EFFECTS OF SPARKING FROM VARIOUS CLASSES OF TOOL STEEL IN EXPLOSIVE MIXTURES OF FIREDAMP AND AIR WITH SPECIAL REFERENCE TO SPARKING FROM COAL CUTTER PICKS, [illegible]

BY

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INTRODUCTION.

For nearly two centuries the Ignition of Firedamp in Coal Mines has given grave concern to the Mining Industry. The causes of these Ignitions are not always obvious, and in many cases Frictional Sparks have been considered the only probable cause, after careful study of the other possible sources of Ignition.

The earliest recorded Ignitions attributed to Frictional Sparking were believed to be produced by sparks either from the blow of a hand pick on hard rock or from the sparks given off by the steel mill and flint used at that time for underground illumination.

The application of machinery to coal cutting has been progressively increasing during the past 50 years or so, and probably no branch of Mining Engineering is receiving more attention at the present time. This outstanding development in the use of mechanical coal cutters is exemplified by the following figures:-

In 1901, 1.4% of total output of coal in Great Britain was cut by machinery (H.M. Insp. Mines Rept. 1928, p.189, chart x,b).

In 1918, 12% of the total output was cut by 4041 machines in 695 separate collieries (H.M. Insp. Mines Rept. 1918, p.138, table 48).

While in 1928, 25.9% of total output of coal was cut by 7131 machines in 908 separate collieries (H.M. Insp. Mines/

Mines Rept. 1928, p.133, table 4L).

The possibility of encountering the harder rocks adjacent to, and disseminated through the coal seams, and the greater amount of energy expended in cutting, accentuates the danger, if any, of sparking effects due to contact with the coal cutter picks. In recent years such sparks have been assigned as a cause of Ignition of Firedamp underground.

Different opinions have been advanced by eminent Mining Engineers, but whether sparks produced from coal cutting picks are capable of igniting inflammable mixtures of Firedamp and Air seems still to be controversial. The following report gives first, an historical review of the subject, and secondly, describes a series of experiments conducted with a view to deciding whether or not Firedamp-Air mixtures can be ignited by sparks from coal cutting picks on hard rock, and any conditions which may influence the incendivity of the sparks.

HISTORICAL REVIEW

The Spedding steel mill, introduced into British and Belgium coal mines about 1765 for underground illumination, is probably responsible for the earlier belief that Firedamp and Air mixtures can be ignited by frictional sparks. The mill consisted of a thin steel disc which revolved at a high velocity A piece of flint pressed against the edge of the revolving disc emitted a stream of sparks which were the means of illumination. Several explosions were attributed to this cause and are more fully referred to later in this report.

1777. Volta was perhaps the first to suggest the possibility of an ignition of Firedamp by sparks from the steel mill. He later carried out a series of experiments with steel on hard rock, and attempted to ignite by the sparks produced, what he termed "inflammable air" obtained from lakes and marshes near Como. He found that it was quite easy to ignite this inflammable air when he concentrated the sparks on the mouth of the vessel containing the gas. The readiness with which ignition occurred gives rise to a suspicion that the inflammable air must have contained a high percentage of hydrogen gas. (Lettere del Sig. Volta sull'aria inflammabile nativa delle paludi. Milan, 1777.)

1783. Mr. John Buddle, an eminent Mining Engineer, in giving evidence before the Select Committee on Accidents in Mines, stated of the Wallsend Colliery in 1783:-

"In cleaning out of these pits again several fatal accidents happened from the steel mill; the people were perfectly/

perfectly ignorant of the effect of the sparks from the flint and steel, and consequently had the most perfect confidence that it would not fire; however, explosion after explosion took place, and life after life was lost, till at last a person using a steel mill when this took place distinctly saw the gas fire from his mill, and indeed two cases of that kind had occurred before people could be convinced that the gas would fire from the spark of the steel mill." (Select Comm. on Accidents in Mines, 1835, p.174).

1815. Sir H. Davy read a memoir before The Royal Society, London, on 9th Dec., 1815, in which he gave particulars regarding ignition of mixtures of Firedamp and Air by electric sparks. He also refers to the ignition of Firedamp by sparks from the steel mill, but does not mention having actually observed ignitions caused by these sparks. (Trans. of North of England Inst. of Min. Eng., vol. 40, 1890-91, pp. 167-168).

1883. Mr H. Lawrence in his paper "The Dangers of Sparks produced from Prickers and Stemmers used for Blasting Purposes in Coal Mines and Sparks otherwise produced" read before the North of England Inst. of Min. Eng. in 1883 gives an account of personally conducted experiments on sparking underground with a compressed air locomotive having iron wheels. It was observed that when the locomotive stuck with its load on an incline/

incline the wheels slipped round with great velocity and long streams of sparks were given off. These were considered a source of danger should Firedamp accumulate in the Mine. The locomotive was therefore condemned unless a sparkless tyre could be produced. He made a series of trials with tyres of various metallic composition on a locomotive raised up so that the wheels were free to revolve. An iron rail was placed under one wheel in order to form a lever and weighted so as to take a great portion of the weight of the locomotive. The engine was then started to run at high velocity. Copper tyres were tried but produced streams of sparks almost as great as iron. In addition there was an unexpected peculiarity in the copper tyre cutting into the iron rail. Ultimately a tyre was produced which did not cause sparks and sufficiently durable. Unfortunately the composition does not seem to have been divulged.

At the conclusion of Mr. Lawrence's paper a communication was read from Mr. Sawyer, Assist. Insp. of Mines, stating that a small quantity of gas had been ignited at Great Fenton Colliery by sparks from a pick during the ripping of a road. He had made full inquiries and was convinced that the cause of the ignition was as stated. (Trans. of North of England Inst. of Min. Eng., vol. XXX111, 1883-84, pp. 6-7).

1880. An ignition at Pentre Colliery, Glamorgan, was attributed to sparks from a pick striking hard rock. (Trans. Inst. Min. Eng., vol. XL1V, p. 741).

1886. **Chief Engineer John Mayer**, in his article "Experiments on the Inflammability of Pit Gases by Sparks disengaged from Working of Hard Rocks with Steel Tools" calls attention to the dangers of the sparks so produced. He carried out a series of experiments by means of a quick revolving disc of hard sand-stone, at the circumference of which were held sharp pointed steel blades. Town gas he found could be ignited with ease, but blower-gas could only be managed with difficulty. He only obtained one ignition in a long series of experiments. (Oesterr. Zeitsch. f. Berg. u. Hutten-wesen 1886, pp. 34, 379, 398).

1887. At the Prussian Firedamp Commission of 1887, the subject of shot lighting materials was under review. Many objections were raised against the practice of ignition by flint, steel, and tinder as being dangerous when Firedamp was present. These objections were really advanced as a result of the experiments of Messrs. De Villaine and Griot, which had shown that town gas could easily be ignited by this means, and also because several explosions in Britain and Belgium had been attributed to the use of the old flint mill, in underground illumination. (Trans. of the Fed. Inst. Min. Eng., 1892-93, vol. 4, p. 670).

The same Commission when considering the subject of "Sparks struck from the Rocks in Working Hard Stone with Steel Tools", again directed attention to the danger of the steel mill as the shower of sparks, to which it gives rise when in use, was responsible for several explosions. (Trans. of Fed. Inst./

Inst. of Min. Eng., vol. 4, 1892-93, p. 679).

1889. In a report by H.M. Insp. of Mines, W. N. Atkinson on the circumstances attending an explosion of Firedamp at the Mossfields Colliery, in 1889, the following statement was made:-

> "It has been proved experimentally, by Mons. A. Macquet, ingénieur au corps des mines, Professeur de Physique et d'éléctricité à l'école du Hainaut, that sparks produced by a blow of a pick on Iron Pyrites may ignite firedamp".

Iron Pyrites was occasionally met with in the Cockshead Seam at this colliery and it was voluntary reported by a workman engaged in driving one of the new roads up Jig XV, where the explosion occurred, that he encountered pyrites which produced sparks when struck with a pick. (Rept. to H.M. Secy. of State for Home Dept. on the Circumstances attending an Explosion at Mossfields Colliery, near Longton on 16th Oct. 1889 by W.N. Atkinson, H.M. Insp. of Mines, p. 13).

In the same report H. Thomas, Barrister at Law, stated that it is possible, although the evidence is slight, that a collier working in Jig XV, where the explosion was supposed to originate struck pyrites with his pick and thus ignited explosive gas there, which initiated the explosion. If the explosion started otherwise than by this means, or elsewhere than in Jig XV, no possible cause can be suggested, since no evidence of any kind was ascertainable. Rept. to H. M. Secy. for State for the Home Dept. for the Circumstances attending an Explosion at Mossfields Colliery/

Colliery, near Longton on 16th Oct. 1889 by W. N. Atkinson, H.M. Insp. of Mines, p. 16).

1890. Mallard, Le Chatelier, and Chesneau in their report submitted to the French Firedamp Commission, 1890, "On the Inflammability of Firedamp by Sparks produced by Steel Tools," record that in consequence of an explosion at Verpilleux, experiments were made at St. Étienne by M. Leclère with lighting gas and sparks produced with a pick on fragments of hard stone and nodules of ironstone, and ignition of the gas ensued. Further experiments were made with sparks produced by pressing a bar of steel against a rapidly revolving emery wheel. A large jet of inflammable mixture of air and marsh gas was directed in various ways on the continuous shower of dazzling sparks so produced without causing ignition. M. Leclère later repeated his experiments using Firedamp from Grand Treuil Pit. Sparks produced from a heavy pick on pyrites and iron carbonate failed to ignite the explosive Firedamp-Air mixtures.(Ann. des Mines, Series 8, vol. XXVlll, 1890, pp. 699-713).

1901. At Caerbryn Colliery (Stanllyd Anthracite Seam) it is reported by H.M. Insp. that a collier hammering out a piece of pyrites with a sledge hammer ignited Firedamp by sparks resulting from the blows. Another Collier working in a skip six yards away was burned as a result of running forward to see what had happened. An investigation by Mr. White revealed the ease/

ease with which a collier could produce a shower of sparks on striking the pyrites, lumps of which are found in the seam. The Inspector further states, it is well known that explosions were sometimes caused in the old days, by sparks from the flint and steel mill used to light the working places, previous to the introduction of the Davy Lamp. (H.M. Insp. Rept. Swansea District 1901, pp. 11-12).

1902. An explosion at Orrel Colliery, Wigan, was attributed to a shovel striking the roof and producing sparks. A miner while swinging his shovel to waft out the gas which had accumulated in his working place struck the roof, and the sparks so produced ignited the gas. (Trans, Inst. Min. Eng., 1912-13, pp. 44, 740).

1907. M. Delacuvillere, Engineer in charge at Fontanie l'Evêque Colliery, Belgium, in reporting an ignition of Firedamp, at this mine, which was seen to occur simultaneously with the striking of a blow by a pick on a piece of hard rock states:-

> "The roadway had been widened at the side in the usual manner and the workmen were fixing props. One of them was enlarging with his pick a hole in which to fix a prop, when a large spark was struck by a blow of the pick. At once a slowly moving flame travelled vertically up the side of the road where it had been newly cut, and propagated along the roadway keeping close to the side." (Ann. des Mines de Belg., 1907, pp. 12, 1117, vol. 4).

1907/

1907. In the Cardiff district at Ferndale Colliery, No. 5, two repairers were enlarging a heading. On pulling out two collars a fall occurred bringing down about 20 tons of dirt. In two or three minutes another fall occurred when about 15 tons of dirt fell. When the second fall occurred the workmen reported seeing a flash under the cavity in the roof similar to that produced when Benzoline is put on fire. About 12 ft. above the rails were two beds of highly silicious rock and it was suggested by the management that the stones from these beds, on falling, produced sparks which ignited a small quantity of Firedamp.

1909. One of the theories advanced as the cause of the West Stanley Colliery explosion was that the sparking produced when a train of tubs came out of the Busty West section ignited the coal dust and so initiated the explosion. The sequence of events in the explosion as suggested by Mr. Hall, Manager of the Colliery were:-

Tubs off the way; cloud of coal dust; fall of stone; sparks; explosion. The feasability of the theory of ignition was questioned as Firedamp was more easily ignited than the finest coal dust, and the French Firedamp Commission had made experiments with Firedamp from the workings of a colliery, and applying sparks produced by a mechanical drill on hard stone, failed to ignite the gas. A dazzling shower of sparks produced by pressing a bar of steel against a rapidly revolving emery wheel also failed to ignite Firedamp which was directed on to the sparks.(Rept. on West/

West Stanley Colliery Explosion by H.M. Insp. of Mines, R. A. S. Redmayne and R. D. Bain, 1909, p. 15).

1910. In the report dealing with Firedamp Accidents in Coal Mines in Belgium, 1891 to 1909, is discussed ignitions of explosive mixtures of Firedamp and Air due to frictional sparks. The report says that the experiments carried out at Frameries on the subject have shown these sparks to be quite harmless in explosive mixtures of Firedamp and Air. (North of England Inst. of Min. Eng., 1910-11, p. 15).

1911. Under the heading of "Dangerous Occurrences" in H.M. Insp. of Mines Rept. it is suggested that two ignitions of Firedamp in S. Wales in the holing cut of an electrical disc coal cutting machine were due to frictional sparks from the cutters. (H.M. Insp. Rept., S. Wales District, 1911, p. 18).

1912. Three explosions which occurred at Bellevue Colliery, Alberta, Canada, were attributed to sparks from falls of silicious rock. Tests were made by fixing a piece of the silicious rock from the roof, instead of flint, in a steel mill and sparks of sufficient intensity to ignite Firedamp were produced. (From a paper by J. T. Stirling, H. M. Insp. of Mines, Alberta, and Prof. J. Cadman, D.Sc., in Trans. Inst. Min. Eng., 1912-13, vol. XLIV, pp. 750-753).

1913. In his evidence on Causes and Circumstances of Senghenydd Colliery/

Colliery Explosion in 1913, Mr. Shaw dealt with the possibility of Frictional Sparks igniting Firedamp. He quoted an incident which happened at Lletty Colliery, Cwmbach on the 27th Jan., 1902 pointing to the possibility of an explosion caused by sparks. The oversman and fireman at this particular pit testified to seeing an ignition of gas by sparks when a fall of the roof occurred. These sparks were due to the rocks striking the iron tangers which supported the roof. Also referred to under "Dangerous Occurrences" in the 1914-15 Rept. of H.M. Insp., S. Wales Division, p. 15. (Rept. by R. A. S. Redmayne, H.M. Insp. of mines, on the Causes and Circumstances of the Senghenydd Colliery Explosion, 1913, p. 15).

1914. At Bannockburn Colliery, Stirling, gas was ignited by the sparks from a brusher's pick striking the sandstone roof when preparing a hole for the top of a prop. No other source of ignition could be found and there appears no reason to doubt that the gas became ignited by sparks as described. (H.M. Insp. Rept., Scottish Division, 1914, p. 14).

1920. An explosion of Firedamp which occurred at Lodge Mill Colliery, Yorkshire was attributed to frictional sparks produced from a steel rope slipping on the return wheel of a haulage. (H.M. Insp. Rept., Yorkshire and N. Midland Division, 1920, p.84).

1920. Two ignitions of gas which took place in the Lochgelly Splint Seam, Blairhall Colliery, Fife, were assigned to sparking by/

by the chain of the coal cutting machine scraping on the hard pavement. (H.M. Insp. Rept., Scotland Division, 1920, p. 14).

1921. From the evidences on the causes of an explosion at Cossal Colliery, Notts, in 1921, it would appear to be established that an ignition of gas took place at the crown wheel of a coal cutting machine from sparks produced by the friction between the crown wheel and the disc. (H.M. Insp. Rept., York. and N. Midland Division, 1921, pp. 8-9).

1924. "At Pontyclere Colliery, Wales, on 20th Dec., 1924, a collier alleges that he threw a steel wedge into a hole he had made at the entrance to his top hole, and as it struck the floor he saw flame. He ran out and informed the fireman, who on going to the place, found a small flame like a candle rising from the floor, which he put out with his cap. A few inches under the floor is a bed of ironstone, and the inference is that a spark struck by the steel wedge from the ironstone ignited the gas. Safety lamps are used in this colliery."(H.M. Insp. of Mines Rept., Swansea Division, 1924, p. 33).

1925. In the Safety in Mines Research Board Paper, No. 8, on Ignition of Firedamp, by Coward and Wheeler, p. 16, the following paragraph appears:-

> "More recently the ignition of firedamp by frictional sparks has been obtained during experimental work. A locomotive wheel/

wheel was caused to rotate about a stationary axis and a steel rail was held against the rim of the wheel with considerable pressure. With a pressure equal to the weight of one ton, a speed of wheel of 1120 revs. per min., and with frequent sanding of the contacts to produce brilliant sparking, an 8% Firedamp air mixture was not ignited during a trial lasting 20 mins., although the rail became red hot at the point of contact. With half the pressure, however, but with a shield (Metal, Firebrick, Wood, or Paper) to concentrate the sparks, ignition was obtained."

1926. On p. 11, 5th Ann. Rept. of Safety in Mines Research Board, there appears the following:-

"It has been found possible to cause the ignition of fire-damp by rock (sandstone) rubbing against rock and by the continued friction of steel picks against sandstone; not however, by sparks then produced, but by reason of the rubbing surfaces becoming sufficiently heated. It will be understood that considerable power, applied continuously at the same spot, is required to heat rock surfaces in this manner. We have not succeeded in obtaining ignitions of firedamp by sparks from picks and we doubt if they are capable of causing ignition."

1927. In H.M. Insp. of Mines Rept. for the year 1927, pp. 38-40, Mr. J. Masterton directs attention, in view of their importance/

importance to two ignitions of gas which may affect the earlier conclusions summed up in the par. quoted above.

* "At Gartshore 9/11 Colliery, Dumbarton, on 1st July, an electrically driven chain machine was cutting a longwall face in the Coking coal seam, the thickness of which is 2ft. 8in. It lies fairly flat and has an uneven sandstone floor. The holing was being done in the seam, but close to the floor, and the machine was travelling some 15 yds. from the end of the face and was just past the first road, cutting normally and doing well, when at 7.30p.m. flame suddenly appeared from the holing.

"The machine man at once switched off the electric current and got the fireman. When he came some ten minutes later flame was seen under the cut in the coal for a length of about 10 ft. at the rear end of the machine, but by means of flue dust and a piece of brattice cloth this flame was quickly extinguished.

"No electrical defect was found in the machine casing by the colliery electrician, the safety lamps were in order, and the pit is one where all men are searched and where smoking is ruled out. The face was well ventilated. The machineman spoke to having seen sparks coming from the cutting picks, and said that the flame first appeared next the jib on which the chain carrying the picks runs.

"Next day it was found that the cutter picks had partly cut through a Pyrites nodule and that certain of the pick points/

* See Appendix A.

points were in contact with the sandstone floor.

* "The second ignition occurred at Valleyfield Colliery, Fife, on 6th Aug., at 3.30a.m. in the Dunfermline Splint Seam, at a compressed air driven chain coal cutting machine There was a short longwall face in a faulted area, and the machine at the place where the ignition occurred was cutting across hill where the seam rose at an inclination of 1 in 3; the seam being undercut was 2ft. 10ins. thick. Good ventilation was passing and the fireman reported all clear of gas at 2a.m.

"The leading machineman was driving the machine and everything was going smoothly until they reached a roadhead. The second man, son of the leading machineman, was at the back of the machine shovelling out the small coal.

"Suddenly the noise of the picks indicated that something hard had been struck. The leading man was about to release the cam plate to stop the travel of the machine when he saw a flash at the holing. It lit up the place so he stopped operations. He waited at the front of the machine a short time, but the air began to feel warm, so making sure that his son got away first he crawled out himself, went down the road a short distance and sent for the fireman. When he arrived in about 20 minutes time they went back into the place and found there a glow from under the holing along the face. They did not try to extinguish/

* See Appendix A.

extinguish it then, but went to the surface for the officials.

"A hole borer was working between 10 and 20ft. behind the machine when the ignition took place. He also had heard the machine running normally until it seemed to strike something hard. He then saw sparks flying, but not for very long before flames came out with a puff. He was shouting to the machineman 'You have struck something hard' when he saw the ignition. Two flashes of flame came out and struck up to the roof, but the flame must have passed him under the holing, because a small feeder was lit on the opposite side of him. He passed this when getting out, and he then saw gas burning in the holing all the way.

"When the officials were informed of the accident and travelled inbye with the fresh air they encountered this feeder of gas burning at the roof 37ft. from the machine and could see the flames popping out of the holing occasionally. They left the feeder burning, as it was doing no harm, until they got the flames extinguished from the return side, because they did not wish to run the chance of passing unburnt gas on to the flame. They made a careful examination, which took up some time, but it was not then a long job to put out the flames with stone dust. They were extinguished between 7 and 8a.m.

"The/

"The only trace of the ignition left was a slight charring of two straps, one distinctly above the jib of the machine and one where the feeder had been burning, 37ft. back.

"On examination it was seen that the four turned down picks in the chain were all badly worn and they had the appearance of having been almost melted at their points. All the other picks were good.

"In the presence of Mr. Frazer and Mr. Flint, H.M. Inspts., the Agent and other officials of the colliery, the coal was cut by hand off the machine jib, and after a careful examination to ensure the absence of gas the machine was started.

"For a few moments a stream of sparks came from the back of the holing.

"The jib was next swung out and it was seen that the machine had left about 2ins. of the floor coal at the front of the cut, but had dipped down into the pavement at the back and had cut a ridge the shape of the end of the jib about ½in. deep in the white rock pavement.

"The floor was not dead smooth, but had waves or rolls in it, giving a variation in the floor of from 1in. to 2ins.

"There was also at the place where the machine stopped a raised fossil stigmaria, about ¾in. high, which the machine had also touched. The filling of the fossil was of white rock, as hard as the pavement.

"The/

"The conclusion arrived at was that the jib, having touched the pavement, encountered this fossil, with the result that the picks were damaged. The heat produced by the picks on the rock must have raised the points to at least a bright red heat, because part of the metal of two of them had been turned back instead of being abraded.

"Tests made with an ordinary pick demonstrated that it would strike long streams of sparks from the pavement."

1927. At Parabelia Colliery, which is the deepest coal mine in India (1500ft.), an ignition of gas was assigned to sparks from a miner's pick. All other possibilities of ignition being eliminated an examination by the Junr. Insp. of Mines detected a white incrustation on the point of the pick for which he was unable to account. At the place where the miner was working a nodule of ironstone was found, and which produced strong sparks when struck with a pick. (Ann. Rept. of the Chief Insp. of Mines for India, 1927, p. 20).

1927. In the Whinmoor Seam, Tankersley Colliery, Yorkshire, where a machine was cutting in the bottom of the seam, probably on a hard silicious fireclay floor, the machineman noticed a flash come from under the machine jib, it travelled for several yards and came back and continued to burn. Investigations indicate that it is outside the range of possibility that the general body of the air was sufficiently charged with Firedamp to/

to be ignited. Both machinemen were unburned and one had a safety lamp hung from a belt round his neck. (H.M. Insp. Rept., Yorkshire Division, 1927, pp. 39-40).

1929. Mr. John Masterton, H.M. Divisional Insp. for Scotland, makes special reference to further ignitions attributed to sparks, on p. 33 of his 1929 Report. He states:-

* "Once more I have to record two cases of gas having been ignited at the points of picks of chain coal cutting machines. One at Gartshore 9/11 and the other at Kinglassie Colliery, Fife.

"In each case coal cutter was in good order electrically; in each case safety lamps alone were being used; in one case the gas burned for 20 minutes and in the other for 10 minutes. Again, as in former cases, the persons in charge of the coal cutting machines were not injured, but this good fortune is mere chance and can only be due to the absence of gas within reach of the flame of the first ignition, which itself can be of substantial value."

He further refers to two factors which have been common to all the ignitions of Firedamp attributed to sparks from coal cutter picks in Scotland

(1) All ignitions have occurred with chain machines.

(2) All ignitions have occurred in Carboniferous Limestone Series Coal Seams.

He stresses the need of investigation into the causes of sparking/

* See Appendix A.

sparking and points to the urgency of such work, due to the extending use of coal cutters in mines in which inflammable gas occurs.

INFLAMMABILITY OF FIREDAMP.

Previous to entering on an account of the experiments conducted on sparking in inflammable gas mixtures, it is necessary to give some consideration to the nature and behaviour of Firedamp.

<u>Composition.</u> The constituent gases of natural Firedamp found in mines may be divided into two classes

(a) Inflammable

(b) Non-Inflammable.

<u>Inflammable Constituents.</u> The principal inflammable constituent of natural Firedamp is Methane (CH_4). This is usually accompanied by Carbon Monoxide (CO) up to 1%, and possibly but not frequently by a small quantity of the Olefiant Gas Ethylene (C_2H_4) also though rarely by Ethane (C_2H_6), but never more than 2%. The three latter gases when present with Methane in natural Firedamp have practically no effect on the initiation or propagation of a flame in Firedamp-Air mixtures as they are usually present in such small quantities as to be almost immeasurable and can be neglected for all practical tests.

<u>Non-Inflammable Constituents.</u> The non-inflammable constituents of natural Firedamp are Carbon Dioxide (CO_2), Water Vapour and Nitrogen. These exist in widely varying amounts in different samples and may be neglected since the possibility of ignition and propagation of a flame due to sparking, will only be concerned with the inflammable constituents already referred to./

to.

Samples of Firedamp are often almost pure Methane containing up to 99%, hence the tendency to use the terms Firedamp and Methane as synonymous, and since the traces of inflammable gases accompanying Methane may be neglected, there is little objection to the practice. It is also noteworthy that the Methane of natural Firedamp, and that prepared from Methyl Iodide, Aluminium Carbide, or by other laboratory method are identical.

Formation. Firedamp is the highly inflammable gas commonly met with during coal mining operations underground. It is formed by the decomposition of the vegetation from which the coal seams have originated and is released, frequently in large quantities, during the working of the coal. It is a colourless gas without taste or smell and having a spec. grav. of 0.65(Air 1), non-poisonous, but if breathed in quantity, 60% to 70% mixture, is asphyxiating, due to the exclusion of Oxygen.

Limits of Inflammability of Uniform Firedamp and Air Mixtures.

It is an established fact that Firedamp can only be ignited when mixed with suitable proportions of air. Experimental work on an extensive scale has been carried out on the ranges of inflammability of uniform mixtures of Firedamp and Air, hence there is much available information on the subject. The recent work of Messrs. M. J. Burgess and R. V. Wheeler, detailed in the Safety in Mines Research Board Paper, No. 15 entitled/

entitled "The Limits of Inflammability of Firedamp and Air" did much to establish these limits, while in the Safety in Mines Research Board Paper, No. 53 by H. F. Coward and R. V. Wheeler -- Ignition of Firedamp, p. 2 -- the ranges of ignitable mixtures of Firedamp and Air are further defined:-

> "So far as concerns the inflammation of a uniform mixture of Methane and Air, free from other inflammable materials such as coal dust, we know that continued propagation of flame is impossible when the mixture contains less than 5% or more than 15% of Methane, if the mixture is at atmospheric pressure and at any temperature at which work is possible."

When high temperature sources of ignition exist, the limits of inflammability of Firedamp and Air mixtures may be less than 5% or greater than 15%, hence the reason for the cap formed above the flame of an ordinary miner's safety lamp burning when there is only 1½% of Methane present. It should be noted however, that the flame produced by the ignition of such Firedamp and Air mixtures cannot be propagated and is extinguished immediately it is without the influence of the high temperature source of ignition.

The most explosive mixtures of Firedamp and Air -- either from a heat production or flame propagation point of view -- seem to be when there is approximately 9.4% of Firedamp present in the mixture. It is noteworthy, however, that the most explosive mixture is not always the most easily ignited, as/

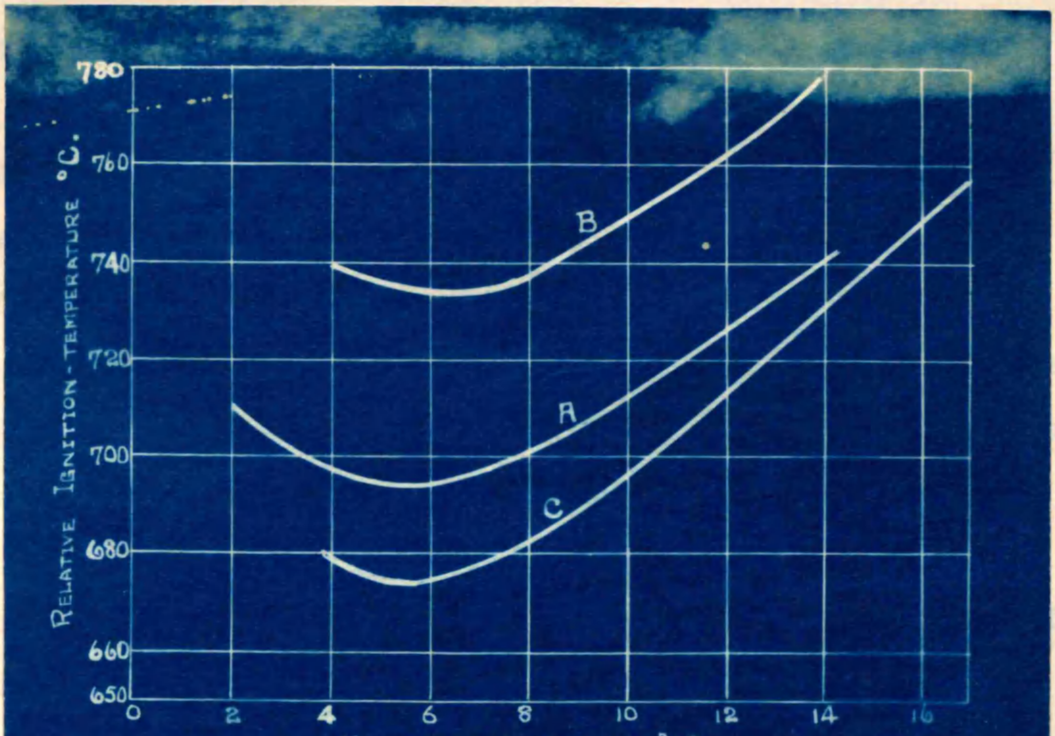
as the latter varies with the means of ignition. The Firedamp-Air mixtures containing 7% of Firedamp are apparently most easily ignited with the majority of sources of ignition. With high tension sparks, however, the most inflammable mixture is that containing 8.3% of Firedamp.

Ignition Temperatures of Firedamp and Air Mixtures.

The Ignition Temperature of Firedamp and Air Mixtures may be defined as the lowest temperature at which flame is produced in the mixtures. There are several factors which influence the value obtained for the Ignition Temperature of such mixtures. For example:-

(a) Source of Heat. If the source of heat is a surface or body there may be a catalytic action which modifies or reduces the Ignition Temperature of the mixtures.

(b) Size of Vessel in which Gas is heated. It has been proved experimentally that the larger the vessel the lower is the Ignition Temperature. This is shown by the graphs in Fig. 1 as taken from a paper on "Ignition of Firedamp"; by H. F. Coward and R. V. Wheeler, p. 9. The values for curve A were obtained when using a vessel of 81 ccs. capacity; curve B, a vessel of 15 ccs. capacity; and curve C, a vessel of 275 ccs. capacity.



Relative Ignition-Temperatures of Mixtures of Methane and Air.

Fig. 1.

(c) Conditions of Heating. If the Methane and Air mixtures are pre-heated separately and then brought together, away from any surface, the Ignition Temperature for any particular mixture is reduced. The values thus obtained range from 650° C to 750° C according to the duration of time the heating is carried out. When such conditions exist the lowest values are obtained for the Ignition Temperatures.

Lag on Ignition of Firedamp and Air Mixtures.

When a source of heat slightly higher in temperature than the Ignition Temperature of a gaseous mixture is introduced into that mixture, it does not follow that ignition results immediately, It is essential to ignition, that, in addition to being of sufficient temperature, the source of heat must remain in contact with the mixtures to which it is imparting heat during a suffiåient time. The time which elapses between the introduction of the necessary source of heat and ignition, is known as "The Lag on Ignition of the Gaseous Mixture."

In Firedamp-Air mixtures the "lag" is greater than with any of the other inflammable gases. For example, mixtures of Firedamp and Air can be maintained during several seconds at temperatures higher than the ignition temperatures of the mixtures without ignition. C. A. Naylor and R. V. Wheeler, Safety in Mines Research Board Paper, No. 9, p. 8, state that:-

> "The lag on ignition, with a number of mixtures containing between 2.5% and 12% Methane, lasted between 10 and 15 secs. when the heated vessel (source of heat) was just at the relative ignition temperature for each mixture. With the vessel at higher temperatures, the lags were of shorter duration; they were constant for a given mixture and could be measured with considerable accuracy."

It should therefore be noted, the more the temperature of the igniting source exceeds the ignition temperature of the gaseous mixture/

mixtures the shorter will be the "lag" on ignition.

The following graphs taken from "The Ignition of Firedamp" by H. F. Coward and R. V. Wheeler, indicate in seconds, the Lag on Ignition of Methane and Air Mixtures, containing from 2% to 24% Methane, at temperatures ranging from 775°C to 1175°C with regular increments of 50°C.

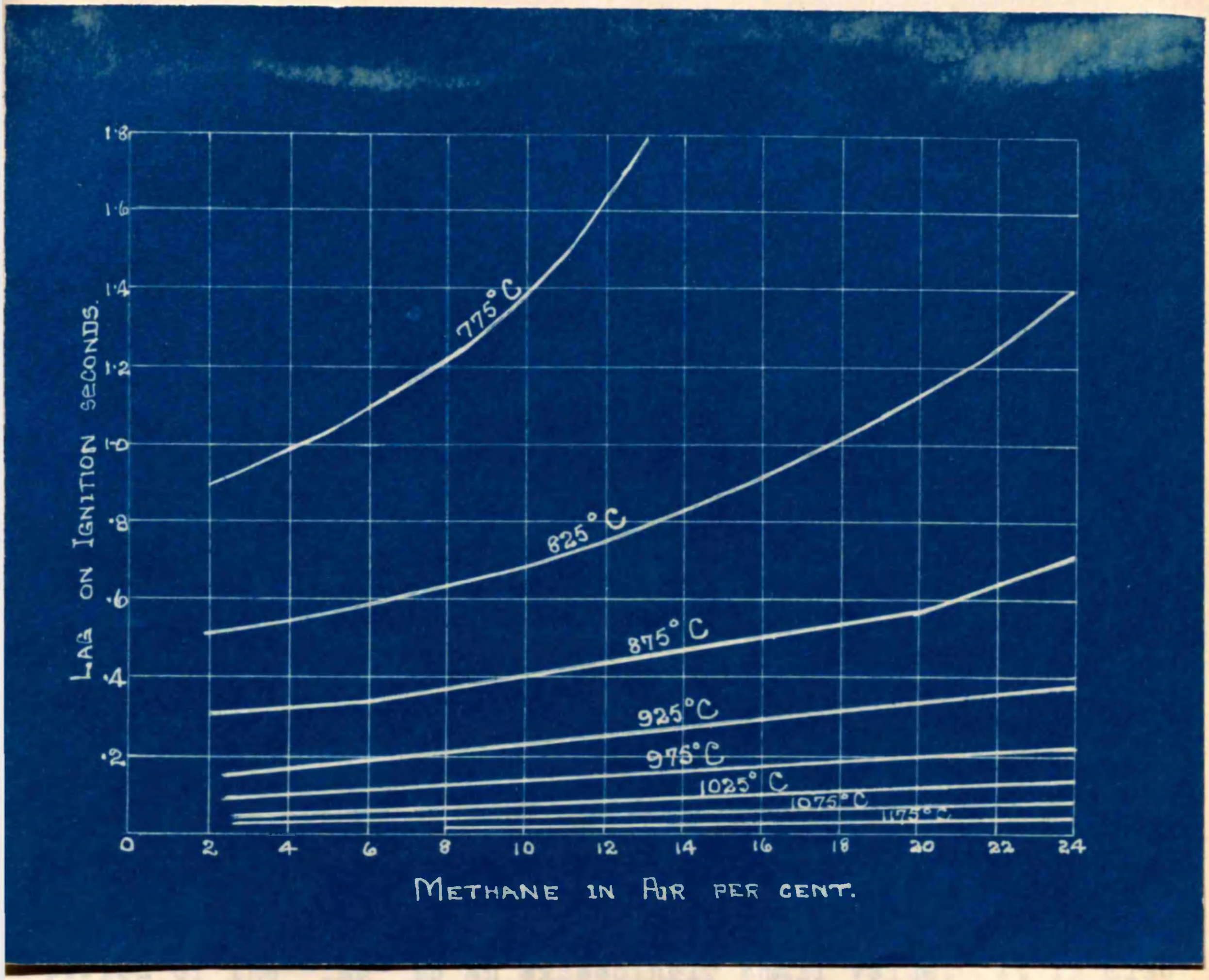


FIG. 2.

The "lag" has an important bearing on the incendivity of

a/

a source of heat with regard to the ignition of Firedamp-Air mixtures.

This was proved experimentally by H. F. Coward and R. V. Wheeler on "Heated Metal Bars" referred to in Safety in Mines Research Paper, No. 53, p. 17. They state that:-

"It is concluded from these experiments that no bar of heated metal is capable of igniting Methane unless its temperature is approaching 1000°C, that is almost white heat. A red hot metal bar would appear quite incapable of igniting Methane."

This is explained by the fact that convection currents which the heated bar set up prevent the particles of Methane-Air mixtures being sufficiently long in contact with the bar to overcome the "lag" and cause ignition.

It has been suggested that the effect of "lag" could be taken advantage of in manufacturing explosives with short duration flames, which would not ignite Firedamp-Air mixtures despite their high temperatures.

Coward and Wheeler, Paper No. 53, p. 23, further suggest that the ability of frictional sparks to ignite Firedamp-Air mixtures must be restricted by their short period of contact with such mixtures. The ignition can only be anticipated when the temperature of the spark is sufficiently high to reduce the period of the "lag" to an exceedingly small value. It is also stated that "possibly even the hottest frictional sparks will be found unable to ignite Firedamp."

GENERAL CONSIDERATIONS

ON

INCENDIVITY OF SPARKS.

It is opportune to describe the sparks under review in the course of this research. The sparks considered are those produced from coal-cutter picks, miner's picks, etc., on hard rock or by the impact or abrasion of rock on rock. These sparks may be described as small particles of solid material, which by friction or impact have become detached from the solid mass and raised to a glow or incandescent state by virtue of the energy expended in their detachment, and may reach a still higher temperature due to rapid oxidation. The mechanical energy expended in spark detachment is partly converted to heating the sparks. Since the sparks are of such a small capacity the heat energy imparted to them can raise their temperatures so that the sparks are brought to incandescence. Should the sparks be of oxidisable material, i.e. iron or steel, their temperatures may reach a still higher value due to the rapid oxidation of their iron contents, and which is hastened by the high temperatures of the sparks themselves. Oxidisable sparks are often completely consumed.

<u>Temperature of Sparks.</u> It is reasonable to assume that the temperature of sparks will depend on:-

(1) <u>Size of Sparks</u>. With other factors constant then the temperature of the sparks will be reduced as the sizes of the sparks increase.

(2) <u>Energy expended in production of Sparks.</u> The temperature of the sparks must depend on the amount of energy expended in their production and the relative part of thatenergy which is converted/

converted to heating the sparks.

(3) Physical Nature of the Material.

(a) Hardness. The harder the material, the fewer and smaller will be the particles or sparks detached by the expending of a given amount of energy, and consequently higher temperatures are reached due to the greater amount of energy available per particle or spark.

(b) Specific Heat.may also influence the temperature of the sparks. The lower the specific heat of the material, the higher will be the temperature of the sparks for a given quantity of heat energy imparted to them.

(c) Oxidation of Material. If the material is readily oxidised there will be a further increase in the heat imparted to the spark with a consequent rise of temperature.

Density of Showers of Sparks. This may have some bearing on the possibility of ignitions of Firedamp due to frictional sparks. The greater the density of the showers of sparks given off, the higher will be the temperature imparted to the mixture in the region of travel of the sparks, and hence the greater probability of ignition.

Possibility of Duration of Sparks overcoming "lag" and causing Ignition. The duration of contact of sparks with uniform inflammable mixtures of Firedamp and Air are comparatively short, therefore, the possibility of the ignition of such mixtures will depend principally on the temperature of the sparks being greatly in excess of the ignition temperature of the/

the mixture to which they are exposed, the excess being such as to reduce the pre-flame period or "lag" to an exceedingly small value.

There may be an ignition of a feeder of gas by frictional sparks when the duration of contact will have a maximum value. For instance, a feeder occurring in the holing cut of a machine, and the picks due to contact with a hard floor or hard material in the seam, are producing streams of sparks travelling in the same direction as the feeder, and if the velocity of the feeder and sparks are the same, then the sparks will be in contact with the same particle or small volume of gas during their whole travel. In this way the period of contact will be increased and may be sufficiently long to overcome the "lag" and cause ignition, assuming of course, that the temperature of the sparks is of the requisite value.

GENERAL LINES

OF

PRESENT RESEARCH.

The following is an outline of the programme of research, which was modified as results indicated.

(1) Investigations as to the possibility of ignition of coal gas by frictional sparks from coal-cutter picks on rock materials. It was presumed that if positive results were obtained then ignition of Firedamp might be possible, the speed of picks being maintained at 300 ft. per minute.

(2) Investigation as to the possibility of ignition of varying Firedamp-Air mixtures by frictional sparks, using the rock materials and picks which gave positive results in No. 1 with the picks at the same speed.

(3) Investigation as to the possibility of ignition of Firedamp-Air mixtures by frictional sparks from low, medium, and high carbon steel picks and at varying peripheral speeds of 300, 360 and 500 ft. per minute. The sandstones used were from Valleyfield Colliery, Fife, and 9/11 Gartshore, Dumbartonshire (where explosions attributed to sparking had occurred), and also an Iron Pyrites from Kirkconnel Colliery. These two sandstones were adopted as a result of correspondence with John Masterton, Esq., H.M. Divisional Insp. of Mines for Scotland, re-frictional sparking explosions.

(4) Additional investigations on No. 3 using a spark concentrator.

(5) Sparking tests with Tungsten steel tipped picks on Kirkconnel Pyrites and 9/11 Gartshore Sandstone in varying Firedamp-Air mixtures. Peripheral speed of picks 500 ft. per minute.

(6) Microscopic examination of rock slides.

(7) Tests comparing the Brinell Hardness of picks and rock materials; consideration of sparking performances and Specific Heat.

(8) Microscopic examination of sparks.

(9) Sparking tests conducted with 9/11 Gartshore Sandstone and Kirkconnel Pyrites on a feeder of Firedamp under conditions similar to a machine holing cut.

APPARATUS.

The apparatus used in the experiments consists principally of a wooden explosions chamber in the form of a cube, having a capacity of 27 cub. ft. (3'x~~3~~'x3') and thoroughly gas tight. On one side of the chamber is fitted an observation window (12" square) with a reflector for the purpose of giving an improved interior view of the chamber during operations. The adjacent side has an opening 12" square, the perimeter of which is raised above the surface of the box, and is fitted with a movable skeleton frame which serves the purpose of holding in position a covering of paper over the opening during tests, and acts as a safety valve when ignition occurs. The gearing for rotating the coal-cutter picks is fitted on a frame bolted to the inside of the chamber, the shaft passing to the outside where the drive is effected. The cutter picks under test are fixed round the circumference of two steel slotted plates or discs, 7" in diameter, bolted together and carried on the shaft. The gearing is so arranged as to give the picks (in a 14" diam. circle) varying peripheral speeds of approximately 230 to 550 ft. per minute. A movable clamp actuated by a strong helical spring on the inside, and controlled by a handle on the outside of the chamber holds the rock materials in position during tests. The spring compels a forward movement and ensures constant contact between the revolving picks and the material under test. The chamber is also fitted with two stop-cocks, one for admitting gaseous mixtures and the other for drawing off samples of the atmosphere/

atmosphere in the chamber; a fan for diffusing gases, and a lighter for testing the ignitability of the atmosphere when negative results are obtained.

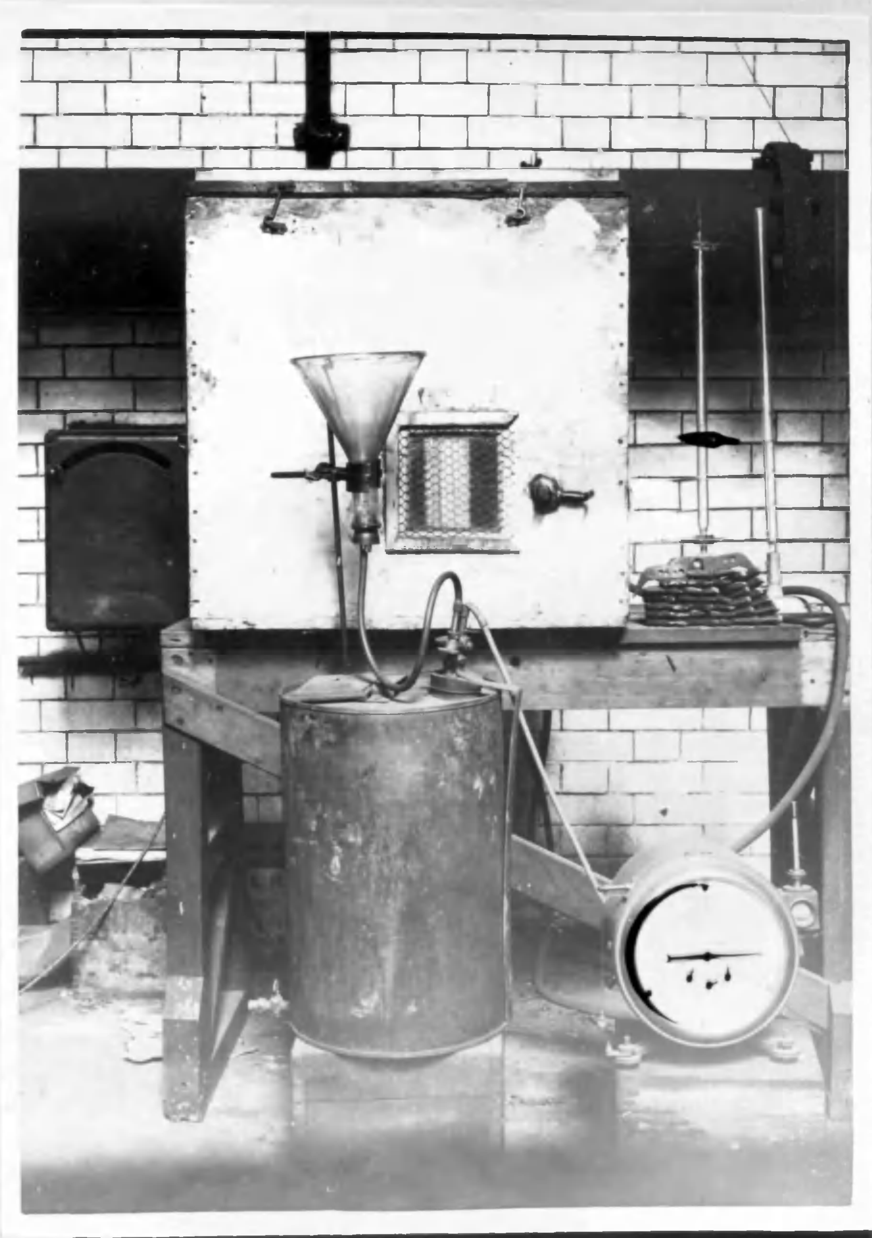


PLATE I.

There is in addition a gasometer for measuring the quantities of gas admitted and specially fitted tanks for the purpose/

purpose of collecting and transporting Firedamp for use in the experiments; burrettes for collecting gas samples; microscope for spark and rock slide examination; camera; heater and

PLATE 2.

calorimeter for specific heat tests.

The gas and steel analysis was carried out in the Mining

and/

and Metallurgical Laboratories. Plate 1 gives a general view of the apparatus, and Plate 2, an interior view of the chamber showing a specimen in position during test.

FIRST SERIES OF TESTS.

TESTS CONDUCTED WITH COAL-CUTTER PICKS AND ROCK MATERIALS IN 10% COAL GAS AND AIR MIXTURES.

Rock Materials. These consist of (a) Sandstones and Fireclays which form the floor or pavement of a wide range of collieries; (b) Iron Pyrites which is found disseminated through the coal seams; (c) Ironstones which are found interbedded with coal seams. During coal getting the coal-cutter and miner's picks unavoidably come in contact with these materials.

The Rock Materials used in the tests were secured from various collieries in Scotland including those where ignitions attributed to frictional sparking occurred. These are as follows:-

Fireclays.

1. Sundrum.
2. Auchenraith.
3. Pennyveenie.
4. Kirkconnel.
5. Gateside.
6. New Cumnock.
7. Grasshill.

Sandstones.

1. Valleyfield.
2. Blairhall.
3. 9/11 Gartshore.
4. 9 Gartshore.
5. Kames.

Pyrites.

1. Kirkconnel.
2. Sundrum.
3. Kirkconnel(Pure)
4. Auchenraith.

Ironstone.

1. Kames(from 7 ft. seam).
2. Kames(from 9 ft. seam).

Coal-Cutter Picks. The ordinary medium carbon variety of steel pick was used. These were kindly supplied by Messrs. Anderson Boyes, Motherwell and Messrs. Mavor and Coulson, Glasgow and taken from the regular stock of these firms. AB_1 and AB_2 indicate/

indicate the two classes of Anderson Boyes picks while MC represents Mavor and Coulson, by which designation they will be hereafter referred to. From an analysis of the picks supplied the following results were obtained:-

	C%	Mn%	Si%	P%
AB_1	0.75.	0.60.	0.025.	0.024.
AB_2	0.60	0.45.	0.023.	0.027.
MC	0.65.	0.40.	0.026.	0.03.

Seven picks were fixed round the periphery of the slotted discs at equal distances apart, the points describing a circle of 14 ins. diameter. The speed of revolution being approximately 80 per min. gave a peripheral speed to the picks of approximately 300 ft. per min.

Explosive Mixture. The atmosphere in the chamber consisted of a 10% mixture of Coal Gas and Air. Coal Gas was used in this series because in all known modes of ignition it has a lower ignition temperature than Firedamp-Air mixtures. Materials which give negative results in Coal Gas and Air mixtures are not likely to give positive results in Firedamp-Air mixtures and may be discarded for further investigations.

The Rock Material was placed in position and the clamp adjusted to the desired position. The chamber was closed, care being taken to see that it was gas tight. The measured quantity of gas was thereafter admitted, and having been diffused by the Fan the gearing was set in motion and continued observations taken through the window. The duration of the tests averaged 5 mins./

5 mins. unless ignition occurred before that time expired, each test being carried out in duplicate.

Table 1, Fireclay; Table 1a, Sandstone; Table 1b, Ironstone, give the results of the tests.

TABLE 1.

Specimen No.	Pick	Material	Results
1.	AB_1	Fireclay (Sundrum Colliery, Coylton, Ayrshire)	No sparks. No ignition.
1.	AB_2	do.	Same result.
1.	MC	do.	Same result.
2.	AB_1	Fireclay (Auchenraith Colliery, Blantyre)	Only an occasional small spark of dull red colour. No ignition.
2.	AB_2	do.	Same result.
2.	MC	do.	Same result.
3.	AB_1	Fireclay (Pennyveenie Colliery, Ayrshire)	Occasional dull red sparks, very small. No ignition.
3.	AB_2	do.	Same result.
3.	MC	do.	Same result.
4.	AB_1	Fireclay (Kirkconnel Colliery)	No sparks. No ignition.
4.	AB_2	do.	Same result.
4.	MC	do.	Same result.
5.	AB_1	Fireclay, very hard (Gateside Colliery, Cambuslang)	Occasional dull red sparks No ignition.
5.	AB_2	do.	Same result.
5.	MC	do.	Same result.

TABLE 1 -- continued.

Specimen No.	Pick	Material	Results
6.	AB_1	Fireclay, very hard. (New Cumnock Colliery)	Small sparks of dull red colour. No ignition.
6.	AB_2	do.	Same result.
6.	MC	do.	Same result.
7.	AB_1	Fireclay, very hard. (Grasshill Colliery, Glenbuck)	Stream of dull red sparks clinging to surface of Fireclay. No ignition.
7.	AB_2	do.	Same result.
7.	MC	do.	Same result.

TABLE 1a

Specimen No.	Pick	Material	Results
1.	AB_1	Hard Sandstone (light grey) Valleyfield Colliery, Fife.	Continuous stream of bright yellow sparks clinging more or less to the Sandstone and forming a glow. Ignition in very short time. (5-10 secs.)
1.	AB_2	do.	Same result.
1.	MC	do.	Same result.
2.	AB_1	Hard Sandstone (light grey) Blairhall Colliery, Fife.	Stream of bright yellow sparks not travelling far from the Sandstone and forming a glow. Ignition in very short time. (5 secs.)
2.	AB_2	do.	Same result.
2.	MC	do.	Same result.
3.	AB_1	Hard Sandstone (light grey) Gartshore 9/11, Dumbarton.	Continuous stream of yellow sparks close to surface of Sandstone forming a glow. Ignition in a short time. (10 secs.)
3.	AB_2	do.	Same result.
3.	MC	do.	Same result.
4.	AB_1	Softer Sandstone Gartshore 9, Dumbarton.	Stream of dull red sparks close to Sandstone. No ignition.
4.	AB_2	do.	Same result.
4.	MC	do.	Same result.

TABLE 1a -- continued.

Specimen No.	Pick	Material	Results.
5.	AB_1	Sandstone (dark grey) Kames Colliery, 30" Seam.	Intermittent sparks of dull red colour. No ignition.
5.	AB_2	do.	Same result.
5.	MC	do.	Same result.

TABLE 1b.

Specimen No.	Pick	Material	Results
1.	AB_1	Ironstone (Clayband) Kames 7 ft. Seam, Muirkirk.	Stream of bright red sparks travelling over chamber. Ignition in short period of time. (10 secs.)
1.	AB_2	do.	Same result.
1.	MC	do. do.	Same result.
2.	AB_1	Ironstone (blackband) Kames 9 ft. Seam, Muirkirk.	Large bright red sparks given off freely and travelling all over chamber. Ignition almost immediately. (5 secs.)
2.	AB_2	do.	Same result.
2.	MC	do.	Same result.
3.	AB_1	Pyrites disseminated thro' coal in thin layers. Kirkconnel Colliery.	Occasional bright red sparks No ignition.
3.	AB_2	do.	Same result.
3.	MC	do.	Got ignition with this pick; dup. tests could not repeat it.
4.	AB_1	Pyrites disseminated through coal. Sundrum Colliery.	Occasional red sparks. No ignition.
4.	AB_2	do.	Same result.
4.	MC	do.	Same result.

TABLE 1b -- continued.

Specimen No.	Pick	Material	Results
5.	AB_1	Pure Pyrites. Kirkconnel Colliery.	Streams of very bright yellow sparks of star-like appearance rebounding off sides of chamber. Ignition immediately. (5-10 secs.)
5.	AB_2	do.	Same result.
5.	MC	do.	Same result.
6.	AB_1	Pure Pyrites Auchenraith Colliery Blantyre.	Abundance of bright yellow sparks thrown all over chamber. Ignition immediately. (5 secs.)
6.	AB_2	do.	Same result.
6.	MC	do.	Same result.

SUMMARY OF TESTS.

FIRST SERIES.

Seven different specimens of Fireclay, ranging from soft to very hard, were used throughout 42 tests. Sparking was infrequent and no ignition occurred during any of the tests. It may therefore be concluded that explosive mixtures of Coal Gas and Air, under the conditions of these tests, cannot be ignited by frictional sparks produced by coal-cutter picks striking Fireclay. This conclusion dispelis any suggestion of ignition of Firedamp and Air mixtures by frictional sparking, since the ignition temperatures of such mixtures (in all known modes of ignition) is higher than that of Coal Gas and Air mixtures. From these results I concluded that further investigation is unnecessary. ???

Thirty tests were made with five different specimens of Sandstone, Nos. 1, 2, and 3, were of a light grey colour, and hard and came from 9/11 Gartshore Colliery, Dumbartonshire, Blairhall Colliery, Fife, and Valleyfield Colliery, Fife. Uniform sparking of a yellowish colour occurred with each of the specimens mentioned, the sparks being inclined to cling to the sandstone at the point of contact with the picks, giving the appearance of one continuous spark, while occasional large sparks travelled further afield. In each case ignition was more or less immediate. Specimen No. 4 was softer than the others and was taken from an area at present being worked in 9 Gartshore. Sparking was not sustained with this specimen and ignition did not occur. No. 5 was from the roof of the 30" Seam, Kames Colliery/

Colliery, Muirkirk, and was inclined to be hard. It was of a greyish brown colour and sparking was intermittent, the sparks being of a dull red colour. Ignition did not occur with this specimen.

Thirty-six tests were made with six different specimens of Ironstone. Nos. 1 and 2 were Blackband and Clayband respectively which are found interbedded with coal seams in Muirkirk district, The former contains a lot of carbonaceous matter. Nos. 5 and 6 were specimens of Pure Pyrites and very hard. No. 5 was from Kirkconnel Colliery, and was a very large tree fossil, the markings of which suggested Lepidodendron, while No. 6 was from a lenticle in the seam at Auchenraith Colliery, Blantyre. Sparking was intensive with all four specimens and ignitions occurred almost immediately. The remaining two specimens were what might be termed coaly brasses, being an intimate mixture of coal and pyrites, the pyrites being in thin layers. Sparking was not general with either specimen. While using an MC pick, an ignition occurred with number three but could not be repeated in duplicate tests. It may be that, in this instance, one of the picks struck a hard part in the Pyrites, and produced a spark of sufficient intensity to ignite the gaseous mixture. With No. 4 no ignition resulted.

The results in this series of tests suggest, that frictional sparks from coal-cutter picks in contact with the aforementioned Sandstones and Ironstones are capable of igniting Coal Gas and Air/

Air mixtures. During the course of observations it was sometimes possible to trace the origin of the ignitions. Sometimes large sparks leaving the pick points could be fixed in the vision and followed to where they landed inside the chamber, and observe that at the moment of landing an ignition was initiated at that point, while in other cases the ignition seemed to occur at the spark as it travelled in space. The short interval which existed in many cases, between the commencement of the test and ignition does not lend support to a possibility of initiation of ignition being the result of frictional heat produced by the rubbing of the pick and rock material.

The following represents the average composition of the Coal Gas used in the tests.

CO_2 5.4%

C_nH_{2n} 2.4%

O_2 0.6%

CO 15.0%

H_2 44.3%

CH_4 21.8%

N_2 10.5%.

SECOND SERIES OF TESTS.

TESTS CONDUCTED WITH COAL-CUTTER PICKS AND ROCK MATERIALS IN VARYING EXPLOSIVE MIXTURES OF FIREDAMP AND AIR.

For the purpose of the Second Series of Tests, the Apparatus and Medium Carbon Steel Picks were as described in the first series. The rock materials under test being those which gave positive results in that series and a few additional tests with materials which gave negative results.

The procedure and conditions were also similar, with a change in the atmosphere of the chamber to that of an explosive mixture of natural Firedamp and Air. The composition of the atmosphere in the chamber was successively varied in proportion of 5% to 10% of natural Firedamp, the increments being in stages of 1% up to 9%, and of 0.5% thereafter. On each occasion that no ignition occurred, the explosibility of the atmosphere was tested by means of a lighter in the chamber.

The natural Firedamp for these and subsequent tests, was obtained through the kindness of Mr. John Mc Kechnie, Millbrae, Chryston.

An analysis of samples from the drums of natural Firedamp was made periodically, and the following may be taken as a representative composition:-

CH_4	82.4%
O_2	5.0%
CO	0.60%
N_2	12.0%

Calorific Value, 780 British Thermal Units.

Table 2 gives the results of the tests made.

EXPERIMENTS WITH ROCK MATERIALS AND COAL-CUTTER PICKS IN 5% FIREDAMP-AIR MIXTURE.

TABLE 2. SANDSTONES.

Specimen No.	Pick	% CH_4	Material	Results
1.	AB_1	5	Hard Sandstone (light grey) Valleyfield Colliery, Fife.	Stream of yellow sparks clinging more or less to Sandstone and forming glow at point of contact. No ignition.
1.	AB_2	5	do.	Same result.
1.	MC	5	do.	Same result.
2.	AB_1	5	Hard Sandstone (light grey) Blairhall Colliery, Fife.	Continuous stream of yellow sparks clinging to the Sandstone and forming a glow at point of contact. No ignition.
2.	AB_2	5	do.	Same result.
2.	MC	5	do.	Same result.
3.	AB_1	5	Hard Sandstone (light grey) Gartshore 9/11, Dumbarton.	Stream of yellow sparks close to surface of Sandstone and causing a glow at point of contact No ignition.
3.	AB_2	5	do.	Same result.
3.	MC	5	do.	Same result.
4.	AB_1	5	Softer Sandstone Gartshore 9, Dumbarton.	Dull red sparks close to Sandstone. No ignition.
4.	AB_2	5	do.	Same result.
4.	MC	5	do.	Same result.

TABLE 2. SANDSTONES -- cont.

Specimen No.	Pick	% CH_4	Material	Results
5.	AB_1	5	Sandstone (grey brown) Kames Colliery, 30" Seam.	Occasional sparks -- dull red colour. No ignition.
5.	AB_2	5	do.	Same result.
5.	MC	5	do.	Same result.

TABLE 2. IRONSTONES.

Specimen No.	Pick	% CH_4	Material	Results
1.	AB_1	5	Ironstone (Clayband) Kames 7 ft. Seam, Muirkirk.	Abundahce of bright red sparks travelling all over chamber. No ignition.
1.	AB_2	5	do.	Same result.
1.	MC	5	do.	Same result.
2.	AB_1	5	Ironstone (Blackband) Kames 9 ft. Seam, Muirkirk.	Sparking freely. Large bright red sparks travelling all over chamber. No ignition.
2.	AB_2	5	do.	Same result.
2.	MC	5	do.	Same result.
3.	AB_1	5	Pyrites disseminated through coal in thin layers. Kirkconnel Colliery.	Occasional bright red sparks No ignition.
3.	AB_2	5	do.	Same result.
3.	MC	5	do.	Same result.

TABLE 2. IRONSTONES -- cont.

Specimen No.	Pick	% CH_4	Material	Results
4.	AB_1	5	Pyrites disseminated through coal in thin layers. Sundrum Colliery, Coylton.	Occasional red sparks. No ignition.
4.	AB_2	5	do.	Same result.
4.	MC	5	do.	Same result.
5.	AB_1	5	Pure Pyrites. Kirkconnel Colliery.	Streams of very bright yellow star-like sparks rebounding off sides of chamber. No ignition.
5.	AB_2	5	do.	Same result.
5.	MC	5	do.	Sameresult.
6.	AB_1	5	Pure Pyrites Auchenraith Colliery Blantyre.	Abundance of bright yellow star-like sparks given off. No ignition.
6.	AB_2	5	do.	Same result.
6.	MC	5	do.	Same result.

EXPERIMENTS WITH ROCK MATERIALS

AND

COAL-CUTTER PICKS IN 6% FIREDAMP-AIR MIXTURE.

TABLE 2. SANDSTONES.

Specimen No.	Pick	% CH_4	Material	Results
1.	AB_1	6	Hard Sandstone (light grey) Valleyfield Colliery, Fife.	Stream of yellow sparks clinging to surface of Sandstone and causing a glow on surface. No ignition.
1.	AB_2	6	do.	Same result.
1.	MC	6	do.	Same result.
2.	AB_1	6	Hard Sandstone (light grey) Blairhall Colliery, Fife.	Stream of yellow sparks not travelling far from Sandstone and forming a glow on the surface. No ignition.
2.	AB_2	6	do.	Same result.
2.	MC	6	do.	Same result.
3.	AB_1	6	Hard Sandstone (light grey) Gartshore 9/11, Dumbarton.	Stream of sparks close to surface of Sandstone and forming a glow. No ignition.
3.	AB_2	6	do.	Same result.
3.	MC	6	do.	Same result.
5.	AB_1	6	Sandstone (grey brown) Kames Colliery, 30" Seam.	Occasional dull red sparks. No ignition.
5.	AB_2	6	do.	Same result.
5.	MC	6	do.	Same result.

TABLE 2. IRONSTONES.

Specimen No.	Pick	% CH_4	Material	Results
1.	AB_1	6	Ironstone (Clayband) Kames 7 ft. Seam, Muirkirk.	Free sparking. Bright red sparks travelling all over chamber. No ignition.
1.	AB_2	6	do.	Same result.
1.	MC	6	do.	Same result.
2.	AB_1	6	Ironstone (Blackband) Kames 9 ft. Seam, Muirkirk.	Large bright red sparks travelling over chamber. No ignition.
2.	AB_2	6	do.	Same result.
2.	MC	6	do.	Same result.
5.	AB_1	6	Pure Pyrites. Kirkconnel Colliery,	Abundance of bright yellow sparks travelling all over chamber and rebounding off sides. No ignition.
5.	AB_2	6	do.	Same result.
5.	MC	6	do.	Same result.
6.	AB_1	6	Pure Pyrites. Auchenraith Colliery, Blantyre.	Abundance of bright yellow sparks given off freely. No ignition.
6.	AB_2	6	do.	Same result.
6.	MC	6	do.	Same result.

EXPERIMENTS WITH ROCK MATERIALS

AND

COAL-CUTTER PICKS IN 7% FIREDAMP-AIR MIXTURE.

TABLE 2. SANDSTONES.

Specimen No.	Pick	% CH_4	Material	Results.
1.	AB_1	7	Hard Sandstone (light grey) Valleyfield Colliery, Fife.	Continuous stream of yellow sparks clinging to surface of Sandstone and forming a glow. No ignition.
1.	AB_2	7	do.	Same result.
1.	MC	7	do.	Same result.
2.	AB_1	7	Hard Sandstone (light grey) Blairhall Colliery, Fife.	Stream of yellow sparks clinging to surface of Sandstone and forming a glow. No ignition.
2.	AB_2	7	do.	Same result.
2.	MC	7	do.	Same result.
3.	AB_1	7	Hard Sandstone (light grey) Gartshore 9/11, Dumbarton.	Stream of yellow sparks clinging to Sandstone and forming a glow. No ignition.
3.	AB_2	7	do.	Ignition in about 90 secs.
3.	MC	7	do.	No ignition.
5.	AB_1	7	Sandstone (grey brown) Kames Colliery, 30" Seam.	Occasional dull red sparks. No ignition.
5.	AB_2	7	do.	Same result.
5.	MC	7	do.	Same result.

TABLE 2. IRONSTONES.

Specimen No.	Pick	% CH_4	Material	Results
1.	AB_1	7	Ironstone (Clayband) Kames 7 ft. Seam, Muirkirk.	Bright red sparks travelling over chamber. No ignition.
1.	AB_2	7	do.	Same result.
1.	MC	7	do.	Same result.
2.	AB_1	7	Ironstone (Blackband) Kames 9 ft. Seam, Muirkirk.	Bright red sparks given off freely and travelling all over chamber. No ignition.
2.	AB_2	7	do.	Same result.
2.	MC	7	do.	Same result.
5.	AB_1	7	Pure Pyrites Kirkconnel Colliery.	Bright yellow star-like sparks travelling all over chamber. No ignition.
5.	AB_2	7	do.	Same result.
5.	MC	7	do.	Same result.
6.	AB_1	7	Pure Pyrites Auchenraith Colliery, Blantyre.	Bright yellow star-like sparks given off freely and rebounding off sides of chamber. No ignition.
6.	AB_2	7	do.	Same result.
6.	MC	7	do.	Same result.

EXPERIMENTS WITH ROCK MATERIALS

AND

COAL-CUTTER PICKS IN 8% FIREDAMP-AIR MIXTURE.

TABLE 2. SANDSTONES.

Specimen No.	Pick	% CH_4	Material	Results
1.	AB_1	8	Hard Sandstone (light grey) Valleyfield Colliery, Fife.	Stream of yellow sparks close to Sandstone and forming a glow on surface. No ignition.
1.	AB_2	8	do.	Same result.
1.	MC	8	do.	Same result.
2.	AB_1	8	Hard Sandstone (light grey) Blairhall Colliery, Fife.	Yellow sparks clinging to close to Sandstone and forming a glow at surface. No ignition.
2.	AB_2	8	do.	Same result.
2.	MC	8	do.	Same result.
3.	AB_1	8	Hard Sandstone (light grey) Gartshore 9/11, Dumbarton.	Yellow sparks clinging to Sandstone and forming a glow at surface. No ignition.
3.	AB_2	8	do.	Same result.
3.	MC	8	do.	Same result.

TABLE 2. IRONSTONES.

Specimen No.	Pick	% CH_4	Material	Results
1.	AB_1	8	Ironstone (Clayband) Kames 7 ft. Seam, Muirkirk.	Bright red sparks travelling all over chamber. No ignition.
1.	AB_2	8	do.	Same result.
1.	MC	8	do.	Same result.
2.	AB_1	8	Ironstone (Blackband) Kames 9 ft. Seam, Muirkirk.	Bright red sparks given off freely. No ignition.
2.	AB_2	8	do.	Same result.
2.	MC	8	do.	Same result.
5.	AB_1	8	Pure Pyrites Kirkconnel Colliery,	Abundance of bright yellow sparks travelling all over chamber. No ignition.
5.	AB_2	8	do.	Same result.
5.	MC	8	do.	Same result.
6.	AB_1	8	Pure Pyrites Auchenraith Colliery, Blantyre.	Bright yellow sparks given off freely. No ignition.
6.	AB_2	8	do.	Same result.
6.	MC	8	do.	Same result.

EXPERIMENTS WITH ROCK MATERIALS

AND

COAL-CUTTER PICKS IN 9% FIREDAMP-AIR MIXTURE.

TABLE 2. SANDSTONES.

Specimen No.	Pick	% CH_4	Material	Results
1.	AB_1	9	Hard Sandstone (light grey) Valleyfield Colliery, Fife.	Stream of yellow sparks close to surface of Sandstone and forming a glow. No ignition.
1.	AB_2	9	do.	Same result.
1.	MC	9	do.	Same result.
2.	AB_1	9	Hard Sandstone (light grey) Blairhall Colliery, Fife.	Yellow sparks clinging to Sandstone and forming a glow. No ignition.
2.	AB_2	9	do.	Same result.
2.	MC	9	do.	Same result.
3.	AB_1	9	Hard Sandstone (light grey) Gartshore 9/11, Dumbarton.	Yellow sparks clinging to surface of Sandstone and forming a glow. No ignition.
3.	AB_2	9	do.	Same result.
3.	MC	9	do.	Same result.

TABLE 2. IRONSTONES.

Specimen No.	Pick	% CH_4	Material	Results
1.	AB_1	9	Ironstone (Clayband) Kames 7 ft. Seam, Muirkirk.	Bright red sparks travelling all over chamber. No ignition.
1.	AB_2	9	do.	Same result.
1.	MC	9	do.	Same result.
2.	AB_1	9	Ironstone (Blackband) Kames 9 ft. Seam, Muirkirk.	Bright red sparks given off freely and travelling all over chamber. No ignition.
2.	AB_2	9	do.	Same result.
2.	MC	9	do.	Same result.
5.	AB_1	9	Pure Pyrites Kirkconnel Colliery.	Bright yellow star-like sparks given off freely. No ignition.
5.	AB_2	9	do.	Same result.
5.	MC	9	do.	Same result.
6.	AB_1	9	Pure Pyrites Auchenraith Colliery, Blantyre.	Abundance of bright yellow star-like sparks given off freely. No ignition.
6.	AB_2	9	Do.	Same result.
6.	MC	9	do.	Same result.

EXPERIMENTS WITH ROCK MATERIALS

AND

COAL-CUTTER PICKS IN 9.5% FIREDAMP-AIR MIXTURE.

TABLE 2. SANDSTONES.

Specimen No.	Pick	% CH_4	Material	Results
1.	AB_1	9.5	Hard Sandstone (light grey) Valleyfield Colliery, Fife.	Yellow sparks clinging to surface of Sandstone and forming a glow. No ignition.
1.	AB_2	9.5	do.	Same result.
1.	MC	9.5	do.	Same result.
2.	AB_1	9.5	Hard Sandstone (light grey) Blairhall Colliery, Fife.	Stream of yellow sparks clinging to surface of sandstone and forming a glow. No ignition.
2.	AB_2	9.5	do.	Same result.
2.	MC	9.5	do.	Same result.
3.	AB_1	9.5	Hard Sandstome (light grey) Gartshore 9/11, Dumbarton.	Stream of yellow sparks clinging to surface of Sandstone and causing a glow. No ignition.
3.	AB_2	9.5	do.	Same result.
3.	MC	9.5	do.	Same result.

TABLE 2. IRONSTONES.

Specimen No.	Pick	% CH_4	Material	Results
1.	AB_1	9.5	Ironstone (Clayband) Kames 7 ft. Seam, Muirkirk.	Bright red sparks given off freely and travelling all over chamber. No ignition.
1.	AB_2	9.5	do.	Same result.
1.	MC	9.5	do.	Same result.
2.	AB_1	9.5	Ironstone (Blackband) Kames 9 ft. Seam, Muirkirk.	Abundance of bright red sparks given off. No ignition.
2.	AB_2	9.5	do.	Same result.
2.	MC	9.5	do.	Same result.
5.	AB_1	9.5	Pure Pyrites Kirkconnel Colliery,	Bright yellow star-like sparks given off abundantly and rebounding off sides of chamber. No ignition.
5.	AB_2	9.5	do.	Same result.
5.	MC	9.5	do.	Same result.
6.	AB_1	9.5	Pure Pyrites Auchenraith Colliery, Blantyre.	Bright yellow star-like sparks given off freely and travelling all over chamber. No ignition.
6.	AB_2	9.5	do.	Same result.
6.	MC	9.5	do.	Same result.

EXPERIMENTS WITH ROCK MATERIALS

AND

COAL-CUTTER PICKS IN 10% FIREDAMP-AIR MIXTURE.

TABLE 2. SANDSTONES.

Specimen No.	Pick	% CH_4	Material	Results
1.	AB_1	10	Hard Sandstone (light grey) Valleyfield Colliery, Fife.	Yellow sparks clinging close to Sandstone surface and forming a glow. No ignition.
1.	AB_2	10	do.	Same result.
1.	MC	10	do.	Same result.
2.	AB_1	10	Hard Sandstone (light grey) Blairhall Colliery, Fife.	Stream of yellow sparks close to surface of Sandstone and forming a glow. No ignition.
2.	AB_2	10	do.	Same result.
2.	MC	10	do.	Same result.
3.	AB_1	10	Hard Sandstone (light grey) Gartshore 9/11, Dumbarton.	Stream of yellow sparks clinging to surface of Sandstone and forming glow. No ignition.
3.	AB_2	10	do.	Same result.
3.	MC	10	do.	Same result.

TABLE 2. IRONSTONES.

Specimen No.	Pick	% CH_4	Material	Results
1.	AB_1	10	Ironstone (Clayband) Kames 7 ft. Seam, Muirkirk.	Abundance of bright red sparks given off freely and travelling all over chamber. No ignition.
1.	AB_2	10	do.	Same result.
1.	MC	10	do.	Same result.
2.	AB_1	10	Ironstone (Blackband) Kames 9 ft. Seam, Muirkirk.	Bright red sparks given off freely. No ignition.
2.	AB_2	10	do.	Sam e Result.
2.	MC	10	do.	Same result.
5.	AB_1	10	Pure Pyrites Kirkconnel Colliery.	Bright yellow star-like sparks given off freely and rebounding off sides of chamber. No ignition.
5.	AB_2	10	do.	Same result.
5.	MC	10	do.	Same result.
6.	AB_1	10	Pure Pyrites Auchenraith Colliery, Blantyre.	Abundance of bright yellow star-like sparks given off freely. No ignition.
6.	AB_2	10	do.	Same result.
6.	MC	10	do.	Same result.

SUMMARY OF TESTS.

SECOND SERIES.

Over 150 tests were conducted in this Series, at a speed of 300 ft. per min., and Sparking was general throughout.

Only in one test did an ignition occur when an AB_2 (.6C) steel pick was being used on hard sandstone from 9/11 Gartshore Colliery, Dumbartonshire, in a 7% Firedamp-Air Mixture. Duplicate tests were made, in this particular case, but ignition did not repeat.

At this stage some tests were made with Firedamp, taken from the boreholes in the coal at 9/11 Gartshore, Dumbartonshire, and supplied by the kindness of Mr. Neil Mc Calpine, Manager, but here again no ignitions occurred.

The following is an analysis of the Firedamp from 9/11 Gartshore:-

CH_4	75.00%
CO_2	4.44%
O_2	1.37%
N_2	19.19%

THIRD SERIES OF TESTS.

TESTS WITH 0.5%, 0.65%, AND 0.9% CARBON STEEL COAL-CUTTER PICKS AND ROCK MATERIALS AT VARYING SPEEDS IN EXPLOSIVE MIXTURES OF FIREDAMP AND AIR.

The general conditions and apparatus were as described under the First Series of Tests.

The coal-cutter picks used were manufactured from 0.5% and 0.9% Carbon Steel, supplied by the kindness of Messrs. David Colville and Son, Ltd., Dalzell Steel Works, Motherwell, and MC (.65% Carbon) steel pick. The former picks are lower and higher respectively in Carbon contents than the usual coal-cutter picks. The following is the respective composition of the three steel picks:-

Lower Carbon Steel		Medium Carbon Steel		Higher Carbon Steel	
Carbon	0.51%	Carbon	0.65%	Carbon	0.90%
Silicon	0.13%	Silicon	0.26%	Silicon	0.12%
Sulphur	0.031%	Sulphur	0.028%	Sulphur	0.031%
Phosphorus	0.010%	Phosphorus	0.03%	Phosphorus	0.043%
Manganese	0.83%	Manganese	0.40%	Manganese	0.52%

The rock materials under test were those of 9/11 Gartshore Colliery, Dumbartonshire, Valleyfield Colliery, Fife, and Kirkconnel Colliery.

Three different peripheral speeds of the picks, i.e. 300, 360, and 500 ft. per min., were employed on each of the rock materials tested; the latter speed being slightly greater than that of modern coal-cutters where the tendency is to increase the speed of the chain or disc carrying the picks so that the motor can be reduced to the minimum size.

The atmosphere of the chamber consisted of mixtures of Natural/

Natural Firedamp and Air, varying from 6.5% to 7.5% by 0.5% increments, this being in the range of the most easily ignitable mixtures. The procedure was the same as pertained to former tests.

Table 3 gives the results of the tests.

TESTS WITH (LOWER 0.51 CARBON) STEEL PICK.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
.51C	6.5	Approx. 300 ft. per min.	Hard Sandstone Gartshore 9/11, Dumbarton.	Stream of pale yellow sparks clinging more or less to surface of Sandstone and forming a glow at the point of contact. Intermittent sparks travelling further afield. No ignition.
.51C	6.5	Approx. 360 ft. per min.	do.	Stream of pale yellow sparks clinging to surface of Sandstone and causing a glow. Larger sparks travelling close together and going further afield. No ignition.
.51C	6.5	Approx. 500 ft. per min.	do.	Continuous stream of pale yellow sparks close to surface of Sandstone and forming a glow or pale yellow flash. Sparks crowded together travelling further afield. No ignition.
.51C	5.6	Approx. 300 ft. per min.	do.	Stream of pale yellow sparks clinging to surface of Sandstone and forming a glow. Intermittent sparks travelling further afield. No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of picks	Material	Results
.51C	7.0	Approx. 360 ft. per min.	Hard Sandstone Gartshore 9/11, Dumbarton.	Stream of pale yellow sparks clinging to surface of Sandstone and causing a continuous spark. Other sparks travelling further afield. No ignition.
.51C	7.0	Approx. 500 ft. per min.	do.	Continuous stream of pale yellow sparks clinging close to Sandstone and forming a glorified spark or yellow flash. Other sparks close together travelling further afield. No ignition.
.51C	7.5	Approx. 300 ft. per min.	do.	Stream of pale yellow sparks clinging to surface of Sandstone and forming a glow. Occasional sparks travelling further afield. No ignition.
.51C	7.5	Approx. 360 ft. per min.	do.	Stream of pale yellow sparks clinging to surface of Sandstone and causing a continuous spark or yellow flash. Other sparks close together travelling further afield. No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
.51C	7.5	Approx. 500 ft. per min.	Hard Sandstone Gartshore 9/11, Dumbarton.	Continuous sparking close to Sandstone surface and forming a yellow flash or continuous spark. Other sparks crowded together go further afield. No ignition.
.51C	6.5	Approx. 300 ft. per min.	Hard Sandstone Valleyfield, Fife.	Stream of pale yellow sparks clinging to surfacecof Sandstone and forming a glow. Occasional sparks travelling further afield. No ignition.
.51C	6.5	Approx. 360 ft. per min.	do.	Stream of pale yellow sparks clinging to surface of Sandstone and forming a continuous spark or glow. Other sparks travelling further afield. No ignition.
.51C	6.5	Approx. 500 ft. per min.	do.	Stream of yellow sparks close to Sandstone surface and forming a glorified spark or flash. Crowded sparks travel further afield. No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
.51C	7.0	Approx. 300 ft. per min.	Hard Sandstone Valleyfield, Fife.	Stream of pale yellow sparks close to surface of Sandstone and causing a glow. Some sparks travelling further afield. No ignition.
.51C	7.0	Approx. 360 ft. per min.	do.	Stream of pale yellow sparks clinging to surface of Sandstone and forming a glow or continuous spark. Other sparks travelling further afield. No ignition.
.51C	7.0	Approx. 500 ft. per min.	do.	Continuous stream of pale yellow sparks clinging to surface of Sandstone and causing a yellow flash or glow. Crowded sparks travelling further afield. No ignition.
.51C	7.5	Approx. 300 ft. per min.	do.	Stream of pale yellow sparks given off close to surface of Sandstone. The larger ones travelling further afield. No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
.51C	7.5	Approx. 360 ft. per min.	Hard Sandstone Valleyfield, Fife.	Stream of pale yellow sparks close to surface of Sandstone and causing a glorified spark or glow. Other sparks travelling further afield. No ignition.
.51C	7.5	Approx. 500 ft. per min.	do.	Continuous stream of pale yellow sparks clinging to Sandstone surface and forming a glow or flash. Additional sparks crowded together travelling further afield. Ignition.
.51C	6.5	Approx. 300 ft. per min.	Pure Pyrites Kirkconnel.	Bright whitish yellow shower of star-like sparks given off and travelling over chamber in all directions. No ignition.
.51C	6.5	Approx. 360 ft. per min.	do.	Showers of bright whitish yellow star-like sparks given off and travelling in all directions over chamber. No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
.51C	6.5	Approx. 500 ft. per min.	Pure Pyrites Kirkconnel.	Continuous stream of bright whitish yellow star-like sparks given off in all directions and rebounding off sides of chamber. No ignition.
.51C	7.0	Approx. 300 ft. per min.	do.	Bright whitish yellow showers of star-like sparks given off in all directions. No ignition.
.51C	7.0	Approx. 360 ft. per min.	do.	Showers of bright whitish yellow star-like sparks given off in all directions. No ignition.
.51C	7.0	Approx. 500 ft. per min.	do.	Continuous stream of bright whitish yellow star-like sparks given off in all directions and rebounding all over chamber. Ignition.
.51C	7.5	Approx. 300 ft. per min.	do.	Stream of bright whitish yellow sparks given off in all directions. No ignition.

TABLE 3.

Speed Pick	% CH_4	Peripheral Speed of Picks	Material	Results
.510	7.5	Approx. 360 ft. per min.	Pure Pyrites Kirkconnel.	Showers of bright whitish yellow sparks given off in all directions. No ignition.
.510	7.5	Approx. 500 ft. per min.	do.	Abundant showers of bright whitish yellow sparks given off in all directions and rebounding off sides of chamber. No ignition.

TESTS WITH (MEDIUM 0.65 CARBON) MC STEEL PICK.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
MC .65C	6.5	Approx. 300 ft. per min.	Hard Sandstone Gartshore 9/11, Dumbarton.	Stream of yellow sparks close to surface of Sandstone and forming a glow or continuous spark. No ignition.
MC .65C	6.5	Approx. 360 ft. per min.	do.	Stream of yellow sparks close to surface of Sandstone and causing a glow. Some of larger sparks travelling further afield. No ignition.
MC .65C	6.5	Approx. 500 ft. per min.	do.	Continuous stream of yellow sparks travelling close to surface of Sandstone and forming a continuous or glorified spark. Larger sparks close together travelling further afield. No ignition.
MC .65C	7.0	Approx. 300 ft. per min.	do.	Stream of yellow sparks close to surface of Sandstone and causing a glow or continuous spark. No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
MC .6&C	7.0	Approx. 360 ft. per min.	Hard Sandstone Gartshore 9/11, Dumbarton.	Stream of yellow sparks close to surface of Sandstone and forming a glow. Larger sparks travelling further afield. No ignition.
MC .65C	7.0	Approx. 500 ft. per min.	do.	Continuous stream of yellow sparks travelling close to surface of Sandstone and forming a continuous or glorified yellow spark. Karger sparks crowded together travelling further afield. Ignition.
MC .65C	7.5	Approx. 300 ft. per min.	do.	Stream of yellow sparks close to surface of Sandstone and forming a glow. No ignition.
MC .65C	7.5	Approx. 360 ft. per min.	do.	Stream of yellow sparks close to surface of Sandstone and causing a glow. Some of the larger sparks travelling further afield. No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
MC .65C	7.5	Approx. 500 ft. per min.	Hard Sandstone Gartshore 9/11, Dumbarton.	Continuous stream of yellow sparks close to surface of Sandstone and forming a continuous spark or yellow flash. Larger sparks travelling close together go further afield. Ignition.
MC .65C	6.5	Approx. 300 ft. per min.	Hard Sandstone Valleyfield, Fife.	Stream of yellow sparks given off and clinging to surface of Sandstone and forming a glow. No ignition.
MC .65C	6.5	Approx. 360 ft. per min.	do.	Stream of yellow sparks given off and clinging to surface of Sandstone and forming a glow. Intermittent larger sparks travelling further afield. No ignition.
MC .65C	6.5	Approx. 500 ft. per min.	do.	Continuous stream of yellow sparks close to surface of Sandstone and causing a glow or yellow flash. Larger sparks crowded together travelling further afield. No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
MC .65C	7.0	Approx. 300 ft. per min.	Hard Sandstone Valleyfield, Fife.	Stream of yellow sparks clinging close to surface of Sandstone and causing a glow. No ignition.
MC .65C	7.0	Approx. 360 ft. per min.	do.	Stream of yellow sparks clinging to surface of Sandstone and causing a glow. Larger sparks travelling further afield. No ignition.
MC .65C	7.0	Approx. 500 ft. per min.	do.	Continuous stream of yellow sparks close to Sandstone surface and causing a yellow flash. Larger sparks close together travelling further afield. Ignition.
MC .65C	7.5	Approx. 300 ft. per min.	do.	Stream of yellow sparks close to Sandstone surface and causing a yellow glow No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
MC .65C	7.5	Approx. 360 ft. per min.	Hard Sandstone Valleyfield, Fife.	Streams of yellow sparks clinging to surface of Sandstone and causing a yellow glow. Occasional large sparks travelling further afield. No ignition.
MC .65C	7.5	Approx. 500 ft. per min.	do.	Continuous streams of yellow sparks close to Sandstone surface and causing a glow or yellow flash. Larger sparks crowded together travelling further afield. No ignition.
MC .65C	6.5	Approx. 300 ft. per min.	Pure Pyrites Kirkconnel.	Bright yellow star-like sparks given off abundantly. No ignition.
MC .65C	6.5	Approx. 360 ft. per min.	do.	Bright yellow star-like sparks given off in all directions. No ignition.
MC .65C	6.5	Approx. 500 ft. per min.	do.	Showers of bright star-like sparks given off in all directions and rebounding off sides of chamber. No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
MC .65C	7.0	Approx. 300 ft. per min.	Pure Pyrites Kirkconnel	Bright yellow star-like sparks given off abundantly. No ignition.
MC .65C	7.0	Approx. 360 ft. per min.	do.	Bright yellow star-like sparks given off abundantly and travelling in all directions No ignition.
MC .65C	7.0	Approx. 500 ft. per min.	do.	Showers of bright yellow star-like sparks given off in all directions and rebounding off sides of chamber. No ignition.
MC .65C	7.5	Approx. 300 ft. per min.	do.	Bright yellow star-like sparks given off freely. No ignition.
MC .65C	7.5	Approx. 360 ft. per min.	do.	Bright yellow star-like sparks given off in all directions. No ignition.
MC .65C	7.5	Approx. 500 ft. per min.	do.	Showers of bright yellow star-like sparks given off in all directions and striking sides of chamber. No ignition.

TESTS WITH(HIGHER 0.9 CARBON) STEEL PICK.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
.9C	6.5	Approx. 300 ft. per min.	Hard Sandstone Gartshore 9/11, Dumbarton.	Very bright yellow sparks which cling to surface of Sandstone and form a glow. No ignition.
.9C	6.5	Approx. 360 ft. per min.	do.	Very bright yellow sparks produced which cling to surface of Sandstone and form a glow or flash. Occasional sparks travel further afield. No ignition.
.9C	6.5	Approx. 500 ft. per min.	do.	Very bright yellow sparks produced which cling to surface of Sandstone and form a yellow flash. Other sparks bunched together travel further afield. No ignition.
.9C	7.0	Approx. 300 ft. per min.	do.	Very bright yellow sparks given off close to surface of Sandstone and forming a glow. No ignition.
.9C	7.0	Approx. 360 ft. per min.	do.	Very bright yellow sparks given off close to surface of Sandstone and forming a glow or glorified spark. Larger sparks travelling further afield. No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
.9C	7.0	Approx. 500 ft. per min.	Hard Sandstone Gartshore 9/11, Dumbarton.	Very bright yellow sparks clinging to surface of Sandstone and forming a yellow flash. The larger sparks close together travel further afield No ignition.
.9C	7.5	Approx. 300 ft. per min.	do.	Very bright yellow sparks given off close to surface of Sandstone and causing a glow. No ignition.
.9C	7.5	Approx. 360 ft. per min.	do.	Very bright yellow sparks given off close to surface of Sandstone and forming a yellow flash or continuous spark. The larger sparks travelled further afield. No ignition.
.9C	7.5	Approx. 500 ft. per min.	do.	Very bright yellow sparks given off close to surface of Sandstone and forming a yellow flash. Larger sparks travel further afield. No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
.9C	6.5	Approx. 300 ft. per min.	Hard Sandstone Valleyfield, Fife.	Stream of very bright yellow sparks given off close to Sandstone surface and forming a glow. No ignition.
.9C	6.5	Approx. 360 ft. per min.	do.	Stream of very bright yellow sparks given off close to Sand-stone surface and forming a glow or yellow flash. Larger sparks travelling further afield. No ignition.
.9C	6.5	Approx. 500 ft. per min.	do.	Stream of very bright yellow sparks given off close to surface of Sandstone and forming a yellow flash or continuous spark. Larger sparks travelling close together go further afield. No ignition.
.9C	7.0	Approx. 300 ft. per min.	do.	Stream of very bright yellow sparks given off close to Sand-stone surface and causing a glow. No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
.9C	7.0	Approx. 360 ft. per min.	Hard Sandstone Valleyfiald, Fife.	Stream of very bright yellow sparks given off close to Sand-stone surface and causing a yellow glow or glorified spark. Larger sparks travell-ing further afield. No ignition.
.9C	7.0	Approx. 500 ft. per min.	do.	Stream of very bright yellow sparks given off, clinging to surface of Sandstone and forming a yellow flash. Larger sparks close together travel further afield. Ignition.
.9C	7.5	Approx. 300 ft. per min.	do.	Stream of verybbright yellow sparks given off close to Sand-stone surface and causing a glow. No ignition.
.9C	7.5	Approx, 360 ft. per min.	do.	Stream of very bright yellow sparks given off and clinging to surface of Sandstone and forming a yellow flash or glow. Larger sparks travel further afield. No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
.9C	7.5	Approx. 500 ft. per min.	Hard Sandstone Valleyfield, Fife.	Stream of very bright yellow sparks given off and clinging to Sandstone surface and forming a yellow flash or glorified spark. Larger sparks bunched together travelling further afield. Ignition.
.9C	6.5	Approx. 300 ft. per min.	Pure Pyrites Wanlockhead.	Showers of very bright yellow star-like sparks given off in all directions. No ignition.
.9C	6.5	Approx. 360 ft. per min.	do.	Showers of very bright yellow star-like sparks given off in all directions and rebounding off sides of chamber. No ignition.
.9C	6.5	Approx. 500 ft. per min.	do.	Continuous shower of bright star-like sparks given off in all directions and rebounding off sides of chamber. No ignition.
.9C	7.0	Approx. 300 ft. per min.	do.	Showers of very bright star-like sparks given off in all directions. No ignition.

TABLE 3.

Steel Pick	% CH_4	Peripheral Speed of Picks	Material	Results
.9C	7.0	Approx. 360 ft. per min.	Pure Pyrites Wanlockhead.	Showers of very bright star-like sparks given off in all directions and rebounding off sides of chamber. No ignition.
.9C	7.0	Approx. 500 ft. per min.	do.	Showers of very bright star-like sparks given off in all directions and rebounding off sides of chamber. No ignition.
.9C	7.5	Approx. 300 ft. per min.	do.	Showers of very bright star-like sparks given off in all directions. No ignition.
.9C	7.5	Approx. 360 ft. per min.	do.	Showers of very bright yellow star-like sparks given off and rebounding off sides of chamber. No ignition.
.9C	7.5	Approx. 500 ft.	do.	Showers of very bright star-like sparks given off in all directions and rebounding off sides of chamber. No ignition.

SUMMARY OF TESTS.

THIRD SERIES.

Eighty-seven tests were conducted in Firedamp-Air mixtures with picks at varying peripheral speeds, viz. 300, 360, and 500 ft. per minute. Before these tests were completed some Pure Pyrites was procured from Wanlockhead Lead Mines and this was used in place of the Kirkconnel samples for the latter tests in this series. Seven ignitions occurred, in each instance the picks being at the highest speed, viz. 500 ft. per minute. Ignitions were obtained with the lower, medium, and higher Carbon picks and both the Sandstones under test. It is noteworthy that one ignition was obtained with Pyrites when testing a .51 Carbon pick in a 7% Firedamp-Air mixture.

These results suggest that the speed and consequently the power expended in spark detachment have an effect upon the ease of ignition. Not only are the sparks probably hotter but there is a greater shower produced and in the case of Sandstone more bunching of sparks.

The difference between the sparking propensities of Sandstone and those of Pyrites was very noticeable. In the case of Sandstone the sparks do not travel but cling to the surface of the Sandstone and give a short glowing stream resembling a yellow flash or flame, apparently composed of incandescent Quartz and fused particles of steel. On the other hand the sparks from Pyrites do not cling to the surface of the material, being produced in showers which break up immediately, each spark appearing to shoot out separately in different directions. The sparks seem to travel at a higher speed than those from Sandstone and are of a

star-like/

star-like appearance. The flame like bunched sparking of Sandstone is evidently more incendive than the scattered sparking of Pyrites, since all ignitions occurred with Sandstones when the bunched effect was greatest.

FOURTH SERIES OF TESTS.

TESTS WITH 0.5%, 0.65%, AND 0.9% CARBON STEEL COAL-CUTTER PICKS AND ROCK MATERIALS AT 500 FT. PER MIN. IN EXPLOSIVE MIXTURES OF FIREDAMP AND AIR USING A SPARK CONCENTRATOR.

The apparatus and picks were the same as in the Third Series of Tests, with the addition of a Spark Concentrator and the rock materials tested were Valleyfield Sandstone, and Wanlockhead Pyrites. The peripheral speed of the picks was 500 ft. per min., being the speed at which ignitions were obtained in Series 3.

The concentrator consisted of a metal 60° angle, approx. 8" long and 4" deep, closed at one end so that the sparks on impinging were collected at the apex of the angle. It was added to the apparatus as a method whereby a more sustained temperature would result from the concentration of the sparks on a small area, and a greater time of contact between sparks and explosive firedamp mixtures, at the high temperatures The arrangement was the outcome of:-

(a) ignitions seemed to occur when the sparks were crowded together or bunched.

(b) in the First Series of Tests it was noticable that when the fan blade in the chamber was omitted to be raised, the impinging of the sparks on it seemed to encourage ignitions in that area.

Table 4 gives results of tests made.

Table 4.

Steel Pick.	$\%CH_4$	Peripheral Speed of Picks.	Material	Results.
.51C	6.5	Approx. 500 ft. per min.	Hard Sandstone Valleyfield Fife.	Continuous stream of yellow sparks close to surface of Sandstone and forming a glow or yellow flash. Sparks impinge on concentrator and collect in apex. No ignition.
do.	7.0	do.	do.	Continuous stream of yellow sparks close to surface of Sandstone and causing a glow or continuous spark. Sparks impinge on concentrator and collect in apex. No ignition.
do.	7.5	do.	do.	Continuous stream of yellow sparks close to surface of Sandstone. Ignition.
.51C	6.5	Approx. 500 ft. per min.	Pure Pyrites Wanlockhead.	Showers of very bright star-like sparks given off in all directions and rebounding off concentrator and collecting in apex. No ignition.
do.	7.0	do.	do.	Same result.
do.	7.5	do.	do.	Same result.

Table 4.contd.

Steel Pick.	%CH_4	Peripheral Speed of Picks.	Material.	Results.
.65C	6.5	Approx 500 ft. per min.	Hard Sandstone Valleyfield, Fife.	Stream of yellow sparks close to surface of Sandstone and causing a yellow flash. Sparks striking concentrator. No ignition.
do.	7.0	do.	do.	Stream of yellow sparks close to surface of Sandstone and causing a yellow glow. Ignition.
do.	7.5	do.	do.	Ignition.
.65C	6.5	Approx. 500 ft. per min.	Pure Pyrites Wanlockhead.	Showers of bright sparks given off in all directions and rebounding off concentrator. No ignition.
do.	7.0	do.	do.	Same result.
do.	7.5	do.	do.	Same result.

Table 4. contd.

Steel Pick	%CH_4	Peripheral Speed of Picks	Material	Results.
.9C	6.5	Approx. 500 ft. per min.	Hard Sandstone. Valleyfield, Fife.	Stream of bright yellow sparks clinging to surface of Sandstone a and causing a yellow flash. Sparks collect in apex of concentrator No ignition.
do	7.0	do.	do.	Same result.
do.	7.5	do.	do.	Same result.
.9C	6.5	Approx. 500 ft. per min.	Pure Pyrites Wanlockhead.	Showers of very bright star-like sparks given off in all directions and rebounding off concentrator. No ignition.
do.	7.0	do.	do.	Same result.
do.	7.5	do.	do.	Same result.

SUMMARY OF TESTS.

FOURTH SERIES.

Only three ignitions were obtained throughout the 18 tests. Two of these ignitions occurred with 0.65 Carbon Steel Picks, and the third with Lower Carbon Steel Picks, The material in each case being Valleyfield Sandstone. These tests give no striking evidence that by the method of spark concentration adopted in this series, ignitions of Firedamp were facilitated.

FIFTH SERIES OF TESTS.

TESTS CONDUCTED WITH TUNGSTEN STEEL TIPPED PICKS ON ROCK MATERIALS IN VARYING EXPLOSIVE MIXTURES OF FIREDAMP AND AIR.

The Apparatus, Conditions and Procedure were as in Second Series of Tests, with the exception of the picks and the speed of rotation.

The special Tungsten Steel Tipped Picks (referred to in H.M. Insp. of Mines Rept., Scotland Division, 1927, p.38) were used throughout the Fifth Series. This pick is supplied by Messrs. Mavor and Coulson, Glasgow, and specially manufactured for use in seams where there is a possibility of gas ignitions through the agency of sparking by pick points. The special pointed picks were employed in 9/11 Gartshore, after the explosion of 1927, noted in the foregoing pages under the heading "Historical Review".

Ten tests were made in varying Firedamp-Air mixtures with the picks operating at the speed of 500 ft. per min., this being approximately the speed of modern coal-cutters. Three analyses of the picks gave an average Tungsten content of 17%. The rock materials in use were Kirkconnel Pyrites and 9/11 Gartshore Sandstone. Firedamp-Air mixtures containing 6% to 10% Natural Firedamp formed the atmosphere of the chamber, the increments being 1%.

Table 5 gives the results of the tests.

TABLE 5.

TUNGSTEN STEEL TIPPED PICKS.

Pick	$\%CH_4$	Material	Results.
MC Tungsten Steel Tipped	6	Hard Sandstone Gartshore 9/11 Dumbarton	Intermittent streams of round sparks of a reddish yellow colour clinging close to surface of Sandstone at point of contact. No ignition.
do.	7	do.	Stream of sparks clinging close to surface of Sandstone at point of contact and forming a glow. No ignition.
do.	8	do.	Stream of sparks clinging to and forming a glow at point of contact of Sandstone. No ignition.
do.	9	do.	Stream of sparks clinging close to and forming a glow at point of contact. No ignition.
do.	10	do.	Stream of sparks clinging close to and forming a glow at point of contact. No ignition.
do.	6	Pure Pyrites Kirkconnel.	Showers of round sparks of a reddish yellow colour given off. No ignition.
do.	7	do.	Showers of round sparks of a reddish yellow colour given off. No ignition.
do.	8	do.	Showers of round sparks of a reddish yellow colour given off. No ignition.
do.	9	do.	Showers of round sparks of a reddish yellow colour given off. No ignition.
do.	10	do.	Showers of round sparks of a reddish yellow colour given off. No ignition.

SUMMARY OF TESTS.

FIFTH SERIES.

Sparking results from the Tungsten Tipped Picks were almost as abundant as with plain carbon steel. The sparks were round and rather small and of a dull red yellow colour. No ignitions occurred in any of the tests.

The ease with which the Tungsten tips are broken is a drawback to the practical use of such picks. This happened in the course of all the tests, the plain carbon pick being exposed to contact with the rock materials, thus defeating the object for which they were introduced.

With no considerable reduction in sparking effects, and a 300% increased initial cost, also additional expenditure and labour of frequent replacement, it does not seem that this specially prepared tip lends any outstanding aid to the solution of the sparking problem. I have reason to believe that these picks are now out of use.

BRINELL HARDNESS

AND

SPECIFIC HEAT.

RELATIVE HARDNESS OF PICKS AND ROCK MATERIALS.

Experiments were conducted to determine the relative hardness of the pick points and rock materials (Sandstones and Pyrites) used throughout the tests. The initial tests were made with a Brinell Hardness Machine using a 10 mm. diam. ball. Results could be easily obtained for the steel picks, but the rock materials splintered and cracked, and in consequence, the results of several tests on the same material varied too much to be considered of any value. A further attempt was made with a lighter machine, viz. Firth's Hardness Tester, using a 4 mm. diam. ball. Again results were easily obtained for the steel picks but the rock materials presented the same difficulty as in the former case. The method of holding the rocks in a clamp was considered unsatisfactory and specimens were placed in Plaster of Paris and Concrete which were allowed to harden. The results were unsatisfactory, the rock materials again giving way under test. The following table gives the Brinell Hardness Numbers of the steel picks with their sparking performances on the same material and at same speed.

Steel Pick	Average Value of Brinell Hardness Number from both Machines.	Sparking Performances on Same Material(Pyrites) and at same Speed.
Steel Pick Lower Carbon (.51C)	230	Sparks freely--large in size--whitish yellow in colour.
Steel Pick AB_2 (.60C)	236	Sparks freely--large in size--whitish yellow in colour.
Steel Pick MC (.65C)	253	Sparks less freely than those above. Sparks bright yellow in colour.
Steel Pick AB_1 (.75C)	522	Sparking not so free as with MC pick. Bright yellow in colour.
Steel Pick Higher Carbon (.9C)	588	Moderate sparking--small in size--very bright yellow in colour.
Tungsten Steel Pick	639	Moderate sparking--small in size--round and reddish yellow in colour.

Photographic evidence of the sparking performances of the Lower Carbon Steel Pick (.51C) having the lowest Brinell Hardness Number of 230 is shown on Plate 3 and that of the Tungsten Steel Pick having the highest Brinell Hardness Number of 639 on Plate 4. Both plates were taken at 360 ft. per min., Pyrites being the material under test.

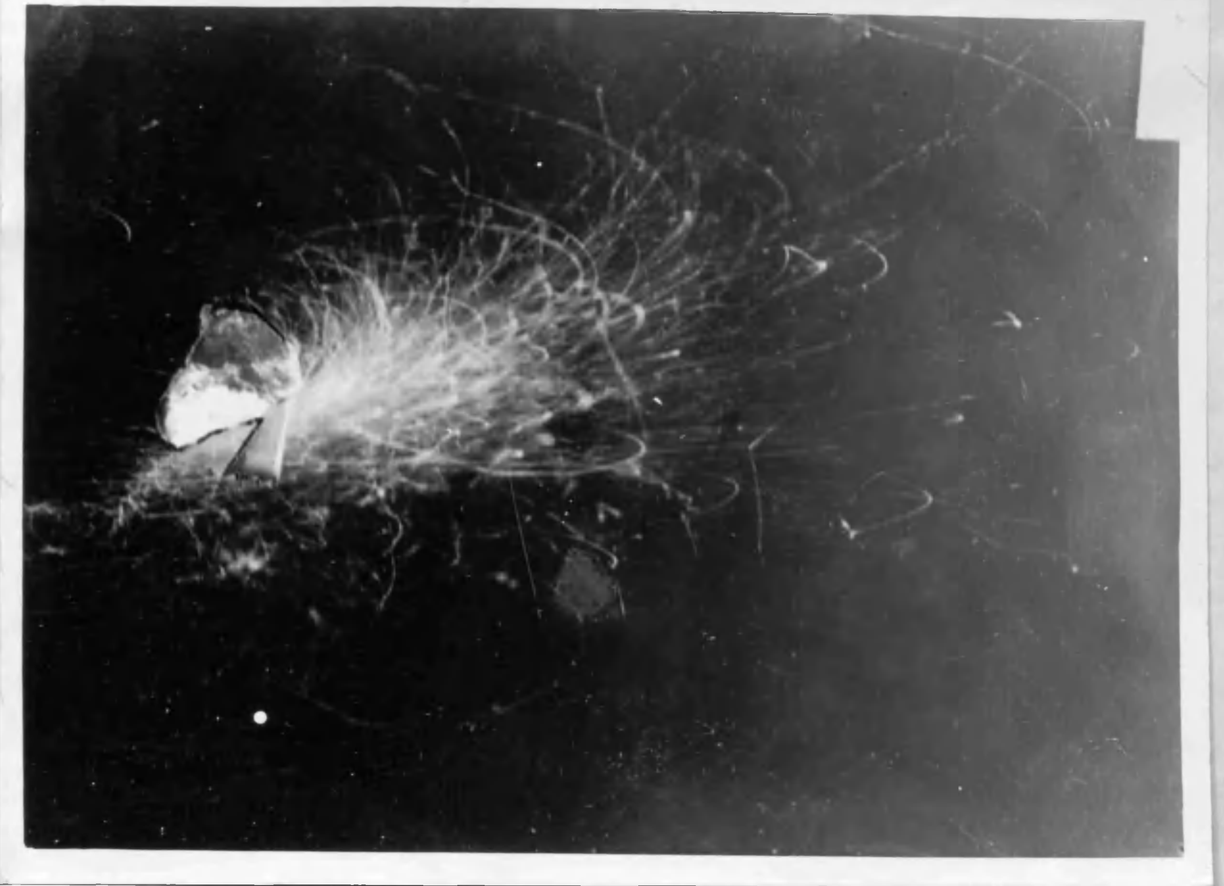


PLATE 3. SPARKING FROM LOWER CARBON (·51C) STEEL PICK
(BRINELL HARDNESS NUMBER 230)

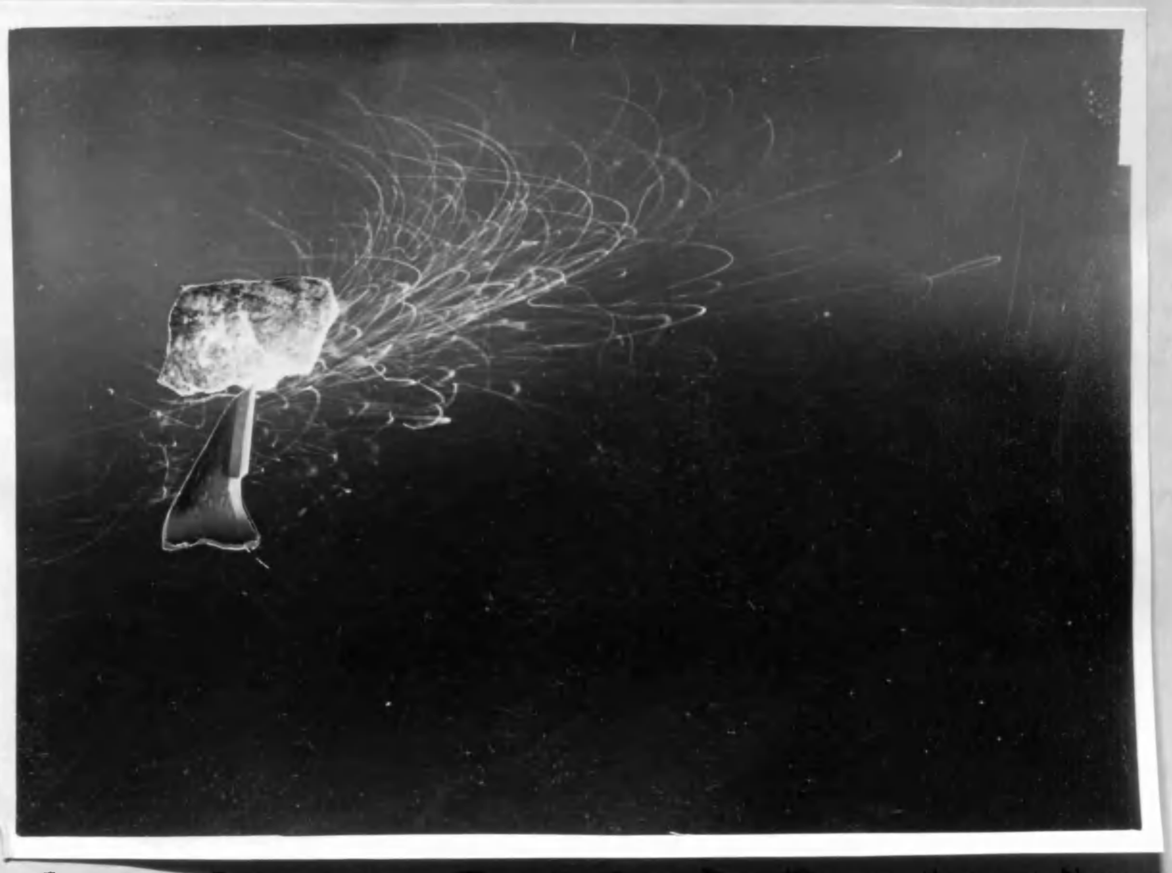


PLATE 4. SPARKING FROM TUNGSTEN STEEL PICK. (BRINELL HARDNESS NUMBER 639)

Since the picks and rock materials could not be correlated on the Brinell Scale, an effort was made to locate them in Moh's Geological Scale of Hardness with the following results:-

Material	Geological Number on Scale.	Sparking Performances.
9/11 Gartshore Sandstone.	5.0	Sparks freely.
Valleyfield Sandstone	5.5	do.
Blairhall Sandstone	5.5	do.
Kames Sandstone.	5.5	Sparks rarely
Kirkconnel Pyrites.	7.0	Sparks very fredy
Tungsten Steel Pick.	6.5	As already described.
Higher Carbon Pick.(.9C)	6.0	do.
AB_1 (.75C) Steel Pick.	6.0	do.
MC (.65C) Steel Pick	5.5	do.
AB_2 (.60C) Steel Pick.	5.5	do.
Lower Carbon Pick.(.51C)	5.0	do.

From a survey of the foregoing results it is noticeable that the hardness of the rocks and steel picks are mostly similar, i.e. in the region of 5.5 or 6.0. It may be deduced from the results of/

of these tests that the liability of rocks to produce sparks is not wholly dependent on hardness. For example, the Kames Roof Sandstone is as hard as any of the other Sandstones and stands up better to the picks without shattering, yet, sparking is restricted, difficult to produce, sparks small in size, and even failed to ignite inflammable mixtures of Coal Gas and Air. These features were likewise apparent while using hard fireclay from Gateside Colliery, Cambuslang, referred to in First Series of Tests, Table 1. The relationship of Hardness, Sparking performances and ignitability is further discussed under the heading of Microscopic Examination of Rock Slides.

SPECIFIC HEAT OF ROCKS AND SPARKING TEMPERATURE.

Investigations were initiated to consider the probable effect that the Specific Heat of the Rock materials might have on the temperature and incendivity of the sparks. A series of tests were made by "The Method of Mixtures" with the object of ascertaining whether any marked difference existed in the Specific Heat of the rocks under test. Additional tests were carried out for comparison on steel (.65C) and on coal of the following composition (Moisture 1.7%, Volatiles 31%, Fixed Carbon 55.9%, Ash 11%). The results obtained are here defined:-

Material	Specific Heat.	Sparking Tendencies.
Coal	0.35	No sparks
Gateside Hard Fireclay.	0.28	Few sparks-Dull red colour
Kames Roof Sandstone.	0.27	Few sparks-Small-Dull red.
Valleyfield Sandstone.	0.24	Free sparking-Yellow Colour
9/11 Gartshore "	0.22	do.
Blairhall "	0.24	do.
Kirkconnel Pyrites	0.15	Abundant sparking-Yellow.
Steel(MC 0.65C).	0.11	- - - - - - - - -

It/

It is logical to assume that the lower the Spec. Heat of a material the greater will be the temperature of the sparks produced for a given amount of energy expended in their detachment. From the results of the foregoing tests (carried out in triplicate) there is unfortunately no marked difference between the Spec. Heat of the Sandstones (Valleyfield, Gartshore, and Blairhall) which give incendive sparks and those(Kmmes Sandstone and Gateside Hard Fireclay, etc) which give non-incendive sparks. The sparks, however, from the rocks with the high Spec. Heat, were of a dull red colour, while those from the low Spec Heat rocks, were yellow in colour.

MICROSCOPIC EXAMINATION OF SPARKS.

The probable composition of the particles produced during sparking operations, suggested more than a passing interest. Their possible bearing on the ignition of explosive mixtures of Firedamp and Air appear to warrant investigation. It was therefore decided to carry out a series of sparking experiments and examine the particles thus emitted. Normal testing conditions were put in operation, and a collection made of the particles produced during sparking. These were taken in small quantities and examined under the microscope. Sandstones and Pyrites with Medium Carbon Steel Picks were used throughout the series of tests, and peripheral speed of the picks being 300, 360, and 500 ft. per min. The following varying kinds of material could be recognised in the particles produced during cutting operations:-

(a) Sandstones.

(1) Quartz grains.

(2) Small lathes and feathery pieces of steel.

(3) Small globules of steel (steel composition was confirmed by tests subsequently carried out).

(b) Pyrites.

(1) Unaltered particles of Pyrites.

(2) Red coloured particles, apparently oxidised Pyrites.

(3) Small lathes and feathery pieces of steel.

(4) Small globules of steel.

The small globules of steel seemed important and their investigation of apparent value. Hitherto these appear to have received/

received no attention as information applicable to their existence or value has not been previously defined.

STEEL GLOBULES PRODUCED BY SPARKING.

PLATE 5.

MAGNIFICATION APPROX. X 3.

Plate 5 gives a typical example of what was found from a microscopic examination of the particles produced during sparking tests.. The arrows indicate the small globules of steel referred to. These were found disseminated throughout the mass of cuttings, and their numbers depending upon the speed and consequently on the/

the power applied in cutting, i.e. the higher the speed, the greater the numbers. During low speeds steel globules were few in number, exceedingly small, and often scarcely discernable.

The size of the globules as estimated by a Stage Micrometer ranged up to about $\frac{1}{50}$ of an inch, while the particles varied considerably in appearance and may be classified as:-

(1) Brilliant glossy and truly spherical. These are highly lustrous and appear to be solid steel. (Plate 6)

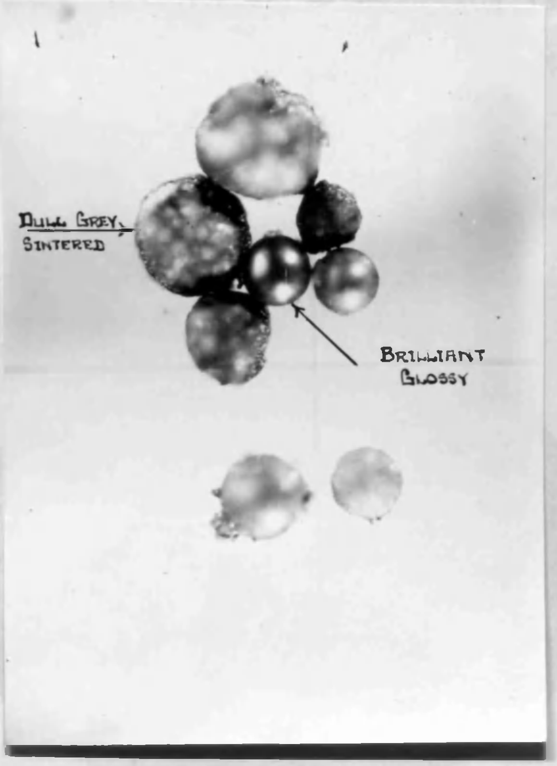


PLATE 6.
MAGNIFICATION APPROX. X20.

(2) Sintered dull grey particles, roughly spherical in shape. Some of these were punctured and revealed hollow/

hollow sintered spheres. (Plate 6)

It is noteworthy that all the globules appear to be magnetic, being attached to the small steel lathes and to one another.

MAGNETIC SEPARATION OF GLOBULES.

It was comparatively easy to separate the globules and other steel fragments from the rest of the cuttings by means of a magnet. The separation of the globules from the other steel fragments could also be effected. The latter separation being facilitated when the magnetic effect of the materials was destroyed by heating.

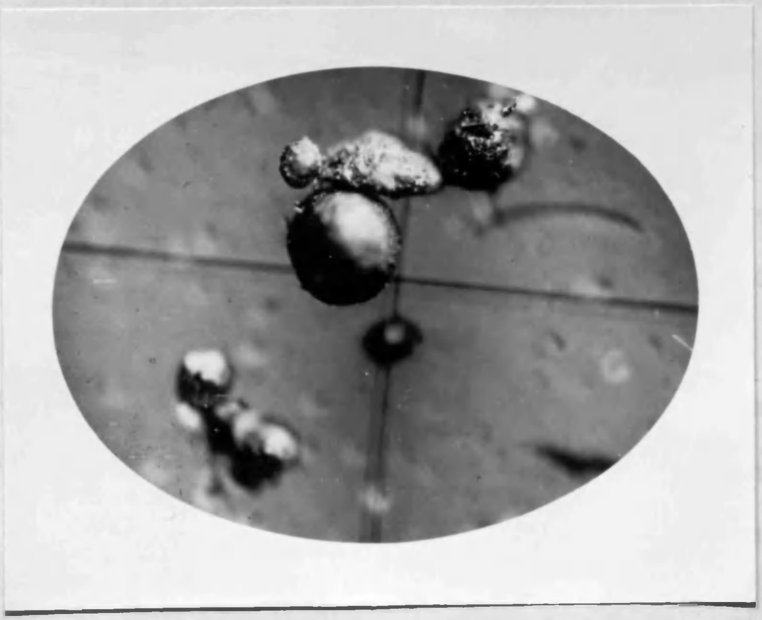


PLATE 7.
MAGNIFICATION APPROX. x 20.

PLATE 8.
MAGNIFICATION APPROX. x 20.

Plates 7 and 8 are Micrographs of the isolated globules produced when using Medium Carbon Steel Picks. Plate 8 showing the result from Pyrites and Plate 7 from Sandstone.

Having become cognisant of the existance of these globules it was possible to detect them with the naked eye among the general debris. In using a cloth for collection of the cuttings these particles could be picked out and were found to have slightly singed the cloth where they rested. A spark could often be followed with the naked eye and picked up as a globule on the cloth.

VERIFICATION OF STEEL COMPOSITION OF GLOBULES.

An iron estimation was made of the globules colorimetrically. Several of the globules were collected and weighed, and then dissolved in Aqua Regia. The same weight of pure iron wire was similarly dissolved and a standard solution thus obtained. The globule solution was diluted until the colour matched that of the standard solution, the iron content being determined from the volumes of the solutions by the undernoted formula:-

$$\frac{\text{Iron in Globules}}{100} = \frac{\text{Vol. of coloured liquid in globule solution}}{\text{Vol. of coloured liquid in standard solution}}$$

The globules were found to be almost pure iron, the average iron content being 95%.

DEDUCTION OF TEMPERATURE OF GLOBULES OR SPARKS.

The spherical shape of the globules suggests that the steel is in a molten state. In the case of the sintered hollow globule s probably the steel is at a more advanced stage of incineration due to the almost complete oxidation while travelling through the atmosphere. The glossy heavy particles may have been suddenly chilled by landing before oxidation was complete. Since the gl globules were found on analysis to be almost pure steel from the picks, it may be tenable to estimate their probable temperature from a knowledge of the melting points of various steels having known carbon contents. (Ref. Jnl. of Iron and Steel Inst., No 1 vol. CX1X, "Third Rept. on the HEterogeneity of Steel Ingots"; by Prof. J. H. Andrew, D Sc, and D. B. Binnie, B Sc., Ph. D., A.R.T.C., p.331, Fig 5). The apparent fusion temperature of the various steels used, and consequently of the globules, may there - fore be accepted as follows:-

0.9% Carbon = 1480°C approx.
0.65% do. = 1500°C do.
0.50% do. = 1510°C do.

Taking the ignition temperature of Firedamp and Air mixtures at a value of 750°C (see graph Fig. 1), the globules would appear to be at least 700°C higher, i.e. 1450°C. Since the "lag" on Ignition of Firedamp-Air mixtures decreases as the temperature/

temperature increases above the ignition point (see Graph Fig. 2) the globules have apparently sufficient temperature to reduce the "lag" to an exceedingly small value, and provided that the globules contain sufficient quantity of heat, it is possible that they can ignite gas while travelling through the mixture. When it is considered that a dense shower of these sparks is often emitted, especially with powerful coal-cutting machines, the necessary quantity of heat is evidently available.

In Safety in Mines Pamphlet No. 46, "the Heat of Impact" is put forward in preference to actual spark temperatures, as being the cause of ignitionsin all ignitions attributed to sparking and suggest that the temperature and duration of spark is insufficient to overcome the "lag" and cause ignition.

In Safety in Mines Research Board Annual Rept., 1926, p.11, the cause of recorded ignitions is attributed to the rock surfaces becoming sufficiently heated by continued friction between the rock and picks.

In view of the series of tests conducted in the present research it is difficult to subscribe to the opinion or theories mentioned in the foregoing pamphlets. From the results of these tests and deductions it is evident that the sparks can be at sufficient temperature to overcome the "lag" and cause ignition, provided the shower is dense enough to supply the necessary quantity of heat.

MICROSCOPIC EXAMINATION

OF

ROCKS USED IN TESTS.

Microscopic Slides were made from the rock materials used during tests and Photo Micrographs taken from the slides. These are shown on plates Nos. 9, 10, 11 and 12.

A rational analysis of the slides gave:-

Valleyfield Sandstone, Fife-- Plate 9.

Quartz	93% to 98%
	Angular
	Evenly Grained
Insterstitial or Binding Material	Practically none
Carbonaceous Material	Pronounced streaks

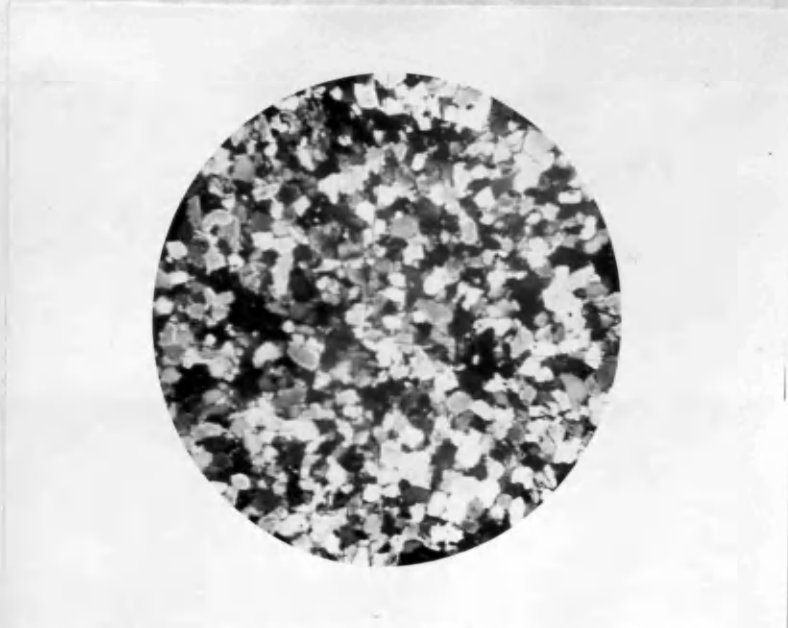


PLATE 9. VALLEYFIELD SANDSTONE, FIFE.

MAGNIFICATION x 30.

Blairhall Sandstone, Fife--Plate 10.

Quartz	90% to 95%
	Angular
	Graded
Insterstitial or Binding Material	A little more than in Valleyfield
Carbonaceous Material	Pronounced streaks

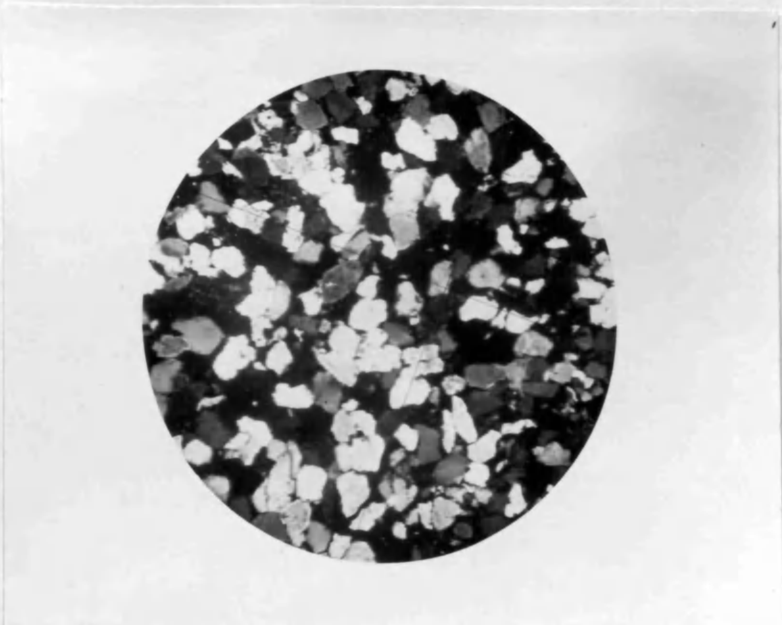


PLATE 10. BLAIRHALL SANDSTONE, FIFE.
MAGNIFICATION X 30.

9/11 Gartshore Sandstone, Dumbartonshire--Plate 11.

Quartz	88% to 93%
	Angular
	Graded
Insetersticial or	
Binding Material	Same as Blairhall
Carbonaceous Material	Pronounced streaks.

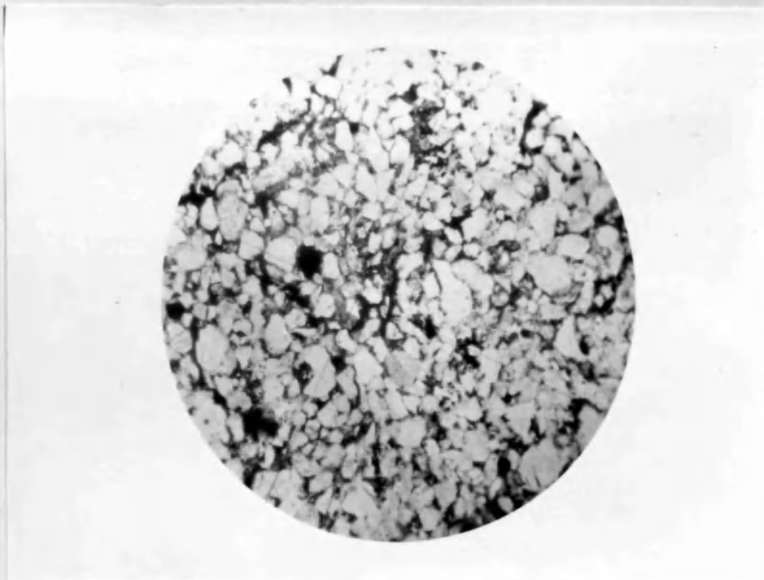


PLATE 11. 9/11 GARTSHORE SANDSTONE,
DUMBARTON.
MAGNIFICATION x 30.

Kames Sandstone, Muirkirk--Plate 12.

Quartz	30% to 40%
	Angular
	Fine Grained
	Present in streaks
Insterstician or Binding Material	Large amount present, principally Iron Carbonate with Mica flakes through it.

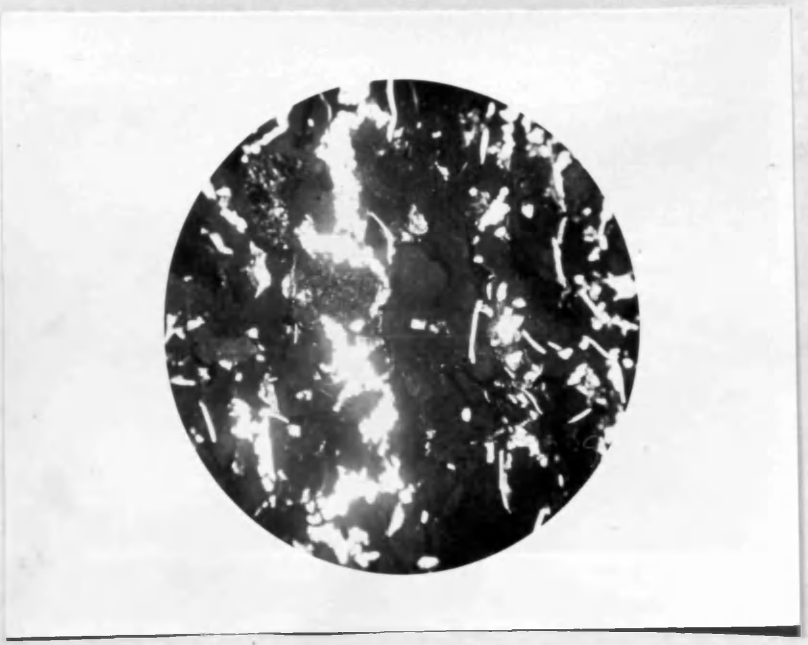


PLATE 12. KAMES SANDSTONE, MUIRKIRK.
MAGNIFICATION x 30.

It is evident that sparking performances of rocks, as already referred to under "Brinell Hardness", does not depend on hardness alone. The quantity and distribution of the quartz appears to be important factors. The Kames Sandstone has a geological hardness similar to that of Valleyfield, 9/11 Gartshore and Blairhall, yet sparks were difficult to obtain. The rocks giving off most sparks are apparently those with the greatest abrasive action. The glow, yellow flash, or glorified spark given off by steel picks and the Quartzitic sandstones seems to be the result of this abrasive action due to the fine and evenly grained quartz particles, the action being similar to that of an emery wheel. Most of the brilliant glossy globules referred to under "Microscopic Examination of Sparks" were obtained with Quartzitic Sandstone. In the case of the poor sparking Kames Sandstone the Quartz grains are embedded in Iron Carbonate cement or binder, which has a cushioning effect on the Quartz grains when impact with steel pick occurs.

With Pyrites the sparks fly in all directions, in comparison with the bunched sparks from Sandstones, and apparently travel at a higher velocity. This may be due to the fact that the grinding action of a Quartzitic Sandstone is absent, the effect being more or less of an impact, and appears to be the reason why ignitions with Pyrites were extremely few.

The carbonaceous or coaly streaks present in the three Quartzitic Sandstones call for special reference. In the tests conducted/

conducted it was noticeable that if a pick travelled along one of these streaks more brilliant and larger sparks seemed to be produced, probably due to the combustion of the carbonaceous matter. It is possible that these streaks may also have a bearing on the ignitions caused by the Sandstones.

IGNITION OF GAS FEEDERS

IN

MACHINE HOLING CUT.

In the H.M. Insp. of Mines Reports (Scotland Division) 1927 and 1929, re ignitions of Firedamp by Frictional Sparking from coal cutter picks, it is interesting to read that in many of the cases quoted no actual explosion of Firedamp occurred, (9/11 Gartshore, Dumbartonshire; Valleyfield, Fife; Whinmoor, Yorkshire, 1927 Rept., pp. 38-40, and 9/11 Gartshore, Dumbartonshire; Kinglassie, Fife, 1929 Rept., p. 33). This striking feature of these ignitions indicates that the general body of the air in the vicinity of the coal cutting machine was not sufficiently charged with Firedamp to be ignitable. This is supported by the further statement that in most of the aforementioned cases of ignition the good condition of the ventilation at the coal face is commented on. From the circumstances quoted it may be assumed that the gas, as a feeder, must have become ignited in the machine holing cut by sparks from the picks. Considering the nature of the sparking produced by certain rocks, the constitution and temperature of the sparks produced, deductions from experiments already carried out, and the result of years of practical experience of machine cut faces, it seemed apparent that the conditions existing in a machine holing cut would be conducive to ignition of Firedamp by sparks. The following reasons supported these conclusions and the diagramatic sketch Fig.3 illustrates conditions re feeders of gas from joints travelling in same direction as picks.

(1) A feeder of gas could be encountered in such a way that the gas would be travelling along with the picks and sparks.

As/

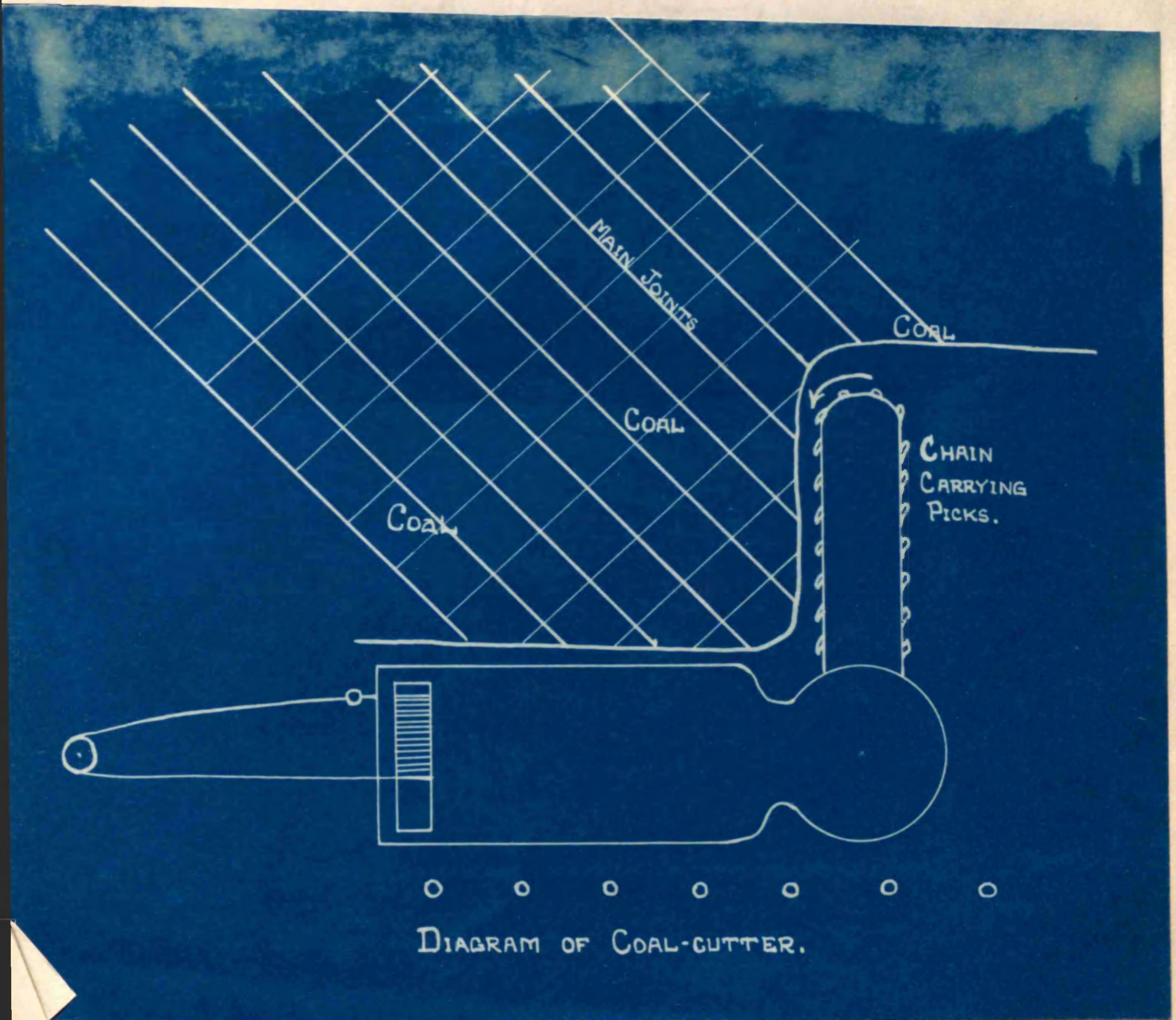


Diagram of Coal-cutter.

Fig. 3.

Feeders given off at Main Joints.

As a result of this greater time of contact the "lag" on ignition could be overcome and the feeder ignited.

(2) The construction and action of the chain coal cutting machine (type referred to in H.M. Insp. Repts., Scotland Division, 1929. pp. 33-34, as being in use when all ignitions occurred) is such that pockets of gas may be carried along with the picks and thus be kept in contact with the sparks emitted during a longer period, thereby overcoming the "lag" on ignition.

(3) The sparks produced are confined in the holing cut of the machine due to blocking by the cuttings so that the heat of the sparks is concentrated in a restricted area.

(4) The general ventilation at the face does not enter the holing cut and diffuse the gases given off from the backs or joints.

(5) It is unlikely that when a coal cutting machine is in operation the sparks will be thrown out of the holing cut into the atmosphere, being impeded by the cuttings and coal gum.

This aspect of feeder ignition in the machine holing cut has not hitherto received attention. Experiments have been confined to charging the general body of the air with firedamp and discharging sparks from steel picks striking hard rock into the explosive mixture, and while ignitions are obtained they are infrequent.

For/

For the purpose of investigating Feeder ignition in machine holing, experiments were conducted with (MC .65 Carbon) Steel Picks on Valleyfield Sandstone, 9/11 Gartshore Sandstone and Wanlockhead Pyrites under conditions similar to those of a holing cut of a machine.

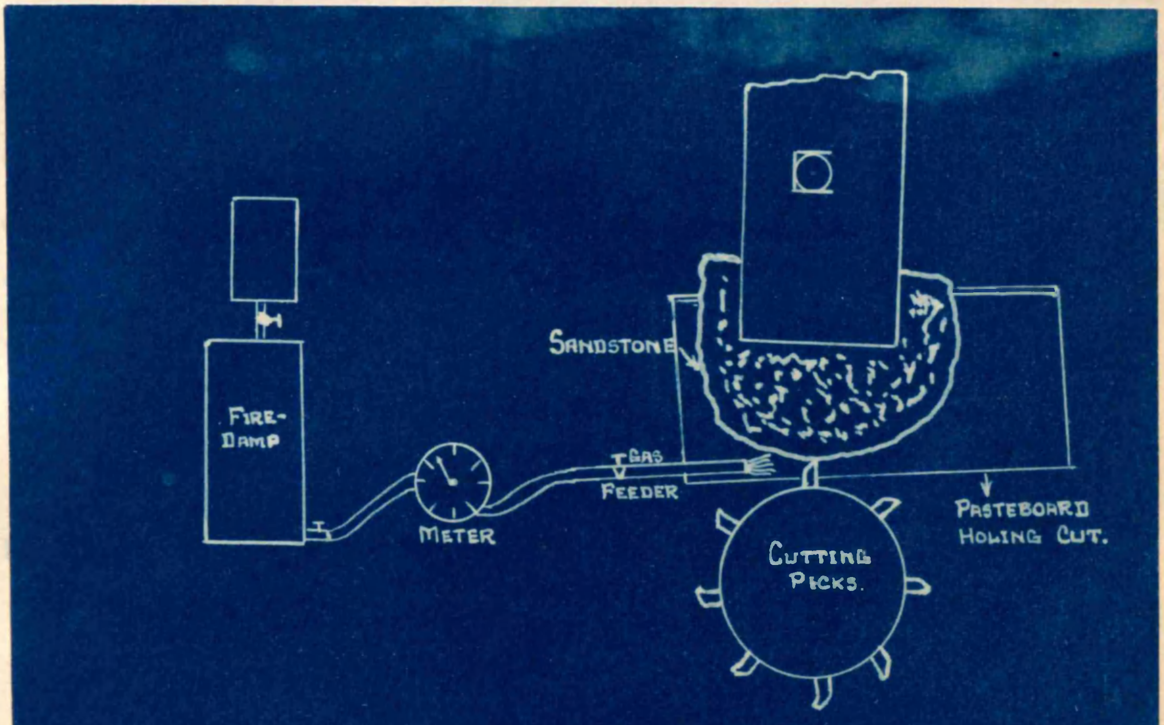


FIG. 4. DIAGRAMATIC ARRANGEMENT OF FEEDER TEST.

The arrangement of the apparatus is shown diagramatically in Fig. 4 and is as follows:-

A pasteboard arrangement consisting of two pieces of cardboard placed parallel to each other at two inches apart and joined by a/

a third piece at right angles, represents the holing cut of a machine. This was so positioned that the sparks would travel in the same way as in a holing cut. A gas pipe with stop cock was fixed to simulate a feeder and so directed that the gas travelled in the same direction as the sparks.

Preliminary tests were carried out in coal gas to determine by trial and error the correct position, direction, and speed of the feeder, relative to the sparks. Having fixed the position, direction, and speed of feeder, ignition of coal gas was readily obtained, the sparks causing ignition almost simultaneously with the opening of the feeder. The gas appeared to ignite, not at the pick points, but at the sparks as they travelled away from the pick points.

Working on the basis of the information gained in the preliminary tests, re position, speed, and direction of feeder, the coal gas feeder was replaced by one of natural Firedamp. Ignitions were definately obtained for three tests each on Valleyfield Sandstone and 9/11 Gartshore Sandstone. Ignitions were not obtained while using Pyrites, although different speeds of feeders were tried and at different positions.

The latter failures may be due to the nature of the sparking of Pyrites, the sparks from which travel in all directions rather than bunched together and the consequent difficulty of getting the feeder and sparks moving in the same direction. The sparks were more the result of impact rather than the abrasive action which exists with Quatzitic Sandstone.

The results of the tests are as follows:-

Steel Pick	Peripheral Speed of Pick	Velocity of Firedamp Feeder	Material	Results
MC .65C	Approx. 500 ft. per min.	222 ft. per min.	9/11 Gartshore Sandstone	Ignition
do.	do.	235 ft. per min.	do.	Ignition.
do.	do.	227 ft. per min.	do.	Ignition.
do.	do.	226 ft. per min.	Valleyfield Sandstone.	Ignition.
do.	do.	230 ft. per min.	do.	Ignition.
do.	do.	232 ft. per min.	do.	Ignition.
do.	do.	Wide range of Velocities tried.	Wanlockhead Pyrites.	No ignition.

The arrangement of the Feeder was obtained so that the gas travelled in the opposite direction to the picks and sparks. In this way the period of minimum contact of gas and sparks was secured. With coal gas as feeder ignitions were obtained with each of Valleyfield Sandstone, 9/11 Gartshore Sandstone and Wanlockhead Pyrites. When a Firedamp feeder was used no ignitions resulted, although variations of speed of feeder and position and direction of feeder pipe were introduced.

The results obtained would seem to justify the theory re "lag"/

"lag" on ignition being overcome by longer contact of feeder and sparks, and appears to be one of the solutions of ignition of Firedamp Feeders by coal cutter pick sparks in a machine holing cut.

In the large scale investigations of the Safety in Mines Research Board a full size coal cutting machine was used, and always operated in a chamber where the general body of the air was charged with a particular Firedamp mixture. Sparks produced by striking hard rock with coal cutter picks were emitted into the mixture and according to the published evidence ignitions have been rare. There is no evidence that the conditions simulating a holing cut with feeders from joints or backs (Fig.3) has previously been tried.

GENERAL SUMMARY

AND

CONCLUSIONS

SUMMARY.

(1) Ignitions of coal gas were readily obtained by the sparking effects of steel picks on hard rocks. With the picks at a speed of 300 ft. per min., which is lower than that of a modern coal cutter, ignitions resulted. In some cases the ignitions seemed to initiate at the spark while travelling, or where the spark landed.

(2) Only one ignition of Natural Firedamp-Air Mixtures was obtained, in a series of over 150 tests, when the peripheral speed of the picks was 300 ft. per min.

(3) In tests at varying speeds, 300, 360, and 500 ft. per min., ignitions of Natural Firedamp-Air Mixtures were obtained only at the higher speeds, viz. 500 ft. per min. These occurred irrespective of the Carbon composition of the pick. All ignitions were obtained with Sandstone sparks, the Pyrites failing, except in one instance, to ignite Firedamp Mixtures.

(4) A metal concentrator did not facilitate ignitions of Firedamp Air Mixtures by sparking.

(5) Tipped Tungsten Steel Picks, while giving practically the same sparking effects as plain Carbon Steel Picks, very easily lose the tip, thereby exposing the plain Carbon Steel and thus defeating their own object. The use of these picks has apparently been discontinued.

(6) The most incendive Sandstones tested were composed almost wholly of Granular Quartz.

(7) The/

(7) The rocks tested had practically the same Hardness Factor as the picks.

(8) Microscopic examination of debris from cuttings revealed fused globules of steel.

(9) These globules appeared most prevalent at high speeds and most numerous when testing Quartzitic Sandstones.

(10) Feeders of Natural Firedamp travelling in the same direction as the picks and sparks were easily ignited.

CONCLUSIONS.

Speed of Picks. The peripheral speed of the picks is an important factor, under the conditions of these tests, No ignitions of Natural Firedamp-Air Mixtures were obtained at the lower speeds, viz. 300 and 360 ft. per min., while at 500 ft. per min. ignitions were frequent. This suggests that the more energy expended in spark production, the greater the danger of ignitions as the sparks will be at a higher temperature and a more concentrated shower or cloud of sparks will be produced.

Rock Materials. Tests indicate that Quartzitic Sandstones composed almost wholly of granular Quartz, with little binding material, are the most dangerous to ignitions of Firedamp underground. This type of Sandstone has an abrasive action on the picks, producing a Flame like Flash or Yellow Glow due to the cloud of incandescent particles of Quartz and Fused Steel. When an appreciable quantity of binding material is present in the Sandstone, it appears to have a cushioning effect, and sparking/

ing is scarce, irrespective of the hardness of the rock.

The sparks from Pyrites seem to be produced by impact rather than by abrasion since they differ from those of Sandstones by flying out in all directions at apparently high velocities. It may therefore be concluded that Pyrites is less dangerous to ignitions of Firedamp-Air mixtures than Quartzitic Sandstones.

The Hardness Factor in Geological Scale for rocks producing sparks is about 5.5, steel being approximately the same. Along with the hardness in rocks, the quartzitic composition already referred to is essential for most incendive sparks.

There is no marked difference in the Specific Heats of the incendive and non-incendive rocks tested, the incendive rocks being only slightly lower than the non-incendive..

Temperature of Sparks. The sparks from Steel Picks appear to reach a fused state, as evidenced by the discovery of the globules of fused steel in collected sparks. These globules are almost pure Iron, and therefore the temperature of the sparks must be in the region of 1450°C to 1500°C. This is double the ignition temperature of Firedamp-Air Mixtures, and seems sufficiently high to overcome the "lag" on ignition of Firedamp-Air Mixtures. The sparks appear capable of igniting an explosive mixture of Firedamp while travelling through it, provided they have sufficient quantity of heat. A bunched shower of sparks satisfies this latter requirement.

Quartzitic Sandstones give a yellow flame like glow near the surface/

surface of the rock, while the larger sparks which travel further afield are bunched together and give a brush like effect 
This crowding or brush like effect apparently gives the necessary quantity of heat for ignition.

Composition of Picks. The carbon content of the picks does not appear to have any great effect on the liability of the sparks to ignite Firedamp-Air Mixtures. The sparks from the higher carbon picks are, to all appearances, smaller and brighter than the sparks from the lower carbon picks.

Tungsten tipped picks are not serviceable because of readiness of tips to break, and the difficulty of re-tipping.

Ignitions of Explosive Atmospheres of Firedamp. The ignition of explosive Firedamp atmospheres by sparks, emitted when striking hard rocks with steel picks can be obtained, though not regularly obtained. This irregularity seems to indicate that unless a bunched effect of the sparks is produced, ignition does not occur. Quartzitic Sandstones are most dangerous in the latter respect.

Ignition of Gas Feeders in Machine Holing Cuts. The conditions in a holing cut appear conducive to ignition of Feeders of Firedamp encountered by the picks and sparks. With the blocking action of the cuttings concentrating the sparks and consequently the heat in a smaller area, and the gas travelling along with the picks and sparks, the conditions seem ideal for ignition.

APPENDIX A

The speed of the picks in operation at the collieries mentioned on pages 19, 20, and 24 was 475 ft./min.

The collieries referred to on these pages are

9/11 Gartshore, Dumbartonshire,
Valleyfield Colliery, Fife.
Kinglassie Colliery, Fife.

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