

figured by Wright in his Monograph, a good figure of it in its various stages would be an advantage.<sup>1</sup>

Besides these species, we have *Am. elegans*, Young, which belongs to the genus *Lioceras*, and we have *Am. bicarinatus*, Zieten, which is distinct from any we have mentioned on account of its smaller centre and furrows on the ventral area, and in all probability belongs to another genus. I do not know if it has really occurred in England.

It may be interesting to notice the sizes of umbilicus in these various species taken from the figures given. The diameter = 100, the umbilicus of *Harp. falciferum* is, youth (Sowerby) 31·9; adult (Wright) 40·5, showing the decrease of inclusion I have mentioned. *Harp. exaratum* (Wright's figure) 20·5 and *Harp. elegans* (Sow. figure) 20·7. (These two have a different sectional view.) *Harp. subplanatum* (D'Orb. pl. 114) 16·76, *Am. bicarinatus* (Zieten's figure) 12·2. Whilst Wright's *Am. bicarinatus*, pl. 82, fig. 9, which I contend is Sowerby's *Am. elegans*, has, umbilicus 19·00, which is almost exactly the same as Sowerby's figure at the same diameter. I have given these measures exactly from the figures. Of course in ordinary work care would have to be taken as to the amount of body-chamber present, and the size of the specimen; but if allowance is made in the present instance for these, it will not account for the variation in the umbilicus in these species.

P.S.—If Sowerby's *Am. Strangewaysi* be really Reinecke's *Am. serpentinus*, I should much doubt, from the indications of suture-lines given by Sowerby, if it be correct to class it in the genus *Hildoceras*. Etymologically, as Dr. Haug wrote to me when making his suggestion, *Harpoceras* is very aptly applied to the true *Falciferi*. It is an important matter to assign a correct place to Waagen's genus which had been partly forestalled by Hyatt's genera *Tropidoceras*, *Hildoceras*, *Lioceras*, *Grammoceras*, *Hammatoceras*, and to another section of which Bayle gave the name *Ludwigia*. In accordance with these genera the restriction of *Harpoceras* becomes a necessity.

#### IV.—ON EXPLOSIVE SLICKENSIDES.

By AUBREY STRAHAN, M.A., F.G.S.

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**D**URING a recent examination of the lead-mines of Derbyshire, I was interested in some accounts of explosions which had taken place, which were not due either to any material used by the workmen or to fire-damp. Though at first inclined to believe that the accounts were exaggerated, I soon found that not only was the evidence of such explosions having constituted a real danger to the men overwhelming, but that accidents are still liable to occur from this cause. The explosions are connected with the structure known as slickenside in the veins. The vein-stuff, consisting generally of galena, calc-spar, heavy spar (sulphate of baryta), and fluor-spar, is divided by the planes of slickenside into more or less vertical sheets

<sup>1</sup> Wherever Dr. Wright has mentioned the zone of *Harp. serpentinum*, it must probably be taken to indicate the zone of *Am. falcifer*.

or slabs. Such sheets, when bared in the mining operations, fly to fragments with explosive violence on being struck, or even scratched by a miner's pick. The following extracts from old authors, and from communications on the subject that I have received, will serve to illustrate the nature of the explosions and the manner in which the danger was met by the men. The accounts relate chiefly to the mines near Eyam, but explosions occurred also in the Odin Mine near Castleton.

The earliest reference to the subject which I have met with is by Dr. Short :—

“On the North Side of this Mountain [Hucklow Edge, near Eyam] . . . is a Mine which cannot be wrought; for in picking or striking the Ore, the sudden shaking of the Metal gives such a violent Motion to the Sulphur, that it makes an Explosion like fired Gunpowder, or a Blast in a Rock, so as great Lumps rise up and fly about along with a Kind of *Terræ Motus*, or Earthquake.”<sup>1</sup>

Pilkington,<sup>2</sup> writing fifty years later, remarks that “the crackling and explosions caused by scraping these slickensides with a pick-axe are well known, but hitherto not satisfactorily accounted for. They are said to lose the above property very soon after they are taken out of the mine. In regard to their external appearance, their smooth side greatly resembles black lead very thinly spread over the surface of any smooth body. But the rough side looks very much like to common limestone.”

But the most detailed account is furnished by John Whitehurst,<sup>3</sup> and is, I think, of sufficient interest to be reproduced here in full :—

“I purpose giving some account of an extraordinary phenomenon which has frequently happened in Haycliff and Ladywash Mines at Eyam, and in Oden Mine at Castleton: the former are thus circumstanced.

“1. The minerals are contained in the fissures of the limestone, covered by a *stratum* of shale and grit, which retain their full thickness of sixty fathoms each.

“2. The minerals contained in the above mines are blended together so as to produce the appearance of white Italian marble clouded with black, and are so extremely hard and compact as to require blasting with gunpowder, to separate them from the general mass.

“3. Those in the Ladywash veins are divided in two equal parts parallel to the sides of the fissure. They may be compared to two slabs of marble, whose polished surfaces are absolutely in contact with each other without the least degree of cohesion.

“4. These naturally polished surfaces are not truly flat, but in some degree waved, as if formed by a carpenter's plane, consisting of various members.

“5. The two surfaces are generally coloured with lead ore, thinly

<sup>1</sup> The History of the Mineral Waters of Derbyshire, Lincolnshire, and Yorkshire, by Thomas Short, M.D., 4to., London, 1734, p. 96.

<sup>2</sup> A View of the Present State of Derbyshire, 1789, vol. i. p. 195.

<sup>3</sup> An Inquiry into the Original State and Formation of the Earth, by John Whitehurst, 3rd edition, 1792, London, p. 218, *et seq.*, plate i.

laid on, as if only rubbed over with black lead, though sometimes thicker.

“6. The vein in Haycliff Mine contains two of the above seams, and therefore may be compared to three slabs of marble, the middle one polished on both sides and in contact with the other two.

“Thus are the above veins circumstanced. Now what is yet more remarkable is this: if a sharp pointed pick is drawn down the vein with a small degree of force, the minerals begin to crackle, as sulphur excited to become electrical by rubbing; after this in the space of two or three minutes, the solid mass of the minerals explodes with much violence, and the fragments fly out, as if blasted with gunpowder. These effects have frequently happened, by which many workmen have been wounded, but none killed, both in the Eyam Mines, and in that called Oden, at Castleton.

“In the year 1738 a prodigious explosion happened in the mine called Haycliff. The quantity of two hundred barrels of the above minerals were blown out at one blast; each barrel, I presume, contained no less than three or four hundredweight. At the same time a man was blown twelve fathoms perpendicular, and lodged upon a floor, or bunding, as the miners call it, in one of the shafts.

“When the above explosion happened, the barrel, or tub, in which the minerals, etc., are raised to the surface, happened to hang over the engine shaft, which is nearly seven feet in diameter, and 448 yards distant from the forefield, or part, where the explosion happened; this barrel, though of considerable weight, was lifted up in the hook on which it was suspended; and the people on the surface felt the ground shake, as by an earthquake.

“Such are the effects which have frequently been produced in all the above mines; but from what cause they proceed, I have not yet been able to discover, nor even the least traces towards it. The substance having been analyzed, is found to consist of fluor and the ore of lead, but the cause of explosion still remains equally mysterious, though some attempts have been made to obtain a knowledge of this curious phenomenon.

“These curious observations I received from Mr. Mettam, of Eyam, overseer of the mines, who also addressed the following account of them to Mr. George Tissington, of Winster, principal agent of the works.

“Eyam, 2 July, 1768. Sir,—I send you by the bearer, two specimens of our *slickensides*, containing all the variety of minerals where the explosions happen; they fly out in such *slappits*,<sup>1</sup> smooth on one side. The explosions are sometimes heard to the surface, and felt like an earthquake; they frequently blow out all the candles in the mine, and split the *stemples*<sup>2</sup> into splinters as small as the twigs of a birch besom, to the distance of thirty or forty yards from the *forefield*;<sup>3</sup> others are broke, and some of them become too short

<sup>1</sup> *Slappits*, fragments of the minerals burst out of the vein.

<sup>2</sup> *Stemples*, joists laid across fissures, when the minerals are cut out, by way of making a floor, on which rubbish is deposited, to save the expense of raising it to the surface.

<sup>3</sup> *Forefield*, that part of the vein under workmanship.

and drop out. The smooth sides lie face to face, and have the appearance of being shot with a plane, consisting of various members. There is generally two of these divisions in our forefield at Haycliff, about eight or ten inches asunder, and a seam of white *kebble*<sup>1</sup> in the middle of that space, half an inch thick, in which the miners rake down a sharp pointed pick until the crackling ceases; then they run away, knowing that the explosion will follow in a minute or two. Sometimes a noise is heard like the beating of a church clock, after which the greatest explosions happen.—I am, yours, etc., William Mettam.—To Mr. George Tissington, Winster.”

John Mawe also writes in 1802 that in the Odin Mine “is found that singular variety of lead ore, called *slickenside*. This galena presents a smooth surface, as if plated. Sometimes it forms the sides of cavities, and on being pierced with the miner’s tool, rends with violence, and explodes with a crackling noise. The cause of this phenomenon has not been fully explained. I have seen a man, when he came out of the mine, only a few minutes after the explosion, who, regardless of the danger, had pierced the sides of this substance, and was much hurt, and cut violently, as if stabbed about the neck and other places with a chisel, whence he was unable to return to the mines for two weeks.”<sup>2</sup>

“Sometimes the vein-stuff is found perfectly divided vertically, throughout, and the surfaces polished; and these are called *Slickensides* or Cracking-whole, which usually are ribbed or slightly fluted, horizontally: the appearances are very similar to those of faults, but extraneous matters do not usually accompany them, the sides being mostly in very close contact; and often, after one side is removed, so as to give room, especially if the surface be pecked or broken, large Slapits, Spels, or fragments fly off, sometimes with loud explosions, and continue so to do for some days or longer, until the gate or passage in such vein is greatly enlarged thereby: this is the case in Gang Mine, in Cromford, where the hard 1st Toadstone also, in the gates and shafts, thus spels off, until they want timbering often, to support the roof and sides. I could not learn, that the Slickensides in the Mines about Eyam explode now, on mere scratching, as they were said to do in the late Mr. Whitehurst’s time.”<sup>3</sup>

“In Gang Mine, where a *Slickenside* runs through the Vein, the Miner avails himself of a curious property attending such Veins, by drawing laces, stoops, or nicks, at about six inches apart and four inches deep, with the point of his Pick, from top to bottom of his face of work, when he then leaves for several hours, and on his return, finds all the Vein-stuff so furrowed, spelled, or slapped off, and laying on the sole ready got to his hands.”<sup>4</sup>

“When their edges occur in the face of the vein, on the miner striking his pick into the vein they separate, in some districts without,

<sup>1</sup> *Kebble*, a white opaque spar, calcareous, but not apt to break into rhomboidal forms.

<sup>2</sup> The Mineralogy of Derbyshire, by John Mawe, 8vo. London, 1802, p. 48.

<sup>3</sup> General View of the Agriculture and Minerals of Derbyshire, by John Farey, 8vo. London, 1811, vol. i. p. 250.

<sup>4</sup> *Ib.* p. 367.

in others with a slight report; and in some of the mines in the neighbourhood of Eyam, in Derbyshire, with *loud* reports, particularly in Cracking-hole vein, in Haycliffe title . . . . where in the centre of the vein, termed a shack vein, was a small white impalpable (not effervescing) powder, called a mallion, a quarter of an inch thick, which on being scratched, a loud explosion immediately ensued, before which explosion a singing kind of noise was heard. By setting a blast in the vein at a short distance from the mallion, after the blast was fired, in a few minutes an explosion took place, when a large quantity of the vein fell down. In the year 1790, a loud explosion took place from a slide joint of Slickensides going across, but not into the cheeks of the vein containing the mallion, which caused on its being stirred the loudest explosion and the largest quantity of vein materials to come down. . . . The last great explosion was in the year 1805. It has sometimes happened that persons have been maimed or even killed by this phenomenon; which, however, has not been noticed from Slickensides *where no shale is incumbent.*"<sup>1</sup>

In writing of the mines on Hucklow Edge, William Wood refers to the Hay Cliff, as "a mine distinguished for having contained in great abundance, that extraordinary phenomenon in the mineral world, provincially called Slickensides. . . . The effects of this mineral are terrific: a blow with a hammer, a stroke or scratch with a miner's pick is sufficient to blast asunder the massive rocks to which it is found attached. . . . A person named Higginbotham once narrowly escaped with life, by incautiously striking this substance in the above mine. Experienced miners can, however, work where it greatly abounds without much danger. It is also known by the name of Cracking-whole."<sup>2</sup>

The phenomenon is referred to by W. Adam also, who supposes that the slickenside has been produced by the rubbing of the rocks against one another. "The intense heat generated by the motion of such vast masses (expanding the air in its pores) may account for its exploding when broken into, similar to lumps of glass when suddenly cooled, which explode on being scratched or slightly broken."<sup>3</sup>

"To avoid the danger attendant on working in its immediate contiguity, the miners use the precaution of merely making a small incision or aperture, with the point of the pick, and then retire to a place of safety, awaiting the result. In case of an explosion, it generally takes place in ten or fifteen minutes, and by the force attendant on which, considerable masses of ore, and even stuff, are detached."<sup>4</sup>

Sir Charles Lyell, referring to this subject in the 6th edition of

<sup>1</sup> An Account of the Explosion of Slickensides, by W. Watson, Edin. Journ. Sci. new ser. vol. ii. p. 186, 1829.

<sup>2</sup> The History and Antiquities of Eyam; with a minute account of the Great Plague, which desolated that village in the year 1666, by William Wood, 8vo., London and Derby, 2nd ed. 1852; 3rd ed. date not stated.

<sup>3</sup> The Gem of the Peak; or, Matlock Bath and its Vicinity, etc., by W. Adam, London, 1845, p. 419, footnote.

<sup>4</sup> Mining Almanack for 1850, by W. English, London, p. 220.

his *Elements of Geology* in 1865, remarked, "these phenomena and their causes (probably connected with electrical action) seem scarcely to have attracted the attention they deserve." In subsequent editions this suggestion of a connection with electrical action was omitted.

Mr. Leonard Maltby, of the Mill Dam Mine, Great Hucklow, informs me<sup>1</sup> that he has had experience of the explosion of slickensides. The explosions take place at the present time in the vein at the Cockersfield Shaft; pieces of mineral burst from the face with a loud noise and with great force, so as to necessitate great care on the part of the men when working. There are also several other places in the Mill Dam Mine where slickensides of an explosive tendency have occurred, as well as in the Silence Mine on the same vein, and in a vein near Eyam, called the Brookhead Vein. At the Lady Wash Mine also, on the eastern range of the vein worked at Mill Dam, the miners noted the same phenomenon. Its prevalence in this neighbourhood leads Mr. Maltby to infer that slickensides will explode more or less, while being cut, wherever they occur. He remarks further that where slickensides occur, the vein is always as hard and fast as it is possible to be, and seems to be under great pressure. "When we work with a pick, cutting one side of the vein, as soon as we have made a little opening, it seems then that the air gets in, and the mineral swells and bursts off with loud noises, and where the vein is hardest and most nipped, the explosions are strongest. It always bursts off just as far as the opening is made." He considers both the slickenside and the explosions to be the result of pressure.

Though some of the veins in which explosions have occurred contain much fluor-spar, yet the phenomenon has been more frequently observed in the hard and tight veins which contain calc-spar, heavy spar (sulphate of baryta) and galena. Fluor-spar, as Mr. Maltby informs me,<sup>2</sup> occurs more commonly in soft veins, such as that at the Dusty Pits, near Eyam, where it was very abundant. In this vein no slickenside was seen and explosions were unknown.

The late Mr. J. A. Phillips, F.R.S., F.G.S., etc., informed me that he had known of several instances of the flying off of fragments of mineral from the slickensided face of a vein, with a sharp report. In one case a fragment was thrown off with sufficient force to break the leg of a man who was passing. The explosions occurred after a portion of the vein had been undercut. Mr. Phillips suggested that the removal of one side of a vein would leave the remaining side in a condition of strain, resembling that of a strung bow, with a tendency to bulge outwards into the workings. The undercutting would free, so to speak, one end of the bow.

Mr. W. Bowman, of Alport, writes<sup>3</sup> that he has seen pieces of limestone in the Ecton Mine fly off with a sharp small crack, some short time after it has been broken by blasting. In one instance, in 1885, two miners were drilling a hole by hand in the Clayton Adit-level, when a piece of rock burst from the face with a loud report,

<sup>1</sup> In a letter dated 22nd October, 1886.

<sup>2</sup> In a letter dated 23rd November, 1886.

<sup>3</sup> In a letter dated 15th October, 1886.

throwing the men to the ground, and bruising them considerably; the thickness of the fragment was equal to the depth of the drill-hole, namely, ten or twelve inches. The toadstone also has been known by Mr. Bowman to break off with a little noise soon after it has been relieved of pressure by excavation. Ecton Mountain is composed of the upper beds of the Carboniferous Limestone, sharply contorted and crushed.

I may refer here also to the description by Mr. W. H. Niles,<sup>1</sup> of the movements of rocks resulting from lateral pressure, and exhibited in quarries. It was found at Monson that the rock has been brought into a compressed condition by a powerful lateral pressure acting in a north and south direction, and that, when opportunity is presented, the compressed rock expands with great energy, often bending, folding, and fracturing the beds, and sometimes producing sudden and violent explosions, and occasionally throwing stones into the air. The expansion became apparent on cutting trenches in the rock in an east and west direction.

At Lemont, Illinois, the bed of rock forming the floor of a quarry was gradually bent up into the form of an anticlinal, trending east and west, and running for about 800 feet with an elevation of six to eight inches. The elevation had taken place in consequence of the removal of the overlying rock, and had been attended by explosive sounds, and sometimes fragments of the rock had been thrown into the air. In the same quarry it was observed that drill-holes bored through two layers of stone became displaced, the upper parts of the holes being no longer vertically over the lower parts. The effects of this force have been noticed at five different localities, ranging over five and a half degrees of longitude.

Mr. Niles refers also to explosions which have sometimes occurred in making railway-tunnels and other excavations, and which could not be accounted for as the results of any artificial power.

The tradition among miners that knockings may be heard underground, where ore exists, is well known, and has often led to the expenditure of much money. That subterranean noises are not uncommon has been proved beyond doubt, and the following account by a working miner is not without interest.<sup>2</sup>

"I have heard some Miners say that it is a Knocking they hear, Striking much like as when one in Boreing, not constantly but resting by Fits, and always seem to be at a distance from him. . . . I once Worked in a Groove not many Years ago, where two more Men wrought, they worked by yards at a deeper Level than I wrought at . . . One day I having some leasure at Work, it struck into my Head to go down to them, . . . but coming there I found no Body, which I did much Wonder at, since I well knew that no Body else wrought within my hearing. Next Day I told the Men how I was mistaken; see you there says one of them to the other, it is what

<sup>1</sup> The Geological Agency of Lateral Pressure exhibited by certain Movements of Rocks, Proc. Boston Soc. Nat. Hist. vol. xviii. p. 272 (1876); see also *ib.* vol. xiv. and Proc. American Assoc. for the Advancement of Science, vol. viii. p. 285, and vol. xxii. part ii.

<sup>2</sup> The Miner's Dictionary, by William Hooson, 8vo. Wrexham, 1747 (under the head Knocker).

we are used to hear; after some little Discourse, they told me that they had heard it very often, and (says they) not long before you came here, we was both at Work and heard a Noise, and we concluded it could be nothing but somebody coming down the Shaft, and in a little while, about the time they might be got to our first Sump-head, we presently heard as we thought, them throwing the Corves down the Sump; we heard 'em rattle so plain against the hard Sides, and amazed at such folly we came in hast up, where we found all things as we had left them when we came down without the least alteration, as we could discern. Thus the Men.

“One Instance more may be of the same kind, where I have been acquainted, and 'tis this: I with others wrought in a certain Work about eighty Yards deep, the Shaft was Sunk in a great and loose Shack of Chirts, which sunk down to the Soles and much further for any thing we know, being exceeding loose, and not any openness seen throughout the whole Work, but the ways that were cut; the loosness of this Work was all the care to keep it up; yet what I Remark is, that the Workmen themselves, but more especially the Labourers, at the Sump-heads and in the Gates, have been often affrighted with such a Noise and dismal Rattle, as if sometimes the Shaft had run in, and at other times the Gates or Sumps; I have heard it my self, and have thought by the Noise, we had been all made fast, but by God's Blessing, never found one Stick of Timber disordered or out of its Place; one would think that the Noise might be caused by something running in some openness, or great Shack, but there was never any such seen in the whole Work; for altho' there were large and wild shaken Places, yet they were all full of loose small Chirts to the Day; . . . what these Noises are, we miners know not, but must leave them to the Disquisition of such learn'd Men as deal in those profound Matters; I mention it because Miners say that the Knocking is some Being, that Inhabits in the Concaves and Hollows of the Earth; and that it is thus kind to some Men of suitable Tempers, and directs them to the Ore by such its knocking, etc.”

In some of the mines near Eyam, which have been referred to above, explosions of fire-damp have occurred from time to time, especially in those which were sunk through the Yoredale Shale into the Carboniferous Limestone, and in the water-levels which were driven long distances through the Millstone Grit and Yoredale Shale to drain the mines. References to such explosions occur in most of the authors quoted above, and in such terms as to show that they were clearly recognized as distinct from the explosions due to slickensides. I am therefore disposed to believe that the great explosion described by Whitehurst as having occurred in 1738 was due to slickensides, but that in the fifty years which had elapsed before Whitehurst wrote, the account of the effects had become considerably exaggerated, or more probably confused with the account of some explosion due to fire-damp.

It is difficult to understand the lifting of the barrel in the shaft, and the blowing of a man twelve fathoms perpendicularly, except



by an explosion of violent expansive power. It will be noticed that the cause of the great explosion of 1790 is distinctly stated by Mr. W. Watson, though writing nearly forty years after the event, to have been a slide joint of slickensides going across a vein.

By the kindness of Mr. Maltby I have been supplied with some specimens of the explosive ore from the Cockersfield Shaft of the Milldam Mine at Great Hucklow, near Eyam. The specimens consist of sulphate of baryta and galena arranged in more or less vertical but irregular ribs. The planes of slickenside are beautifully polished, so much so in places as to possess the reflective power of a looking-glass, but they show also the usual ribbing or striation which so strongly conveys the idea of slickenside having been produced by the rubbing of two surfaces together. The planes of slickenside were clearly formed after the filling in of the vein by the minerals mentioned above. They cut through the galena and baryta impartially, nor in any of the specimens in my possession is there any appearance of a rearrangement of the minerals having resulted from the existence of the plane of slickenside, except that the slickenside surfaces are slightly stained by iron oxide, or coated by a microscopically thin film of galena.

The spar in these specimens has the granular appearance of white lump sugar, and readily crumbles into a gritty powder. Whether this granular structure is the result of the explosions by which the specimens were detached, there is no evidence to show. The specimens themselves average from half an inch to three inches across, and are of all shapes. Attempts have been made to prepare microscopic sections across the planes of slickenside, but up to the present without success.

The first explanation that suggested itself to me was that the mass of rock, separating two planes of slickenside, was comparable to a huge sheet of very brittle glass, placed on its edge; a slight blow on the lower part of which might bring down the whole mass in fragments. This, however, provides no explanation of the explosive power, which is so clearly brought out in the above quotations.

Secondly, it will be familiar to all who have been in mines, that newly bared shale swells and crumbles on exposure to air and moisture. This is probably due in many cases to chemical processes set up in the mass of the rock, principally no doubt in connection with the salts of iron. It seemed conceivable that such processes, taking place within a brittle rock, might place it in a condition of strain, under which it would fly to pieces with a mere touch. But there is no sign of any chemical alteration having taken place in these explosive spars.

The explanation, which perhaps best satisfies the requirements of the problem, appears to be that the spars are in a state of molecular strain, resembling that of the Rupert's Drop, or of toughened glass, and that this condition of strain is the result of the earth-movements, which produced the slickensides.