. Why timber laundering was used, as opposed to open cutting is unknown; it has now been destroyed to make a footpath.

Those who have inspected Taylor's lower leat, which supplied the Goginan Mine in Cardiganshire, which runs across the near-vertical face of Pencraigddu, must inevitably be led to the conclusion that launders hung on chains here would have been necessary, so vertical and exposed is the situation. Short of rock climbing techniques, there is now no way one can traverse this section across the crag on line with the leat channel at either end. Whilst the magnificent flumes of the American West puts one wonderfully in mind of Brunel's trestle viaducts which once strode across the Cornish landscape with the Great Western Railway on their backs, there is much to be said for our 'home grown' artisans charged with bringing home water supplies to the mines.

Finally, a reference to construction costs. Lewis[36] states that leats could be constructed for about £22 per mile in the 1850s. Across easy ground with few engineering difficulties, this figure could possibly be fairly accurate but in areas of high relief topography one cannot but think such a figure is a gross underestimate.[D] In the 1890s, American leats were costing between £520 per mile to as much as £4700 a mile, indicative of the differing costs of engineering work involved.[37] Moreover, Western leats were generally much larger than the British counterpart, being some six to eight feet wide and four feet deep. A twenty mile leat (9 feet wide x 4 feet deep x 6 feet at the bottom) which supplied water to the La Grange workings in the States, cost £4500 per mile, a high figure which reflects the job of blasting much of its length through granite.[38]

Leats were a vital part of a simple but effective – and, for the most part, lost – technology and their sinuous, dried-up courses are a source of admiration to the 20th century mining historian, much as perhaps our abandoned railway lines will be to historians of the future. Like the attendant runs of flat rods, pulley stands, angle bobs and associated paraphernalia, we tend to view such equipment and undertakings through rose-coloured spectacles but, in reality, they were simple affairs, conceived and constructed by men whose practical experience was based, in essence, on empiricism.

The miners who dug and blasted their courses saw nothing romantic or out of the ordinary in their work (like those who toiled underground) but, if nothing else, the countless miles of these abandoned waterways remain as a mute testimony to those numberless, nameless men who, like the canal navvies of the 18th century, earned their daily bread – such as it was – by pick, shovel, wedge and borer. 'Tools and methodology of a discarded technology; whispers from the past'.

A. p.21 Roman mining often reached surprising depths; their workings for lead in the south east of Spain, near Cartagena, for example, reached over 1100 feet. Here, however, the arid conditions obviated complex pumping operations, the water being handled manually by baling. There was no water available at surface anyway, from which any power could be derived if needed. (See: Beyshlag et. al. ORE DEPOSITS Vol. II 1916).

B. p.23 In 1860, a note in the Mining Journal stated that the bed of the leat was "scarcely sufficiently staunched to convey one half of the stream which runs into it at the weir head". The leat discharged into the River Mardle, to supplement the latter's water capacity, and which passed close to the mine.

C. p.37 Additional to the needs of waterpower, leats have had widespread use for other purposes. Irrigation is perhaps their main *raison d'etre,* but such waterways were also constructed to feed purely aesthetic systems. The leat which delivers water to the Emperor Fountain and water gardens at Chatsworth House, Derbyshire and that which feeds the waterfall at Canonteign House, Devonshire, immediately spring to mind.

D. p.42 E.G. Holland in his book 'Coniston Copper" (1986), refers to the building of water races at Paddy End in 1846. Construction of 242 yards at 3d per yard he quotes, (p.133) equates exactly to £22 per mile.

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36. Lewis, W.J. op. cit. p.399.

37. Lock, C.C.W. op. cit. p.317.

38. ibid. p.317.

“Bull’s Eye”, Sortridge Leat.

SOME EXAMPLES OF MINING LEATS IN THE SOUTH WEST AND WALES

Mine served	Approximate commencement N.G.R.	Approximate delivery point N.G.R.	Items of interest
SOUTHWEST			
Fowey Consols	SX028595	SX085558	Treffry Viaduct
Bedford United	SX445702	SX437726	Tunnels at Morwell rocks
Devon Great Consols*	SX415737	SX433729	Inscribed arch
Wheal Emma	SX623710	SX718675	Extreme length
Sortridge Consols	SX554773	SX515707	Bulls eyes
Wh. Friendship	SX550830	SX506795	Wh. Jewel reservoir
Who Lopes$	SX530644	SX518634	Long tunnel and aqueduct
WALES			
Goginan etc.	SN754905	SN692818	Outstanding length and reservoirs
Dyfngwm	SN840930	SN848932	Rock arch
Temple	SN751799	SN748793	Site of launders
Hafan	SN720897	SN729879	Exceptional contouring in very difficult ground
Drwsycoed	SH535523	SH551533	Tunnels
Llangynog	SJ009250	SJ054255	Llyn y Mynydd reservoir
Penyfron (Mold Mines)	SJ196628	SJ198662	‘The Leete’

* Erroneously marked as ‘old canal’ on 2½ inch O.S. maps.

$ Wh. Lopes gets its name from the Lopes family, mineral owners of the locality, of Maristow House. Whilst philanthropic to a degree (Sir Manasseh Masseh Lopes’s name is to be seen over the doorway of the chapel in Buckland Monachorum, consequent upon his financing repairs to the building in 1830), the latter gentleman tended to be far from indulgent towards his mining lessees. His exorbitant water rent demands caused much ill feeling in mining circles hereabouts. In 1846, the Plymouth and Dartmoor Mining Company, which had previously operated the mine, had for sale a 40' x 3' wheel; a 39' x 6' wheel and an almost ‘square’ wheel of 9' 6" x 9'. Small wonder that considerable efforts were made to secure adequate water supplies for the mine. (See: Barton. D.B. *Essays in Cornish mining history.* Vol.1., p.l72). Of no less interest is the fact that, in 1858, during the driving of the Leighbeer Tunnel on the Plymouth to Tavistock railway, a bore which virtually paralleled the older leat tunnel, a copper lode was struck. Variously described as four feet wide or more, this was never developed. (See: Jenkin. A.K.H. *The Mines of Devon.* Vol.1., p.117.)

* Another tunnel to be found in the region is located on the Devonport leat at Nun’s Cross. This pierces the watershed between the catchment area of the River Swincombe to the east and Newleycombe lake – a tributory of the Meavy – to the west.