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II. *Report from* Messrs. Faraday *and* Lyell *to the* Rt. Hon. Sir James Graham, *bart., secretary of state for the home department, on the subject of the explosion at the Haswell Collieries, and on the means of preventing similar accidents*

To the right honourable sir James Graham, bart., &c. &c.

where *the glacier is most dislocated*, and not where it is most compact, because it is in those places that I conceive the sliding of one part past another to take place. That such is the case in many places is as unquestionable as the continuity of the motion observed by Prof. Forbes. It must not be supposed, however, that I reject the notion of ice having a certain degree of *plasticity* and *flexibility**. It would be absurd for any one to do so who has witnessed how the glacier de l'Echaud and the glacier du Tacul form, by their union, the Mer de Glace, and the glaciers of Finsteraar and Lauteraar form that of the Lower Aar. But I believe that these properties are only developed in glacial ice to any considerable extent, by the enormous forces to which certain portions of a glacier are subjected; and I contend that this plasticity is not such that the mechanism of glacial motion can be correctly represented by that of a semifluid or viscous substance. But I must reserve the subject of the mechanism of glacial motion for my next communication.

Your obedient Servant,

Cambridge, November 19, 1844. W. Hopkins.

II. *Report from* Messrs. Faraday *and* Lyell *to the* Rt. Hon. Sir James Graham, *Bart., Secretary of State for the Home Department, on the subject of the Explosion at the Haswell Collieries, and on the means of preventing similar accidents*†.

To the Right Honourable Sir James Graham, Bart., &c. &c.

Sir,

Having, in our former letter, expressed our entire concurrence in the verdict of the jury, which exonerated the proprietors of the Haswell Colliery from any blame in connexion with the late fatal accident (September 28, 1844), we

* The terms *plastic, flexible, viscous, semifluid,* &c., appear to have been used by Prof. Forbes too indiscriminately, as if they were convertible terms, which is very far from being the case. The application of the two latter terms to a hard mass, like glacial ice, capable of supporting itself when bounded by a free vertical section of a height at least a hundred, and perhaps many hundred feet, I cannot but regard as a departure from all propriety of established language.

† [To this Report, which has been published by the Home Office with illustrative plans, and which has been obligingly communicated to us by the Authors, the following notice is prefixed:—

"Home Office, Nov. 13th, 1844.

"On the occasion of the late fatal Explosion in the Colliery at Haswell, Messrs. Lyell and Faraday were appointed by Sir James Graham to attend at the Coroner's Inquest, for the purpose of affording any information in their power, and for reporting also whether any means could be suggested for preventing similar accidents. The following Report has been received from those Gentlemen."]

now proceed to consider how the recurrence of similar catastrophes may be obviated in future.

The Haswell Collieries, where the explosion occurred, are situated about seven miles east of Durham, in that part of the Durham coal field which is overlaid by the magnesian limestone, and about two miles within the outer limit or escarpment of that formation. In sinking the main shaft, which is 155 fathoms deep, they passed through, below the outset or artificial elevation, first, 18 feet of soil, gravel, &c., then 363 feet of limestone, red shale, and sandstone of the magnesian limestone formation, and afterwards through 540 feet of the coal measures; the strata of both formations being so nearly horizontal, that they may be considered as being here in parallel or conformable position. The accompanying section [as annexed to the original report] of the beds passed through in excavating the shaft, will show that no less than ten seams of coal were met with, varying in thickness from 1 inch to 3 feet 7 inches; and that at a depth of 925 feet from the surface, the coal called the Hutton seam was gained, which is 5 feet 5 inches thick, comprising, first, the top coal of superior quality, 4 feet 1 inch thick; secondly, layers of impure coal, 16 inches thick, the upper portion of which, called the brassy coal, is much charged with pyrites; and the lowest part, of better quality, is said to give out much more gas than the top coal. The dip of the beds is about 1 foot in 24 to the S.E.*

In the Great Pit, which lies to the S.W. of the Little Pit, and is ventilated by the same shafts, a large dike of trap or greenstone was encountered, which had turned the coal into coke, with numerous veins of calcareous spar, for a distance of about 40 yards from the point of contact. Notwithstanding the intrusion of this igneous rock, the strata in general are remarkably undisturbed. In the Little Pit, which we examined carefully, only two or three slips of a few inches, and one fault of two or three feet, appeared. The roof near the entrance shaft was of white sandstone, with occasional seams of mica, but throughout the greater part of the workings, which are about 250 acres in extent, the roof or ceiling is composed of shale, very unbroken and secure, and having given rise to extremely few accidents, by falling in, in the course of the thir-

* As no part of the section obtained in sinking the shaft of the Haswell Pit was exposed to view at the time of our visit, except the lowest ten or twelve feet, the division into coal measures and magnesian limestone, and of the latter into upper magnesian and lower red sandstone, with about twenty feet of superficial gravel and clay, has been inferred from the description of the beds given in the miner's section. We have substituted geological names for the miners' terms, as far as we were able to do so.

teen years during which the pit has been opened. The chief danger to be guarded against, arises from what are termed "caldron bottoms," which are the stools or lowest portions of erect fossil trees, filled with sandstone or shale, and having their bark converted into coal, which gives way when they are undermined, and allows the heavy cast of the interior of the trunk, several feet or yards in height, to descend suddenly. The Hutton seam rests on a sandy clay, which has not been found adapted for a fire clay. The floor composed of it does not often rise in creeps.

It will be seen by the section, that several upper seams of good coal, the united thickness of four of which is no less than 13 feet, have been left untouched, in order that the thicker and more valuable seam called the Hutton, should first be worked out. In adopting this plan, the proprietors have been guided by considerations of present profit, which the competition of other neighbouring coal works renders indispensable. Nevertheless, it may not be improper for us to advert to two evils which result from this system.

First. The upper seams which are undermined on the extraction of an inferior bed of coal, sink down, often unequally, from failure of support, and become fractured, and therefore much more liable to give out gas, which gas (it is well known by experience) has sometimes found its way into the workings far below, as attested by Mr. Buddle in his evidence given to the Committee of the House of Commons in 1835; by which some of the most serious accidents from fire-damp have been occasioned. The greater the number, and the larger the size of the upper seams, and the nearer they lie to the seam which is worked at a lower level, the greater the risk of such communication by fissures.

Secondly. The higher beds of coal, which might have been worked to advantage before they were undermined, and when the expense of a shaft had been already incurred, may never be available after the workings have been for many years abandoned, and the shaft partially filled up, and after the coal has been injured by the continued permeation of water and gas through its fissures, whereby property of great value may be irrecoverably lost to the country. With a view to prevent this prospective evil in the mines belonging to the Duchy of Cornwall in Somersetshire, it has recently been proposed to make provisions in the new leases to secure the more regular extraction of all the workable seams which, exclusive of the great seam, range from 14 inches to 2 feet in thickness, the whole of them being less considerable than five of the seams neglected in sinking the Haswell shaft.

Before going into a particular consideration of the causes of the late accident at Haswell, and the possible means of preventing the recurrence of the like in future, we wish to point out the fact well known to the viewers in this district, that the pits on the north side of the Wear, in which the Hutton seam is worked, are more infested with fire-damp than those on the south side of that river. If, therefore, at Haswell Colliery, situated among the latter, the danger has proved to be so great, still more necessary will it be to endeavour to take additional precautions elsewhere.

There can be no doubt, that as regards the safety of the men in coal mines from injury consequent upon fire-damps, ventilation is of the utmost importance, but there is a practical limit beyond which it cannot be carried, for in works deep and extensive, as the coal mines often are, to dig shaft after shaft would quickly involve an expense more than the value of the produce of the mine, and have the effect of closing it altogether. There is one point in ventilation, however, which, at the same time that it appears to us capable of improvement, touches a part of the mine of the utmost consequence to the safety of the whole; and though our observations and thoughts are not founded upon long experience, or the examination personally of many mines, yet considering that the one we have so recently been called to observe is as simple in the character of its workings, contains as small a proportion of fire-damp, and is as well-ventilated as any in that part of England, surpassing in these respects most of the mines, we do not think that they will be exaggerated in respect of, or less applicable to, other cases. We allude to the ventilation and general character of the *goaf*.

The *goaf* is a mass of ruins in the middle of the works, growing from day to day, as the workings of the mine extend. The miner, as he works in the undisturbed coal (which is called the *whole*), removes it, so as to form passages which are usually parallel to, and at right angles with, each other; the square portions of coal left between them are called *pillars*; the passages or ways are, upon the average, about 5 yards wide, and the pillars are about 16 yards by 22 yards; the pillars, whilst they remain, support the roof, and the superincumbent rocks and strata; this part of the works is called the *broken*.

Afterwards the coal of the pillars has to be removed, and as it is carried off, the roof so exposed is supported by many wooden props; this state of things constitutes a *jud*: at last these props are withdrawn, and this is called *drawing a jud*; during or after which the roof falls in masses, larger or smaller according to circumstances, a fall being sometimes many tons in weight. The pillars are not removed indifferently, but those next the mass of ruins already formed are taken away first, so that the first *jud* which is drawn produces a heap of broken strata, and this increasing with every succeeding jud that is removed, forms the *goaf*.

These goafs grow to a great size*. There are three in the Haswell Little Pit; two are small as yet; the largest has an extent of 13 acres. At the edges they are very loose and open, having accidental cavities and passages for air running into them, as might be expected from the falling of rocks from a height of five feet one upon another. There is every reason to believe, that the falling goes on towards the middle of the goaf, but how high the heap of broken strata and the vault inclosing it extend, is not known in a large goaf, or, as far as we are aware, even in a small one. The goaf may be considered as a heap of rocky fragments rising up into the vault or cavity from which it has fallen, perhaps nearly compact in the parts which are the oldest, lowest, and nearest the middle, but open in structure towards and near its surface, whether at the centre of the goaf or at the edges; and the vault or concavity of the goaf may be considered as an inverted basin, having its edge coincident with the roof of the mine, all round the *goaf*. Within this basin there must be air space (as long as the surface of the country above has not sunk), either in the space between it and the goaf, or in the cavities of the goaf itself, nearly equal to the bulk of coal removed; this in a goaf of 13 acres, and a seam in which $5\frac{1}{2}$ feet of coal, including the top and bottom, are taken away, is equal to a vault $5\frac{1}{2}$ feet high and 13 acres in extent.

Let us now consider this goaf as a receptacle for gas or fire-damp, a compound of hydrogen and carbon, known as light hydro-carbonate, and by other names. The weight of pure fire-damp is little more than half that of air; it gradually and spontaneously mixes with air, and the weight of any mixture is proportionate to the quantities of air and fire-damp. Any gas that may be evolved in the goaf, or that may gradually creep into it along the roof of the workings, against which it will naturally flow, will ascend into the goaf vault, and will

* Goafs vary in size: that at the Meadows Flat Little Pit is 13 acres; the goaf of the High Brockley Whin is $1\frac{3}{4}$ acre, and the one at the Low Brockley Whin $1\frac{1}{2}$ acre. In the North Way of the Little Pit at Haswell, there is a goaf of 35 acres, and in the Engine or Great Pit, one of 17 acres. Perhaps the greatest goaf is that at Felling, near Newcastle-upon-Tyne; it is in the same seam as the Haswell, and has an extent of upwards of 100 acres.

find its place higher, in proportion to its freedom from air; and this will go on continually, the goaf vault forming the natural basin into which all gas will drain (upwards), from parts inclining to the goaf, just as a concavity on the side of a gentle hill will receive water draining downwards from its sides, and from the parts above inclining towards it.

The gas which may thus be expected to collect in the goaf of a mine, where there is any fire-damp at all, cannot escape at the top of the goaf vault; instead of passing away there, the whole surface of the vault may rather be viewed as having a tendency, more or less, to evolve gas from the upper broken and bruised coal measures (often containing small seams not worked) into the space beneath; and the only escape for the gas is by the flowing of it under the edge of the goaf vault into the workings of the mine. Two main circumstances tend to this effect; the one, the continued accumulation of gas in the upper part of the goaf vault; the other, the continual tendency to mix with the air beneath, and consequent formation of mixtures larger and heavier than the gas itself. As Sir Humphry Davy has stated, any mixture containing from one-fifth to one-sixteenth of the gas will explode. These mixtures are of course from six to seventeen times greater in volume than the fire-damp in them, and evidently not much lighter than air (0·91 and 0·96). Except, therefore, in the almost impossible case of a goaf quite filled with fire-damp, it will be these or weaker mixtures that underflow the edge of the vault, unless upon extraordinary occasions.

The underflow will not take place all round the edge of the goaf basin, but at that point which is highest; for just as water takes its level in a pond on the side of a hill, and flows over the lower edge, so here, air strata of equal density will be horizontal. Coal seams are rarely quite horizontal; in the Little Haswell Pit, the rise is about 1 in 24, and the coal very regular. At the lower edge of such a goaf, nothing but pure air might be present in the air space, and also for a considerable distance up into the vault; yet at the upper edge, a mixture of gas and air, and even a highly explosive mixture might be escaping.

Thus goafs are evidently, in mines subject more or less to fire-damp, reservoirs of the gas and explosive mixtures; giving out their gas into the workings of the mines by a gradual underflow in smaller or larger quantities under ordinary circumstances, or suddenly, and in great proportion on extraordinary occasions: and they may either supply that explosive mixture which first takes fire, as appears to have been the case at the spot called Williamson's *jud*, close to the goaf of the *Mea-*

dows working of the Haswell Little Pit; or they may add their magazine of fire-damp and explosive mixtures, to increase the conflagration when the fire reaches them from an explosion in some other part of the mine: this appears to have been the case at the goaf of the *High Brockley Whins* working, on the occurrence of the Haswell event.

We are bound from all the evidence, and from our own personal examination, to state on the part of the owners and officers of the Haswell Colliery, that, as far as the principles of ventilation in coal mines have been developed and applied, and in comparison with the general practice of the trade, the Little Pit appears to have been most admirably ventilated. No expense seems to have been spared in the first setting out of the works, or in carrying them through, or in the daily arrangements under ground; and this care was further favoured by the natural circumstances of the mine, the seam of coal being very regular, having a strong shale roof or ceiling, and with scarcely any fault. The mine has the character of being one of the best ventilated in the whole trade, a circumstance which, though it leads us in the fullest degree to exonerate the owners and officers from all blame in reference to the late terrible event, makes us more anxious, if possible, to discover its cause, and suggest some practical guard against its recurrence in future. With this intention, and without going into the ventilation generally, we will state our view of its effect at the goaf. A great body of air, equal to 25,400 cubic feet per minute, is sent into the Little Pit, and a third part of that goes to each of the three workings. This is directed, according to the judgement of the viewer, to various parts; the main portion to where the men are at work, and certain portions to the waste and the *goaf.* In the main passages, as the Rolley way, Mothergate, &c., the wind is so strong, that it is almost impossible to keep a candle lighted; but where the works expand, it becomes slower, and the speed is least in the waste and the goaf. As a matter of observation, we found the speed small at the goaf, though full care had been taken by stoppings, &c. to make the current good and strong in the workings near it, *i. e.* in the upper boards. If it be considered that the goaf is about 13 acres in extent, and that with the surrounding workings it can hardly be less than 26 or 30 acres, the diminution in speed of the current of air there can easily be understood.

The air which flows into a mine will generally tend to move along the floor, for it is colder, and therefore denser than the air against the ceiling, warmed as it is by the men and the lamps, and it is heavier than any mixture of air and fire-damp.

Where the men are at work, this tendency is guarded against by the force of the current sent in, which sweeps the air already there before it; but in the goaf, near which the current is slow, where the roof is a large concavity, where the gas, if present, is likely to be present in greater quantities, and so to make a mixed atmosphere which is lighter than that in the working parts of the mine, there the current probably never ascends to any height, but takes its way sluggishly through the lower parts of the goaf, or moves round the outside of it. We think it probable that the current does not rise much above the level of the highest point in the edge of the goaf basin, and that the top of the goaf is seldom, if ever, reached by it in any sensible degree.

We have thus far considered the goaf as if in something like a constant state, but there are occasions of sudden and limited disturbance which affect the atmosphere of gas within and about it. The evidence at the inquest states, that a rumbling was heard on the morning of the accident within the goaf, and this was probably a fall somewhere from its roof. Such falls tend to mix the lighter and heavier strata of gas and air, and so virtually cause the gas to descend. Again, if the atmosphere four or five feet up in the goaf be an explosive mixture, and a fall of this kind take place there or near it, such an event is very likely to throw out a portion of explosive mixture into the workings of the mine, not merely by the agitation, but also by the mixture of upper with lower strata of air, making the lower explosive.

One cannot but suppose that another source of sudden and partial evolution of gas or explosive mixture from the *goaf*, may be the fall of upper parts of its roofs, and the crushing of the rocks there, by which gas pent up into the seams of coal above and the strata associated with them, has passages open for its escape into the goaf. If a bag of gas (as it is called) were thus opened into the goaf, it would rapidly increase the quantity of gas in it, and might soon cause explosive mixtures, or the gas, almost pure, to underflow the edge of the concavity into the mine.

If the goaf cavity were full of gas or explosive mixture to the highest edge level, the mechanical fall of the roof, in drawing a jud close to that edge, would, by mere agitation, drive some portion of the gas or mixture into the workings of the mine.

When a jud is drawn, and the roof has fallen in, the fall becomes part of the goaf, and the cavity left by it becomes a part of the goaf basin, the edge of the basin extending to, and enclosing the new fall. If this take place at the highest point of the basin, it suddenly opens a passage into the mine for a great quantity of air and gas, which before, by its relative levity to the air, was retained in the goaf basin. Thus, assuming a goaf of 13 acres in a coal seam inclined 1 in 24, and that a fall of 6 feet in extent takes place in the roof at the highest edge of the goaf, it would heighten the edge at that spot 3 inches; and if the goaf were full to the edge, either with fire-damp or explosive mixture, these would flow out more or less rapidly into the workings of the mine, until a horizontal stratum of 3 inches in thickness had thus escaped. Even if the roof of the goaf rose very slowly, making an exceedingly flat dome, this stratum would extend to four-fifths or more of the horizontal area of the goaf: and assuming that the greater part of this space is occupied, not by gas, but by the solid materials of the goaf, and that only a band round the goaf could be considered as air space—still from what we saw of the goafs at the Haswell Little Pit, this would be from 4 to 6 feet in horizontal extent, so that a mass of explosive atmosphere or fire-damp might escape equal to a band about 3000 feet long, by 5 feet wide, and 3 inches deep, making about 3750 cubic feet. It is not likely that this would escape all at once; but the tenth, the twentieth, or the fiftieth part, or even the hundredth part, would be enough to take fire at an injured lamp, and to communicate fire to the whole, though the whole condition between safety and danger up to that moment may have depended upon 3 inches of the roof.

The above is no hypothetical case, but must occasionally, and as to the evolution of gas, frequently occur. If there be gas in the mine, it is expected at the goaf: gas does come from the goaf. All working at the goaf, except with safety lamps, is forbidden: the seams in mines are usually more or less inclined; and this mine at Haswell, where gas *has come* from the goaf, is very free from gas, and well-ventilated, as compared with other pits.

There is one other point connected with what may be called the action of the goaf, and the occasional sudden and temporary discharge of gas from it. One of the witnesses on the inquest, Mr. G. Hunter, pointed out the effect he had observed in the mine on a change in the barometer:—that as the barometer fell, fire-damp would tend to appear, and that it did this the more suddenly and abundantly, if the barometer, having continued high for some time, fell suddenly: and Mr. Buddle has already strongly stated his opinion that accidents from fire-damp always occur with a low barometer. This is very natural; for during a high barometer, the fire-damp, tending to escape from the coal and strata, would be in some degree pent up or restrained by the pressure of the atmosphere; and the diminution of pressure indicated by a sudden fall taking off this restraint, would let the gas expand and escape more freely, and hence its more abundant appearance. Now, without reference to the fire-damp which would ooze out of the strata and from the surface of the goaf basin, let us for a moment consider what would happen as respects the gas already free, but held by its small specific gravity in the upper part of the basin. The barometer will sometimes sink an inch in twelve hours: on such an occurrence, any portion of air or gas pressed on merely by the atmosphere will expand about one-thirtieth part in that time. The portion of air or gas contained in the inverted basin of the goaf is, as has been said, equal to the volume of coal withdrawn beneath, as long as the surface of the country above has not sunk; but because of the inclination of the coal seam, which we may for the present assume as that at the Haswell Little Pit, the air space which is above the level of the highest point of the edge of the concavity may be taken for illustration, as four-fifths of the bulk of the coal, or four-fifths of 13 acres by a thickness of 5 feet (2,265,120 cubic feet); of which the one-thirtieth part, or 75,500 cubic feet, will by expansion be driven below the level of the highest point of the goaf basin. If it contain any portion of gas, it will by its lightness begin to flow out at that particular part; if it contain much, it will flow out the more rapidly, and be the more dangerous; and if, in a mine much infected with fire-damp, it be an explosive mixture, it is easy to imagine that such a cause may occasionally bring about most fatal results.

A fall of an inch in the barometer, of a sudden, is rare, but a fall of one-tenth of an inch is not, and that in such a goaf as the one supposed would place 7550 cubic feet below the edge of the cavity; this all tends to issue forth at one place, and that generally a place where the ventilation is weakest. If, as an influential circumstance tending to diminish the quantity of issuing atmosphere, we assume that the country above has descended, so as not to leave more air space in the goaf than one-fourth of the volume of coal removed, still that would permit 1887 cubic feet to issue forth at one spot, on the occurrence of a fall in the mercury of the barometer equal to one-tenth of an inch. Hence it does appear to us that the goaf, in connexion with barometer changes, may in certain mines be productive of sudden evolutions of fire-damp and explosive mixtures, and that the indication of the barometer, and the consequent condition of the mine, ought to be very carefully attended to.

The recent terrible event appears to have originated at the Meadows Flat workings, at a point near to the upper edge of the goaf concavity, at a place where a *jud* was in the act of being drawn. A man of the name of Williamson, and other men, were engaged in this work at the time of the accident; all were killed, and the jud has since been named after Williamson. All the evidence derivable from the way in which the stoppings were blown, the charring of the posts, and the adhesion of charred coal dust to them on this or that side, as also to the walls of the mine and edges of the irregularities of the walls, confirm this view in the opinion of practical men, the viewers of the mines, and with this conclusion the results of our own close inspection perfectly agree. At this place Davy lamps were found. The state of the gauze indicated that they had been in good condition prior to the accident, but two of them were much crushed and bruised, and one of the others had the oil plug out; this and the fourth were probably found lying on their sides, for the oil was out of the bottom part of the lamps, and had soaked into half the gauze along the cylinder, as they may have lain on the ground. We could get no exact evidence as to how the lamps were in respect of position and other circumstances when found. The gauze of one of these lamps had been heated all round for about 2 inches from the bottom, as if fire-damp had been burning inside at that part of the cylinder; and there was also on the side of the upper part of the gauze of the same lamp, an oblong spot of oxidation exactly such as would have been produced at the first entrance of increasing fire-damp into the lamp, and consequent elongation of the flame, supposing the lamp had been placed a little obliquely against the wall of coal or any other upright object. These appearances accord perfectly with the idea that fire-damp came into the workings whilst this lamp (which had been given out that morning perfect) was there and in use.

At this place the men were drawing a *jud*. It may be that fire-damp issued into the workings there independent of anything the men were doing, or it may be that in the falls of the roof (for it had fallen, as was evident by the stone and timbers) they broke away a portion of the upper edge of the goaf concavity, and by that, both let out explosive mixture into the works, as before explained, and mechanically mixed it up with the air beneath. This issue of gas would not of itself have caused the explosion if the lamps had been right; but of these lamps there are now three that might have fired the gas, for two of them are so bruised, that if these bruises were occasioned by a fall of stones either before or at the time of the issue of gas, then the gas may have taken fire at them; or if they were not bruised by a fall before the explosion, but by one consequent upon it, then it is possible (though not probable) that the third lamp, with the oil plug out, may have occasioned the firing.

When once the combustion began, even though from only a small quantity of gas sent out of the goaf, it would instantly reach up into that greater portion within the goaf vault, and we believe that it was the inflammation of this large portion which gave such force to the blast as to blow down the stoppings between the Meadow and High Brockley Whin workings, and to reach so far as to the goaf of the latter works. Here, from the appearance of the posts and walls, and also from the burnt bodies found, it would appear as if the fire-damp in this goaf had been driven out, mixed with air and inflamed; a very natural result of the circumstances.

In considering the extent of the fire for the moment of explosion, it is not to be supposed that fire-damp is its only fuel; the coal dust swept by the rush of wind and flame from the floor, roof, and walls of the works would instantly take fire and burn, if there were oxygen enough in the air present to support its combustion; and we found the dust adhering to the face of the pillars, props, and walls in the direction of, and on the side towards the explosion, increasing gradually to a certain distance, as we neared the place of ignition. This deposit was in some parts half an inch, and in others almost an inch thick; it adhered together in a friable coked state; when examined with the glass it presented the fused round form of burnt coal dust, and when examined chemically, and compared with the coal itself reduced to powder, was found deprived of the greater portion of the bitumen, and in some instances entirely destitute of it. There is every reason to believe that much coal-gas was made from this dust in the very air itself of the mine by the flame of the fire-damp, which raised and swept it along; and much of the carbon of this dust remained unburnt only for want of air.

At first we were greatly embarrassed by the circumstance of the large number of deaths from choke-damp; and the evidence that that had been present in very considerable quantities compared with the small proportion of fire-damp, which, in the opinion of those in and about the works just before, must have occasioned the explosion. But on consideration of the character of the goafs, as reservoirs of gaseous fuel, and the effect of dust in the mine, we are satisfied that these circumstances fully account for the apparent discrepancy. The blowing down of the stoppings, by destroying the ventilation of the mine, caused all this choke-damp to be left for a time in the workings; and there is reason to believe, from the circumstances, that the men met with a death comparatively sudden.

With such views of the character and effect of the goaf as we have ventured to express, and with a strong belief that it has been the cause of the recent sad event at Haswell, it will not be thought surprising, that, in thinking of the means of preventing such calamity in future, we should turn our attention almost exclusively to it. The first idea is to ventilate the goaf. If a shaft could be sunk over the crown of the goaf, it might perhaps carry away all the fire-damp; but the probability is that where furnaces are used in the upcast shaft, *that* over the goaf would become a downcast shaft, so that all the fire-damp evolved into it would have to pass into the mine and out with the ordinary ventilation. Besides that shafts of such magnitude are very expensive, the bottom part would be liable to fall in; the crown of the goaf vault, also, is in many cases probably changing its place continually, and in inclined strata it might easily happen in the course of working that the bottom edge of the shaft would soon be below the upper edge of the goaf basin *in* the mine, when it would be of comparatively little use. These are difficulties and objections which occur to us even in our theoretical considerations: whether practical men would set them aside, or whether they would add to their number, we cannot say.

Another mode of action has occurred to us, which, the more we think of it, seems the more practical, and offers greater hopes of service to humanity, and which, therefore, we shall venture somewhat minutely to explain. It is founded on the principle of drawing away the atmosphere in the goaf, not of ventilating it by blowing air into it; it is better in principle than blowing into the goaf, because it proposes to take away the fire-damp in a concentrated form, and never to give it to the air of the workings; whereas blowing would first dilute and expand the gas, and then throw it into the works. The difference is especially important for mines where the gas is abundant; for suppose for a moment a goaf cavity full of fire-damp, and an apparatus that could either blow into it or take from it an equal quantity in each case, of air or gas; to take out one cubic foot of fire-damp would be to prevent the formation of from 6 to 15 feet of explosive mixture; to drive in one cubic foot of air would be to send an equal quantity of fire-damp by displacement into the mine, there to form, at one moment or another, from 6 to 15 feet of explosive mixture, which would afterwards have to be carried out of the works by the usual mode of ventilation.

In the first place, we propose that the pillars and juds should be so worked and drawn as to have reference to the form which it is desirable to give to the goaf. This form must be dependent on circumstances, but the point required is that it should draw together at its termination in the upper part of the works, *i.e.* that as the strata rise, the goaf should not have several projections or bays, running independently into the higher works, but one only where the highest point of the goaf basin may occur, and towards which all the fire-damp in the goaf may drain and tend to run under. It is as if in making a pond on the side of a hill,—there should not be two or three low places on the bank where the superfluous water may run over, but one only, *that* being the lowest, as in the fire-damp case it would require to be the highest. This condition would probably be obtained with facility by continually keeping one jud drawn in advance of the rest; and the inspection of a working plan with the inclines drawn on it would easily determine, in every case, what should be done. The next point is to drain or clear this place as well as may be of its fire-damp, which if it could be done effectually, would, in all probability, prevent danger from the goaf, if not absolutely, yet to an extent far beyond what is the case at present; and for this purpose two plans suggest themselves, the same in principle, but differing in extent.

The first plan consists in laying a pipe from the goaf to the upcast shaft, introducing the one extremity into the vault of the goaf at the upper edge of its brim, and furnishing the other extremity with necessary means of drawing the air out of the pipe. The pipe itself may be of cast iron in lengths, joined together with sockets and caulked joints, or in any other of the many well-known manners: its diameter may be about 12 inches, until experience may have directed some other dimensions. Its place, for the chief part of its course, would probably be in the return way; for it ought to be tight, having no other opening than the two extremities; and in the return way it could be best examined from time to time, and would be safest from the effects of creep.

The exit or upcast end of the pipe is to be supplied with means of draught or suction; this might be either a blowing cylinder, or a rough box double bellows, or a revolving fanner, any of which might be worked by the engine, or even by a man or boy, for the work would be easy, there being no resistance to the exit of the air analogous to that offered by the contraction of the stream of air in the ordinary use of blowing machines. But even these are, in our opinion, not required; for from the powerful draught in the return of the Haswell Works, we are at present fully persuaded, that if the goaf ventilation pipe, of the size proposed, simply entered the upcast shaft, there would be draught enough to draw away the atmosphere of the goaf. It is true, that if the atmosphere in the goaf vault, to which the end of the pipe might penetrate, were pure fire-damp, we should have to consider its lightness, and the vertical height between that extremity and the end in the upcast shaft. But this probably is a state of things which could happen very rarely, if ever, in the Haswell Pit; explosive or still lower mixtures, there and in most cases, are rather to be expected, and these, as has been shown, are not so much lighter than air as to offer difficulty in this respect. If a case of pure fire-damp, or a mixture so rich as to offer difficulty on account of its lightness, were to be reached by the pipe, then, indeed, it would be well worth putting on the mechanical means already referred to, to drain it out*.

The goaf end of the pipe offers more difficulties, but we do not see at present that there are any that are not easily surmountable. It has to rise up into the cavity of the goaf, at the point nearest to the highest part of its edge; to enter into this cavity, four, five, or six feet or even more, if possible; and to be temporary, moveable, and tight. The iron tube

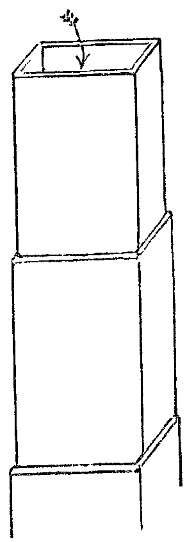
[* In the Phil. Mag., First Series, vol. xxxviii. p. 120, was reprinted from the Transactions of the Society for the Encouragement of Arts, vol. xxviii. (for 1810), a paper by Mr. John Taylor, "*On the Ventilation of Mines, with the Description of a new Machine for that purpose,*" dated April 9, 1810.

The method of ventilation proposed in this paper and effected by the machine described, "instead of using the machines which serve as condensers," is that of exhaustion—pumping out of the mine all the air that was impure as fast as it became so.

In Thomson's Annals of Philosophy (for March 1814), vol. iii. p. 196, Mr. John Taylor published a paper "*On the Ventilation of Coal Mines,*" in which he refers to the paper cited above, extracts from it certain suggestions relative to the application to coal mines of the method of ventilation he had proposed and successfully practised, and enters into some details on this particular subject, insisting on the principle of "the removal of the noxious air by some apparatus proper for the purpose, connected with pipes which are to be fixed so that they may be made to draw from any part or parts of the works, as occasion may require." To this paper Dr. Thomson appended a figure and description of the machine extracted from the paper in the Trans. Soc. Arts. We recommend the perusal of these papers to all who are interested in the subject.

In a lecture on mines, delivered at the London Institution, at the Soirée of February 13, 1833, Mr. Taylor (who was at that time one of the managers of the Institution) exhibited a working model of the machine he had described in 1810, showing its action by experiment, and explaining the method of ventilating mines by its means.—Ed. Phil. Mag.]

may in the first place be continued from the upcast shaft, by any course which on consideration of the works may be thought most expedient, towards, and within a certain distance of, the draining point of the goaf, as near to it as is practicable, probably to within 15 or 20 feet. From thence the pipe may be continued, by wooden trunks fitted together temporarily, having the same sectional area as the pipe itself; and where the pipe rises in the cavity of the goaf, it does not seem difficult to fix wooden adjusters together, either square or round, the joints of which may be made tight by a little mortar. It is even probable that the upper extremity of the pipe might be a tube of air-tight cloth kept open by rings, and raised into its place from a safe distance by a rod of iron or wood. In all cases this end of the tube should be fully open, not allowed to collapse or be contracted in any part; and the joints, if adjusters are used, should be in the direction which opposes least resistance by irregularities to the passage of the air: the roof should of course be propped up as much as may be required about this end of the pipe to protect it; the character of a fixture being in some degree given to the arrangement, until such time as it is again necessary to extend the goaf in that direction.



The *second plan* which we propose is of the same nature, but more local in its arrangement. In this plan, we contemplate carrying the exit end of the drainage pipe only into the return way, but into a part where there is such current of air that the goaf gas thrown in is sure to be thoroughly diluted and carried away. It ought not to be near the furnace, lest at any time there should be gas enough to take fire at the furnace, and communicate explosion back through the pipe into the goaf.

The goaf termination of the pipe will be as before. But in some part of the course of this pipe is to be placed a blowing apparatus, either bellows or fanner, as before directed, drawing from the goaf, and blowing towards the return way. The apparatus may be placed in any convenient part of the course of the pipe, but would probably be more effectual, the nearer it were to the goaf, as there is then the chance of fewer leakages between it and the goaf. It would probably have to be worked by a man, or by any power that was available; whether the draught into that part of the return where the goaf pipe entered, would be sufficient alone or not, is a point which must depend on the nature of the works, and must be determined, if determined at all, by experience.

Such is the general plan, which, with some degree of confidence in its principles, we venture to submit to practical men for their consideration; and we do it with more readiness, believing, from the spirit which we have seen manifested at the Haswell mine, that they are earnestly desirous of carrying into effect everything that can be practically useful. The effect of it would be to remove that condition of the goaf atmosphere, which ordinarily exists at the upper edge of the goaf basin, to a distance of four, five, or more feet higher up within the basin, so as to allow abundant space for all the variations of this atmosphere, without the underflowing of any explosive, or perhaps even contaminated portion of it into the mine. In the case of a regular mine working downwards or into deeper parts, there does not seem much difficulty of application, since the highest edge of the goaf is there stationary. Where the pitmen work towards the rise or upwards, as is the case at the Haswell Little Pit, then the goaf end of the pipe must change its place from time to time. Where faults occur, and the mine is irregular in its workings, each case must be considered by itself, and met, if it can be, upon the same principles. The more faults there are in a mine, the more difficult it may be to regulate the place and form of the upper edge of the goaf cavity; but on the other hand, the more faults there are, the more fire-damp is there generally in the workings, and therefore the more occasion for some means of obtaining the end proposed. If, as is manifested by the Haswell Pit, mines considered the most safe and best ventilated need some such means, how much more must others require it!

It would be a very important addition to the information requisite to indicate and lead to the fittest means of guarding against such events as that at the Haswell Pit, if the state of the atmosphere in the goaf vault were from time to time *examined*, and especially upon fallings of the barometer; so that we might have a general knowledge of its nature. This would not be at all difficult in the hands of an intelligent man; for a piece of small copper pipe about one-third of an inch in diameter, and 25 or 30 feet in length, might easily be introduced by hand into the cavity of the goaf, at the place where the edge is highest, and this being attached to an air-pump syringe below, a few strokes of the hand would suffice to make the latter bring down the gas or air from the place reached by the upper end of the pipe; and if, after the pipe and syringe were filled with such air, a large and sound bladder, or gas-bag, were screwed on to the syringe, it could then easily be filled with other portions of air drawn from the same place. The bag being carried away to a safe part of the mine, could easily have the character of its contents examined into, either by a Davy lamp, or by a candle placed in a glass cylinder, as, for instance, the chimney of an Argand lamp, the air from the bag being then passed in from beneath. Specimens of the air from the goaf might be obtained in a still simpler way, by having a tin, copper, or other close vessel, of the capacity of three or four quarts, with a stop-cock at the top and another at the bottom, filling it with water, attaching it to the lower end of the small copper pipe proceeding up into the goaf, and then opening the cocks until the water had run out. On shutting the cocks, the vessel would be filled with, and would retain a specimen of, the air of the goaf.

Supposing that such a ventilating arrangement as that proposed were established, *another place* for examination would be at the exit end of the goaf ventilation pipe. Ordinarily, we trust, but little gas would be found there, because of the effect of the continued drainage by the arrangement. But this examination, like all others, should be made with every care, lest upon any sudden evolution of gas, or fall of the barometer, an explosive mixture should be issuing forth, and this by a naked light, if such were used for the examination, communicate combustion to the goaf gas through the pipe itself.

Both in the mines and at the inquest, our attention was called to the *stoppings* and *doors* in the workings, upon which the course of the general ventilation depends. When these are blown away by an explosion the ventilation is altered, and at times, as in the Haswell Pit accident, entirely withdrawn. Mr. Buddle proposed to have dam doors so arranged, that when the stoppings were thrown down, these should come into action. We do not think that it would be impossible, or even very difficult, to carry such a plan into effect in some of the permanent ways of the mine; but, considering that if the stoppings were not blown down, the probable effects after an explosion would be the firing of the mine, and also that Mr. Buddle did not himself work out his own proposition in the many mines where he had power, we are not prepared to say that it is a matter that can be brought into practice, and ought to be enforced; or to give any opinion on the subject.

We perhaps ought to apologise for this lengthened statement, especially as we have no right to assume that we have that kind of knowledge that can be gained only by practical men; but we have been encouraged to proceed by the hope of being useful; and have endeavoured to write this report, not in technical phrase, but in plain and simple language, which, if useful in its suggestions, may be comprehended by all.

In conclusion, we cannot but express a hope that some step may be taken without delay, with a view to afford a better education to the persons engaged in working in collieries. When attending the late inquest, we were much struck with the fact that more than half of the pitmen who gave evidence, some of them persons of great intelligence, and one master wasteman, were unable to write, or even to sign their names as witnesses. The best-conducted and well-informed from amongst the pitmen are occasionally promoted to some of the subordinate offices of charge in the mines; and it would be in the highest degree useful, if greater facilities were given to the underviewers, overmen, wastemen and deputies, to learn the elementary knowledge more immediately bearing upon their business. They might be taught, for example, such simple parts of chemistry and pneumatics as relate to the nature of gases and air; the first principles of hydrostatics and of geology, as far as concerns the position and dislocation of strata, the intrusion of trappean or volcanic rocks, and other points.

In countries such as France and Germany, where a far less amount of capital is embarked in mining enterprises, there are large schools of mines and scientific establishments, in which professional men, of different grades, are carefully instructed in those branches of knowledge which are closely connected with the art of mining. We are aware that, notwithstanding the want of such institutions, viewers in this country combine a large amount of scientific information with great practical experience. But such qualifications are enjoyed by a comparatively small proportion of those engaged in the superintendence of coal pits, especially of that class to whom the subordinate offices are intrusted*. If peculiar difficulties attend the organization of schools for the mining population, owing to its migratory habits, and because the workpeople are often congregated suddenly at places far distant from towns and villages, and do not remain permanently resident at fixed

* In the present state of science it is unworthy of the viewers and other mining agents that the nomenclature employed by them in the description of rocks should neither be intelligible to the geologist nor uniform in neighbouring mining districts. Such terms as *post, metal, whin, splint coal, mild* and *strong, thill, scares, girdles,* and others used in the original of the section copied for this report, are illustrations of the strange phraseology which prevails, and which cannot easily be interpreted, even where the miner attaches a definite meaning to the terms he uses.

points, it is the more necessary to endeavour to overcome these obstacles; and provision might, perhaps, be made for appointing teachers, whose duty it should be to visit, in succession, the different localities where the large pits are opened from time to time. Among the many thousands whose thoughts are now continually engaged in the coal mines, there will be always some individuals of strong natural powers, who, if they had mastered the elements of the sciences above enumerated, might be enabled to invent new methods, or at all events would be far more capable than persons unconnected with the business to appreciate the dangers to which they are exposed, and to judge correctly of the adaptation of philosophical principles to practice. We believe, therefore, that if the education of the miners generally, and especially of those set over them, can be materially raised, it will conduce to the security of the lives of the men, and the perfecting of the art of mining, more effectually than any system of parliamentary inspection which could be devised.

There is no reason to fear but that the owners, and all the authorities, high and low, would combine with the men in enforcing regulations for the application of scientific principles to practice, if their minds were prepared by instruction to estimate the true value of the new methods proposed, and if by that instruction those prejudices were removed which disincline the ignorant to every change of system.

There are here no conflicting interests to contend with, for the proprietors are always anxious to prevent explosions and accidents, not only by their feelings of humanity, but by a regard to the property they have at stake; while the viewers, underviewers, and other officers, are continually risking their own lives, and share in every danger with the men.

We have the honour to be, Sir,

Your obedient humble Servants,

M. Faraday,

Chas. Lyell.

III. *On the Purification of the Soluble Salts of Manganese from Iron.*

To the Editors of the Philosophical Magazine and Journal.

Gentlemen,

YOUR correspondent Mr. Kemp, in the last Number (169) of your valuable Magazine, has given a process for the purification of the soluble salts of manganese from iron, which, doubtless, he considers new, but which is identical with the formula of Sir J. Herschel, published in the Philosophical