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# *OCCURRENCE, RESEARCH AND COMBATTING SUDDEN OUTBURSTS OF COAL AND GAS IN CANADA*


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T.H. Patching* and J.C. Botham**/Canada

## Occurence, Research and Combating Sudden Outbursts of Coal and Gas in Canada.

In Canada sudden outbursts have occurred only in coal mines. Because outbursts of potash and gas do occur in other countries, and because we are currently opening several new potash mines, we have an interest in their mode of occurrence in saline rocks. However, all of our experiences and studies regarding outbursts have been concerned with those of coal and gas.

Ground failure phenomena of many kinds have been experienced in Canadian coal mines. "Bumps", which result from sudden failure with violent release of the elastic energy of deformation, have occurred in a number of mines, including those of the Crowsnest Pass area (Southwestern Alberta--Southeastern B. C.) and the Springhill district of Nova Scotia. In most cases "outbursts" in Canada have been fairly distinct from "bumps", showing those characteristic features that have been reported from other countries. These include a large yield of gas, production of fine-sized coal which is spread for a considerable distance from the coal face, a tongue-shaped cavity, and comparatively minor damage to the roof

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or the mine timber. In a few cases "bumps" have been reported from mines where outbursts have also occurred. Other events called "push-outs" seem to show characteristics intermediate between bumps and outbursts. In these the coal is pushed or squeezed away from the face in blocks with little fragmentation and sometimes little gas emission, and usually with little violence. In other instances, especially when working in thick weak inclined seams, a moderate amount of gas has been released by falls of coal, but these have generally not been considered as outbursts. There also have been instances when outbursts were followed by caving and strata failures that caused shocks and vibrations to be felt at considerable distances.

Outbursts, and the threat of outbursts, have interfered with normal mining operations in several districts in Canada and have prevented the employment of efficient and economical mining methods. Extreme outburst hazards have caused certain seams to be abandoned and a few mines to be closed, and a number of casualties have been caused.

Most outbursts of coal and gas have been reported from three districts in Western Canada (Fig. 1). These are the Nanaimo district of Vancouver Island, the Coal Creek and Morrissey district in the Crowsnest area of Southeastern British Columbia, and the Canmore district near Banff in Alberta. In addition, in the Nordegg district many falls and push-outs of coal seemed to show some of the characteristics of weak outbursts, but mining was at fairly shallow depths. All of these districts are in foothill or mountainous areas where the coal seams are highly disturbed and sheared by tectonic movements. No outbursts have been recorded in the flay-lying coal seams of the plains regions of Western Canada or in the gently dipping seams in Eastern Canada. The only district in Canada where seams that are liable to outburst are mined at present is at Canmore.

Coal mining in these three districts has generally been done by some form of bord-and-pillar method, in seams usually 2-1/2 to 3-1/2 meters thick. Development entries and raises, 2-1/2 to 5 meters wide, are driven to divide the coal into square or rectangular pillars of about 15 meters or more in dimension. The pillars may be extracted in whole or part, either by splitting or by mining slices from the sides. Almost all outbursts have occurred while driving the development headings; a few occurred when starting to mine pillars, but only in pillars of unusual size. In most cases the outbursts broke ahead, or at an angle ahead and to the high side, from the development faces. In some instances the outbursting zone only included the upper layers of the seam.

Most coal outbursts in the Nanaimo district of Vancouver Island occurred prior to 1932. This coal is Upper Cretaceous in age and high volatile A bituminous in rank. At the Cassidy colliery 260 outbursts were reported, and outbursts also were reported from two other nearby mines (1). The seam at the Cassidy colliery dipped about $18^{\circ}$, the roof was generally regular, and variations in thickness occurred due to rolls or small faults in the floor where there was evidence of lateral and obstructed movement of the seam.

Most of the outbursts occurred either while approaching or while mining in zones which were pinched by the rolls. In two instances which involved loss of life, outbursts occurred without previous warning in carbonaceous clay which replaced the coal in pinched out zones. In this mine outbursts occurred at depths ranging from 180 to 700 meters. Gas was given off in great volume by some outbursts and was almost absent in others. At the neighboring No. 10 Mine it was reported that nearly all outbursts occurred after the firing of shots, particularly the second one in a round, at depths from the surface exceeding 300 meters.

In the Crowsnest area the first outbursts occurred at the Carbonado colliery (Morrissey) during the first decade of the century (1, 2). One outburst in 1903 threw out over 1500 tons, and another six weeks later threw out 800 tons and killed four men. In 1904, after the mine had been shut down for two weeks, an outburst occurred upon resumption of work in which about 3500 tons of coal were thrown out, releasing 60,000 to 140,000 cubic meters in 30 minutes and asphyxiating 14 men.

At Coal Creek, about 7 miles north of Morrissey, the first outburst occurred in 1917, and thereafter they were regularly encountered. In 1928 the most violent outburst in this district occurred from which it is reported that 120 tons of dust, 200 tons of rock, and 1400 tons of coal were loaded. At that time more than 200 outbursts had been reported from this district.

The coal seams in the Crowsnest area were laid down in the Lower Cretaceous period, and the coal bearing formation in the western district occurs in a basin with the center covered by a great thickness of younger rocks except where cut by sharp valleys. There has been a variable amount of faulting and folding which has caused the coal to be often intensely sheared and very friable. The coal is generally of medium-volatile bituminous rank, although the rank and quality of the coal vary according to the seam and location.

At Canmore the coal is also of Lower Cretaceous age, and the coal-bearing formation occurs as an assymetric syncline with the southwestern limb partly overturned by the thrust of the older Palaezoic formations from the southwest. The coal varies from semi-anthracite in the lower seams to low-volatile bituminous in the upper seams. Tectonic movements during the folding of the coal basin caused many small folds and faults in the coal seams and enclosing strata. The thickness of the seams varies because of these folds and faults and also because of the original irregular deposition of the coal deposits.

Outbursts have occurred in two of the seams in Canmore, the No. 4 and the Upper Marsh (3). They were first encountered in the No. 4 Seam in 1944 when sinking the main slope.at a depth of about 200 meters of cover, and over 25 occurred during the development of this seam of coal. The coal in No. 4 Seam is relatively strong with some evidence of the original banding, but there is frequent evidence of differential movement in the coal mass, especially in the vicinity of the folds and some of the faults. On the other hand, the Upper Marsh Seam, where numerous outbursts began to be encountered soon after it was opened in 1950, is of very soft coal which is so badly sheared and broken that there is almost no evidence remaining of the original coal structure. The roof and floor of both seams is of strong shales or sandy shales. Numerous small faults cut the roof and floor strata, but in most cases there is no correspondence between those in the roof and those in the floor.

When it was recognized that mining in certain of the Canmore seams might continue to be hazardous because of outbursts, several programs of study were initiated into their control and causes. These studies involved the participation of the mining company staff, the provincial mine inspectors, the federal Department of Mines and Technical Surveys, and some university staff members (4, 5, 6, 7, 8).

Investigations began with a study and review of outbursts and current methods of control in several European mining districts, and with the testing and application of shock (or concussion) blasting at Canmore where the method became standard practice in seams subject to outbursts at depths of over 200 meters. Other percussive work is prohibited in these places. While shock blasting has prevented accidents, it has led in some instances to an increased incidence of outbursts and some deterioration of the roof through loss of support provided by the solid coal walls of the mine working: this situation has caused increased mining costs.

In the Canadian mines that are troubled by outbursts it has not been practical to employ other protective measures. There have been no opportunities to work protective seams in sequence mining. In the earlier years of mining, attempts to drain gas by small-diameter holes drilled in advance were unsuccessful. The friable and stressed nature of the coal has given little promise of successful large-hole drilling for drainage. In recent years, because of the necessity of low-cost production, the mine management has selected sections of seams with less than 200 meters of cover to be mined by combined (continuous) mining machines. The unrestricted use of high production machines will only become standard practice when the mine officials are convinced that no outbursts will be encountered or when positive methods are found to control or eliminate this hazard when such machines are used.

A structural geology study emphasized the deformation of the coal bearing strata in which outbrusts occurred. Over-riding compression and folding were held to be responsible for the intensely fractured and faulted condition of the coal measures. It was found that about 90% of the faults that were mapped underground in the mountain districts were due to extension and about 10% were due to compression. The study noted that outbursts were not characteristically associated with faults in the accessible parts of the mines investigated, although mine officials generally state that major outbursts occur coincident with or in reasonably close proximitiy to faults.

A program of detailed mapping and recording of outburst phenomena was carried out from 1957 to 1959, and showed several relationships. Fig. 2 shows a plan of one area of the No. 3 Mine at Canmore where outbursts were very troublesome. It was noted that most, but not all, of the outbursts occurred in the vicinity of a fault or thrust in the roof or floor. The relation between the depth and the frequency and size of outbursts in this section of the mine is shown in Fig. 3.

Convergence of the roof and floor was measured in several headings as they were driven in an outbursting area, and also in neighboring stationary places, using Davis Recorders. These measurements showed slow steady convergence of the seam prior to outbursts, but there was no indication of an increase in the convergence rate immediately before outbursts. However it was not possible to place the recorders near to the working faces where the outbursts occurred, so abnormal convergence at or ahead of the face may have escaped observation. After an outburst all recorders in the vicinity showed sharp convergence of roof and floor, in some cases amounting to several inches, and then the convergence rate gradually diminished for a day or so until the normal slow rate was again established. It has been estimated that the extra convergence recorded after an outburst was about the same as one might expect if the coal thrown out had been mined by conventional methods, allowing for the delay in placing supports while the expelled coal was removed. A typical convergence record is shown in Fig. 4.

A survey was made of the impact strength of coal at different places throughout the mines at Canmore, taking samples from outbursting and non-outbursting seams, from different bands in the seams, from places near and away from outburst sites, and from places near to and away from faults and folds. The Impact Strength Index as developed by Pomeroy (9) is obtained by repeatedly dropping a given weight on a sample of sized coal under standard conditions and then recording as the index the percentage weight of undersized coal produced. This study showed appreciable differences in strength (or hardness) between the different layers or bands of coal in all seams, generally agreeing with the miners' observations of the differences. However no support could be found for the hypothesis that there was a marked reduction of strength in the vicinity of rolls or faults, except in the immediate crush zones, nor could any patterns of strength be related to zones where outbursts had occurred. However in this survey no samples were obtained from zones which subsequently outburst, and it is recognized that the coal samples when tested had lost most of their contained gas, so the test results perhaps do not fairly represent the strength "in situ" of coal which is involved in an outburst.

A series of tri-axial compression tests were undertaken on fragmented coal from various sources to determine if differences could be found in the strength of coal in confinement which might be related to outburst behavior. No characteristic differences could be found in the angle of internal friction of bursting and non-bursting coals. It was observed during the course of loading the specimens that the gross volume of the specimens first decreased as load was applied and then, as the failure point was approached, the volume of the samples began to increase (dilate). It is considered that this effect also occurs when a mass of friable coal is loaded differentially to the failure point, and that dilation occurring just prior to failure enables the fracture surfaces in the coal to be opened so that the contained gas can become desorbed and released. Dilation has not been verified for solid specimens of coal.

Attempts were made to obtain solid cores of coal from outburst-prone areas for triaxial compression tests. The friable nature of the coal, the unequal release of stress on the samples as they were cut free, and perhaps the effect of gas within the coal have made it impossible to get unbroken cores.

As another approach to determining the solidity or degree of fracturing of coal from various seams, a series of tests was made on the size distribution of fragments produced when various coals were broken to a maximum size of 4 mesh (5 mm). It was surmised that coal which had been sheared by tectonic forces would break with a greater proportion of fine sizes when a sample was submitted to a crushing force. This was found to be generally true, and typical size distribution plots are shown in Fig. 5 for the soft and sheared Upper Marsh coal and for hard unsheared coal from the Cairnes (Canmore) seam. It is suggested that if a sample of coal is broken to minus 4 mesh (4.76mm) in one stage of crushing, then the percentage that passes through a 28 mesh screen (0.60 mm) can serve as an index of the fine shearing that has taken place in the coal. Rough correlations have been found between this index and the Impact Strength Index as proposed by Pomeroy and also with the Hardgroves Grindability Index.

A project of measuring the electrical resistivity of the coal ahead of a working face was undertaken in the hopes that some identification could be made of potential outburst zones. It was thought that either zones of stress or zones of different moisture content might be related to outbursts and could be identified. Holes of about 5 cm diameter were drilled up to 15 meters ahead of the end of advancing entries, and by means of a two-electrode probe the resistivity of the coal along the length of the hole was measured. Changes of 4 to 5 orders of magnitude, within the general range of $10^5$ to $10^{11}$ ohm-cm., were found within intervals of less than a meter. It proved to be impossible to obtain useful correlations between the electrical resistivity of the coal and subsequent outburst history, and the project was discontinued.

The behavior of the coal while the resistivity holes were being drilled indicated its stress state in a qualitative way. Generally 1 or 2 meters of loose or "dead" coal were first encountered, from about 1 to 4 meters of depth the coal was usually very tight and hard to penetrate, and thereafter it was often softer but tending to cave and close the hole. Often it was impossible to drill the holes deeper than 3 to 5 meters. This general pattern, despite considerable variations from hole to hole, indicated the existence of zones of different pressure conditions and different strengths of coal with distance ahead of the face. Occasionally small amounts of gas were released while the holes were being drilled but this did not usually persist after drilling stopped.

Attempts were made to measure the gas pressure in boreholes in gassy seams, but only very low pressures were recorded. It is believed that it was not possible to seal the holes tightly enough to prevent the leakage of gas past the seals, and that actual gas pressures were considerably higher than observed.

In the following references to studies of gas contents, several comparisons are presented of information obtained with Canmore coals in contrast with Springhill, N. S., coal. The former is low volatile coal of Lower Cretaceous age and has an outbursting history; the latter is high volatile coal of Carboniferous age and, though mined at depths of over 1300 meters, has never experienced an outburst as defined earlier. Typical characteristics of these coals, and also of an outbursting coal from the Crowsnest area, are shown in Table I.

Samples of gas from boreholes in the Upper Marsh seam were found to be composed mainly of methane, but it was always accompanied by about 6 to 12 percent of carbon dioxide and usually a few percent of nitrogen. Ethane was reported in two samples of borehole gas from Canmore. Gas extracted from coal samples taken at various depths of boreholes yielded up to 20 percent carbon dioxide at Canmore and very little at Springhill but there was somewhat more ethane in the Springhill coal.

Determinations were made of the gas quantity in several seams at Canmore and Springhill (8). Coal samples were taken from boreholes at various depths and quickly sealed in special cells, crushed and heated to about 95°C, and the gas released was collected and measured. An unknown amount of gas was undoubtedly lost after the coal samples were exposed and before they could be sealed in the cells (45 to 60 seconds), so the quantity recorded was less than the original amount of gas in the coal. Up to 12 cubic meters of gas (at N. T. P. ) per ton were recovered at Canmore (about 16 volumes of gas per unit volume of coal). Little difference was found in the

TABLE 1

COALS STUDIED

| Identification | Upper Marsh (Outburst) | Springhill (Non-Outburst) | Elk River (Outburst) |
|---|---|---|---|
| Area | Canmore | Springhill | Crowsnest |
| Province | Alberta | Nova Scotia | British Columbia |
| Rank (ASTM) | Low Vol. Bit. | High Vol. "A" Bit. | Med. Vol. Bit. |
| Spec. Vol. Index | 204 | 168 | 195 |
| % Carbon (dmmf) | 91 | 84 | 89 |
| % Hydrogen (dmmf) | 4.3 | 5.4 | 5.3 |
| Percent minus 1/8 in. from mine run screen analysis | 44 | 22 | 29 |
| Percent Porosity (approximately) | 8 | 2 | 7 |
| Relative Methane Sorptive Capacity (cu ft/ton) | 600 | 300 | 500 |
| Internal Surface* Measurements (sq m/gm) | 32 | 18 | 25 |

* Determinations made by Dr. N. Berkowitz, Research Council of Alberta; heat of wetting by methanol used.

maximum amount, whether from bursting or non-bursting seams. Samples taken from stationary faces carried up to 6 cubic meters of gas per ton, the amount depending on the time the face had been exposed and the apparent hardness and permeability of the coal. Appreciable differences were noted between samples from the same location, perhaps due to losses in the sampling and testing procedure, but perhaps also indicating differences in the gas capacity or content of different samples of coal. A typical plot of results is shown in Fig. 6.

By way of camparison, Springhill coal, despite being lower in rank and with less gas sorption capacity, yielded "residual" gas contents of approximately the same order as Canmore coal. This is attributed to a larger number of small pores producing " tighter" structure. Springhill coal, unlike coal from Canmore, showed a remarkably even distribution of gas from various locations. The quantities obtained indicated that very little gas had been lost during sampling. The gas content of samples taken in depth increased progressively but they showed no significant difference from the face surface to borehole depths of 4 meters.

Some of the borehole samples that were obtained while determining gas contents at Canmore were first tested for the rate of gas emission in a portable unit devised by Prof. A. Hargraves of Australia. Plots of the rate of emission from several of the samples that are included in the previous figure are given in Fig. 7. It may be noted that the rate of gas emission from one of the samples was very slow in comparison with others from the same location, although the ultimate yield was similar. This indicates appreciable variation in the rate of emission from coal samples from the same approximate position. Although it was not possible, because of the sequence of work in the mine, to carry out a thorough investigation of desorption rates in outbursting and non-outbursting seams, and although emission patterns varied from sample to sample, in general high emission rates were observed from samples from outbursting seams.

Initial rates of gas desorption were also observed to be much greater for Canmore coal than Springhill coal, indicating easier access to the internal surfaces of the former coal.

A program of laboratory tests was begun to study the rates of desorption under controlled conditions, especially during the intitial few seconds after release, since this is the interval when emission is significant during an outburst. Typical plots are shown in Fig. 8. The laboratory investigation has not been carried to completion and results are not conclusive. It is planned in future work to compare results from our procedures with $\Delta P$ tests as made in Europe.

Experimental studies were carried out to determine under fixed laboratory conditions the relative sorptive capacity of coal samples from Canada, France, Belgium, and Australia (8); the results obtained using methane are graphically summarized in Fig. 9. As may be observed, a catenary type of isotherm is obtained when capacities are plotted against coal rank expressed in per-cent total carbon; carbon dioxide was also used and the quantity sorbed was found to be approximately three times that of methane. The relationship agrees, in general, with that of other investigators and follows the same pattern as internal surface measurements of coals of different rank.

Sorptive capacity isotherms were determined for Canmore and Springhill coal using coarse and fine coal particles. In the case of the Canmore coal equilibrium could be reached and the results could be reproduced with the coarse and the fine coal during a 24-hour period of sorption; coarse Springhill coal could not be saturated during this short period. Typical results are given in Figure 10 for methane at various gas pressures and at 24°C temperature.

In order to investigate the factors that control the gradient of gas concentration in the coal ahead of the face, and the rate of release of gas at the time of an outburst, laboratory investigations were made of the permeability of coal to gas (8, 10). An early set of experiments showed that movement of gas through coal is essentially along fractures and that no significant amount of gas can move through unbroken coal. Therefore the effective permeability of coal depends on the frequency and openness of fractures which are often the result of deformations of the coal seams. Subsequent tests of the permeability of coal samples subjected to confining pressure of up to 3000 psi (200 atmospheres) showed very marked decrease of permeability with increase of confining pressure. Figure 11 shows changes of permeability with pressure for a number of samples from the Upper Marsh Seam. No signigicant difference in permeability due to sorption of gas in the coal was observed. It is apparent that "in situ" permeability measurements, or estimates of gas movement through coal "in situ" must take into account the mechanical stress conditions in the seam as well as the gas pressures that may exist.

At present some success is achieved in other mines in measuring "in situ" stresses in firm rock and coal, but we have not yet adapted these techniques for use in disturbed coal. Until this is possible it is difficult to estimate changes in permeability and gradients of gas pressure in soft coal ahead of a face.

As early as 1953 a series of comparative tests were made to demonstrate the mechanics of outbursting on a laboratory scale. Coal specimens from Canmore, Springhill and Elk River were chosen (see Table 1). Test pieces were prepared by shaping solid coal samples into discs 5 cm. in diameter and 1.8 cm. in thickness. They were placed in a cell for testing coal under various gas atmospheres, and in some tests an additional axial load was applied. After prolonged periods of conditioning the pressurized gas atmosphere was instantaneously released and the degree of coal disintegration observed.

From a limited number of tests the following general observations were made:

(a) The fine coal ejected from the test apparatus had a size consist similar to the fine coal (" wild flour" or "folle farine") characteristic of an actual outburst.

| | Fine Coal<br>Mine Outburst | Ejected Coal<br>Laboratory Test |
|---|---|---|
| Minus 100 mesh | 90% | 90% |
| Minus 325 mesh | 40% | 34% |

(b) The degree of coal disintegration was proportional to the molar concentration of the sorbed gas, and also to the coal friability.

(c) The application of mechanical load in the test appeared to reduce the tendency for coal disintegration.

(d) Increased pressure of the free gas was observed when applied load was increased on a speciman with free and sorbed gas in equilibrium.

Regarding items (c) and (d) above, it is postulated that applied mechanical load reduces the sorptive capacity of the coal. Alternatively sorbed gas can be converted to free gas with increasing load. These observations are in agreement with Khodot (11, 12).

In conclusion, our studies have shown the influence of stress, coal strength and deformation, gas content, and permeability on outburst occurrences. At present the only effective control measure that is applicable in Canadian conditions is shock blasting, and the application of mechanization in outburst-prone seams is restricted by our inability to predict or eliminate these curious and hazardous phenomena.

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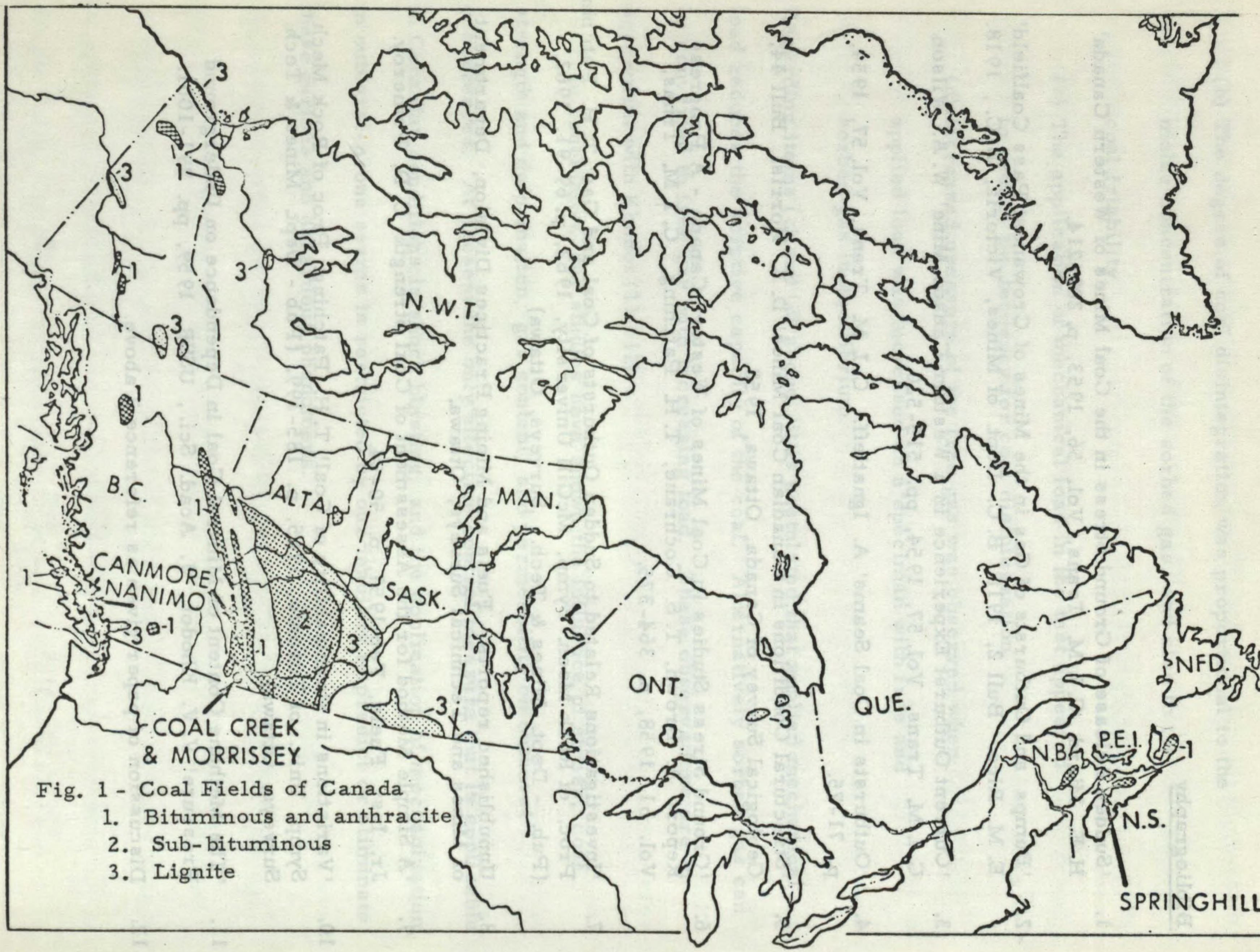



Fig. 1 - Coal Fields of Canada

1. Bituminous and anthracite
2. Sub-bituminous
3. Lignite

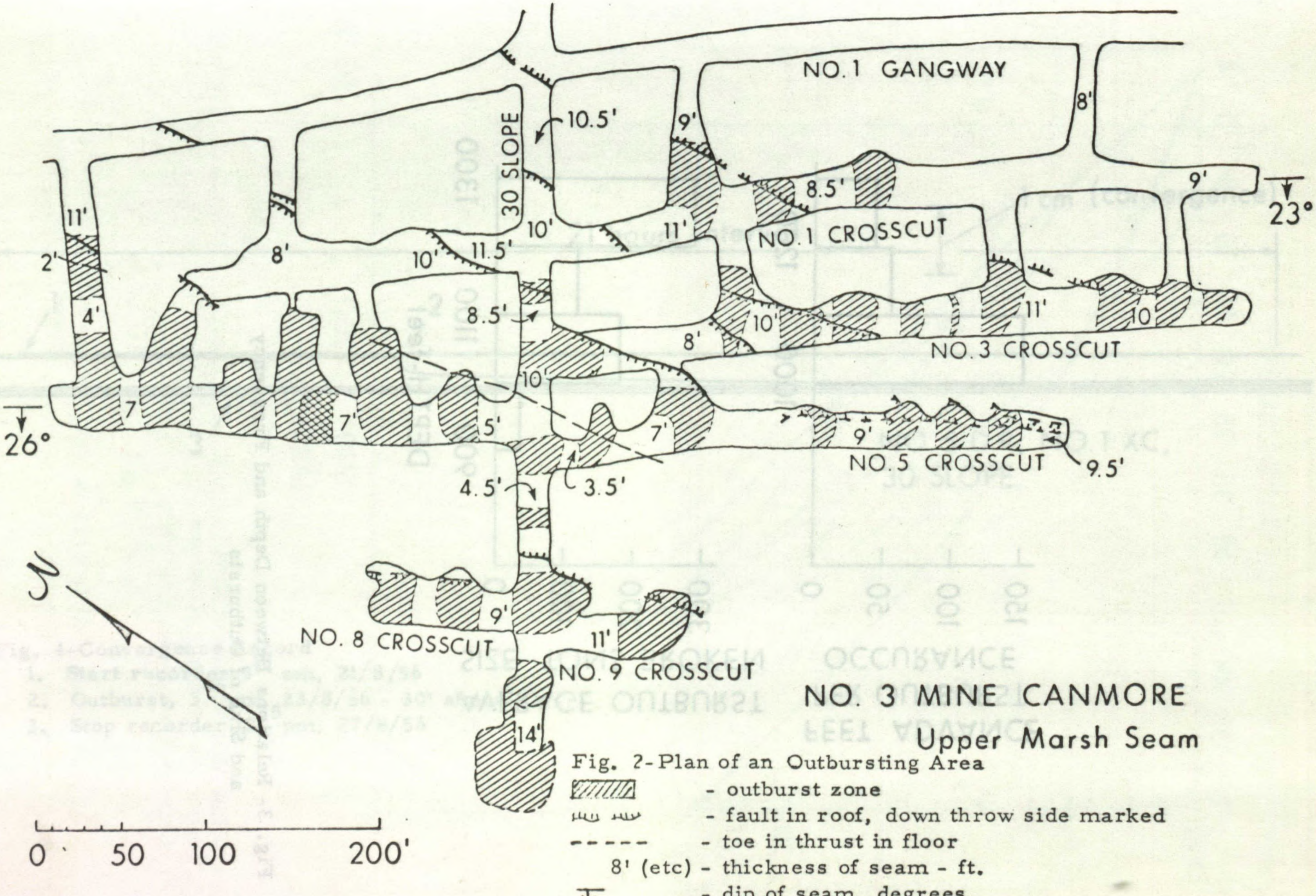



Fig. 2-Plan of an Outbursting Area

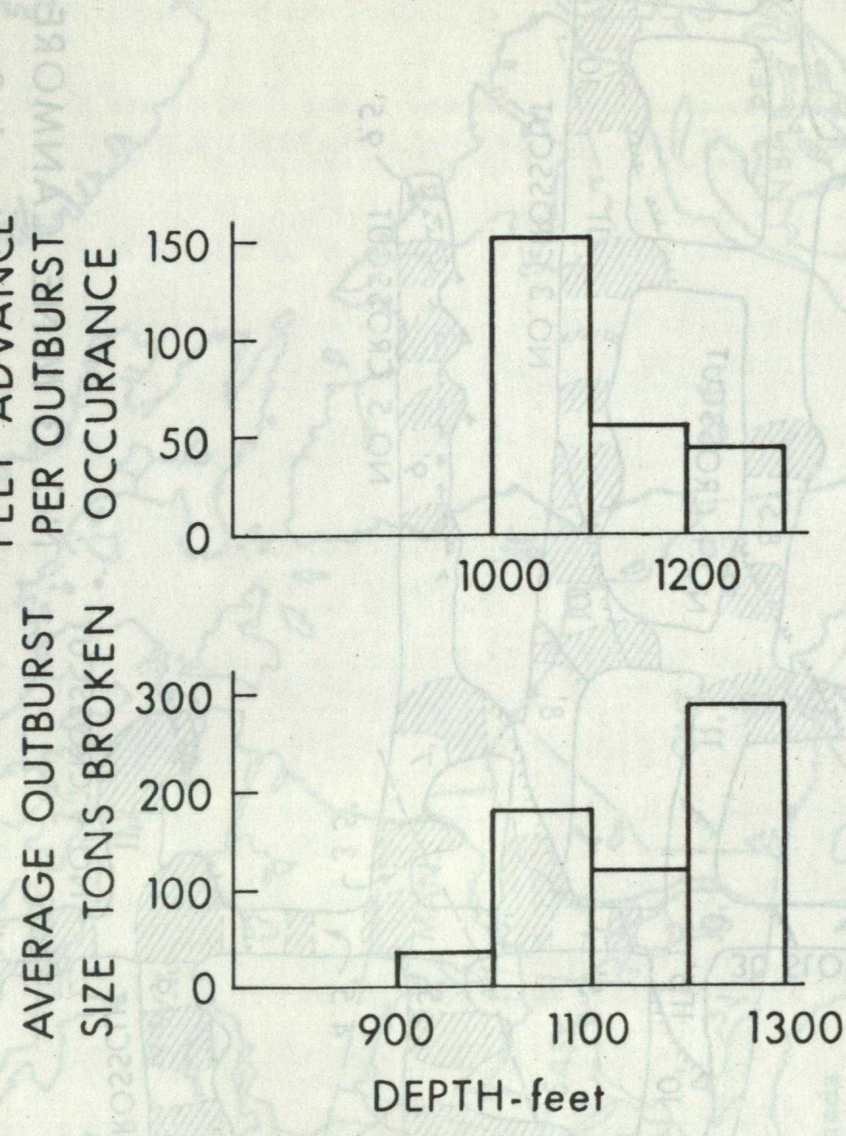



Fig. 3- Relations Between Depth and Freguency and Size of Outbursts

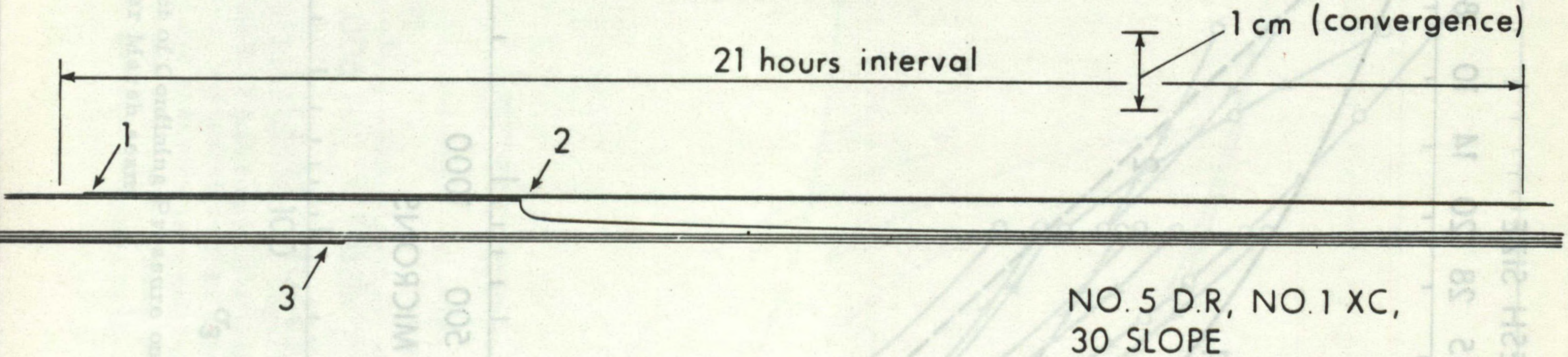



Fig. 4-Convergence Record

1. Start recorder $9^{10}$ am, 21/8/56
2. Outburst, $3^{05}$ pm, 23/8/56 - 30' ahead
3. Stop recorder $12^{35}$ pm, 27/8/56

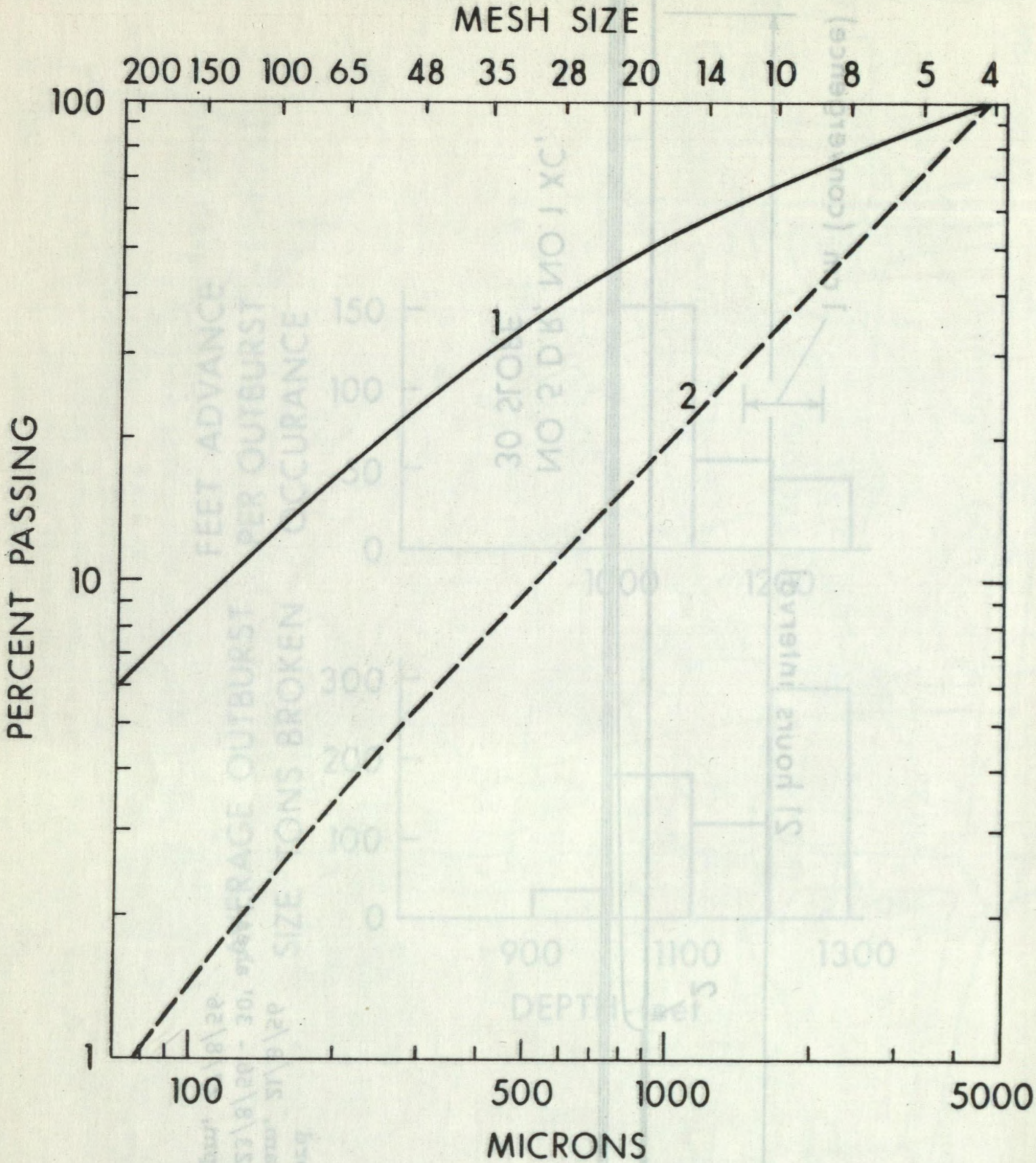



Fig. 5-Size Distribution of Coal
1. Upper Marsh Coal, Canmore
2. Cairnes Seam Coal, Canmore

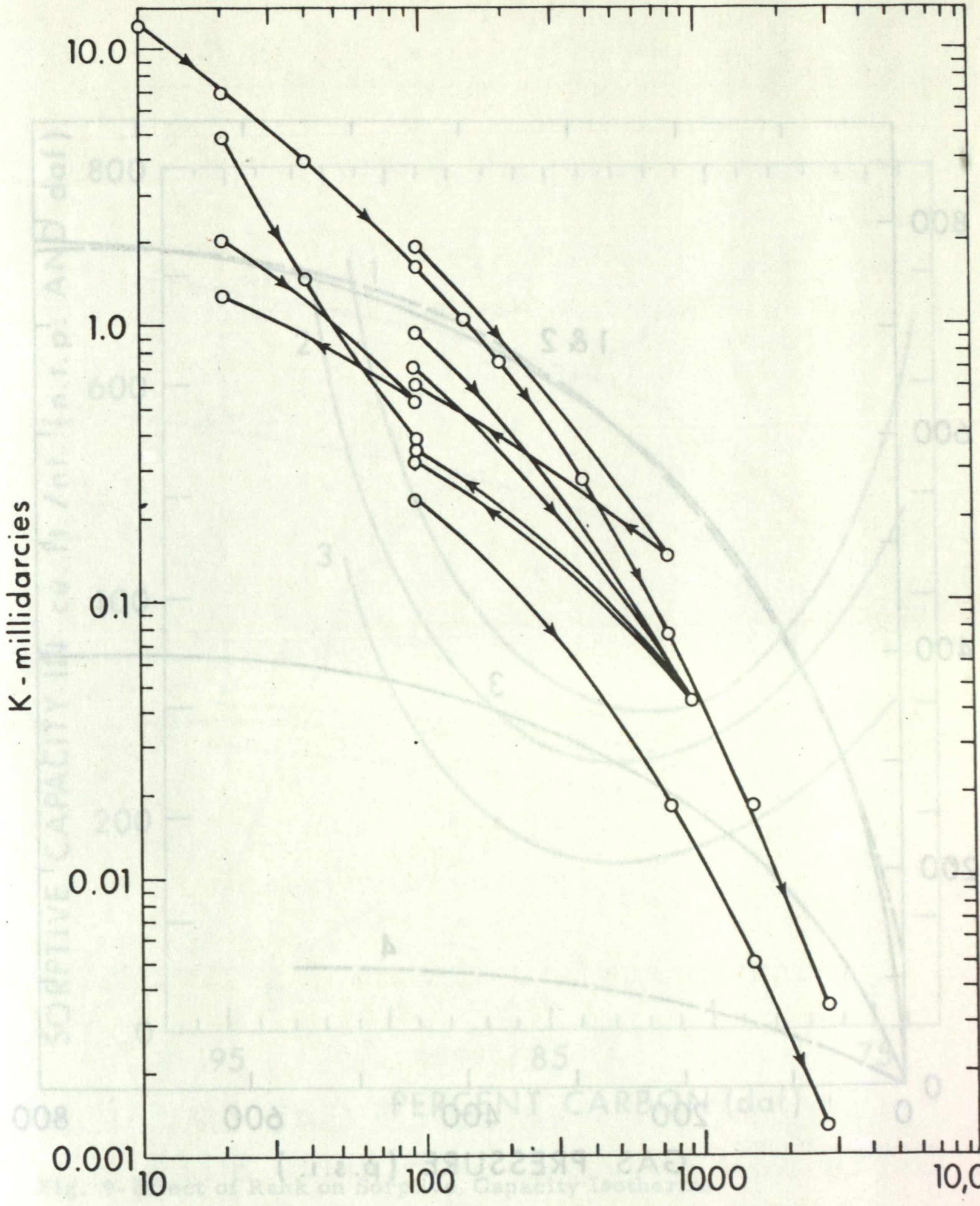



Fig. 11- Effect of Confining Pressure on Permeability Samples from Upper Marsh seam

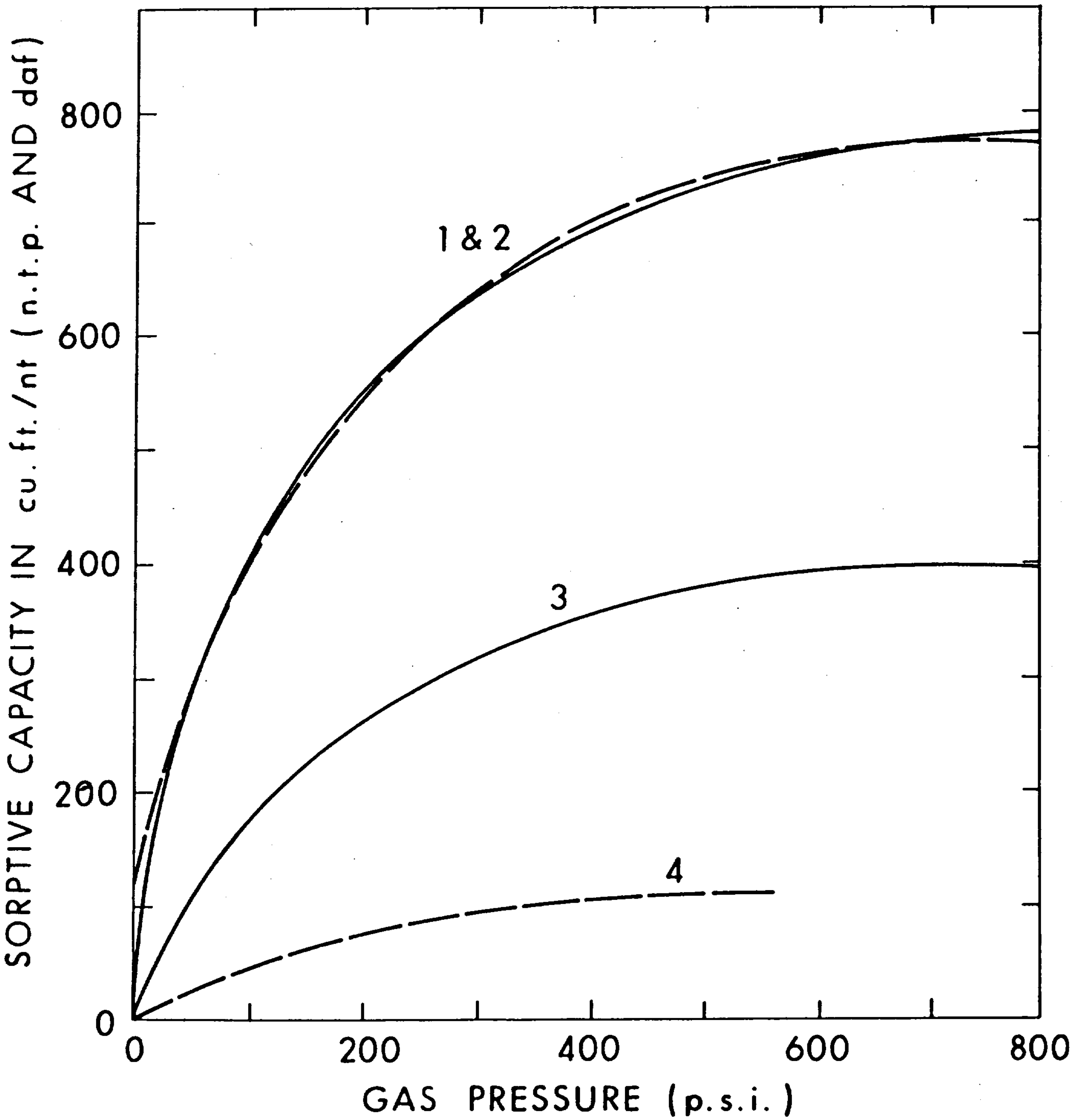



Fig. 10- Sorptive Capacity Isotherms for fine and coarse Coal
Gas - Methane, Temperature 24°C
1 and 2 Canmore coarse and fine coal
3. Springhill fine coal (-60 mesh)
4. Springhill coarse coal (4+42 mesh)

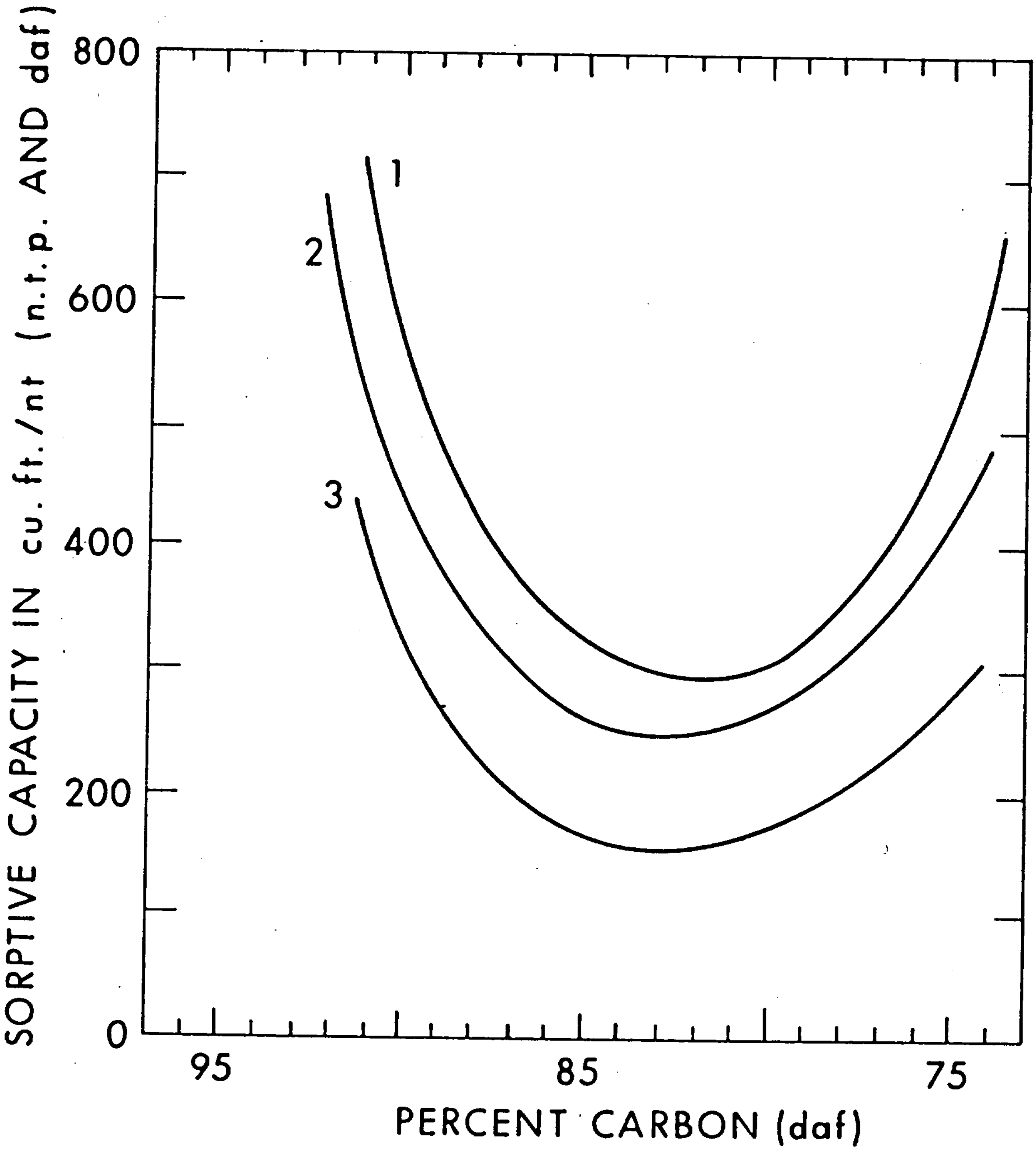
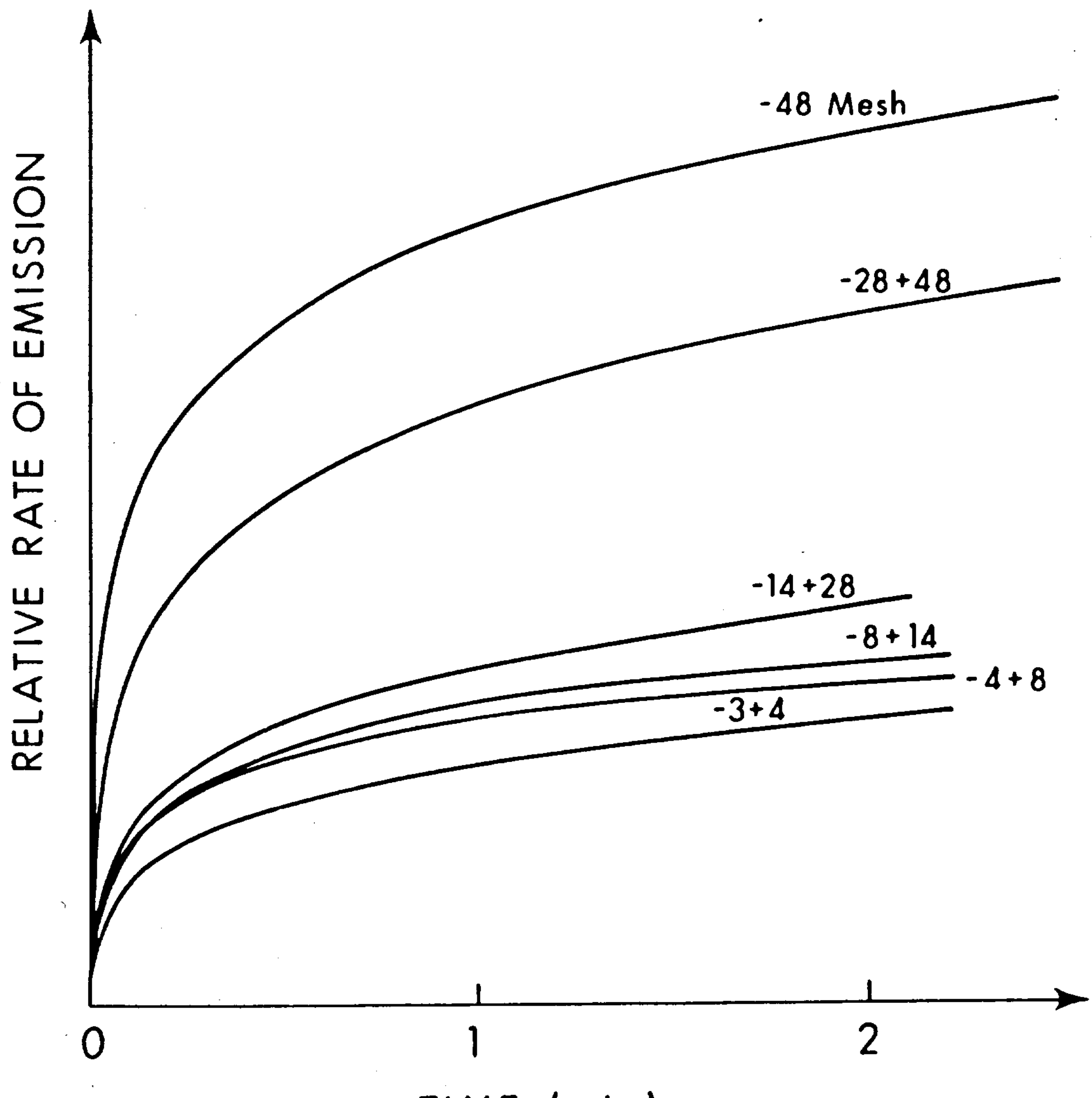



Fig. 9-Effect of Rank on Sorptive Capacity Isotherms
Based on 52 Samples from 14 different sources
Gas - Methane, Temperature 24°C

1. at 100 psi gas pressure
2. at 300 psi gas pressure
3. at 500 psi gas pressure




COMPOSITE PLOT RATES OF GAS EMISSION
UPPER MARSH COAL- DIFFERENT SIZES

Fig. 8 Relative Rates of Gas Emission

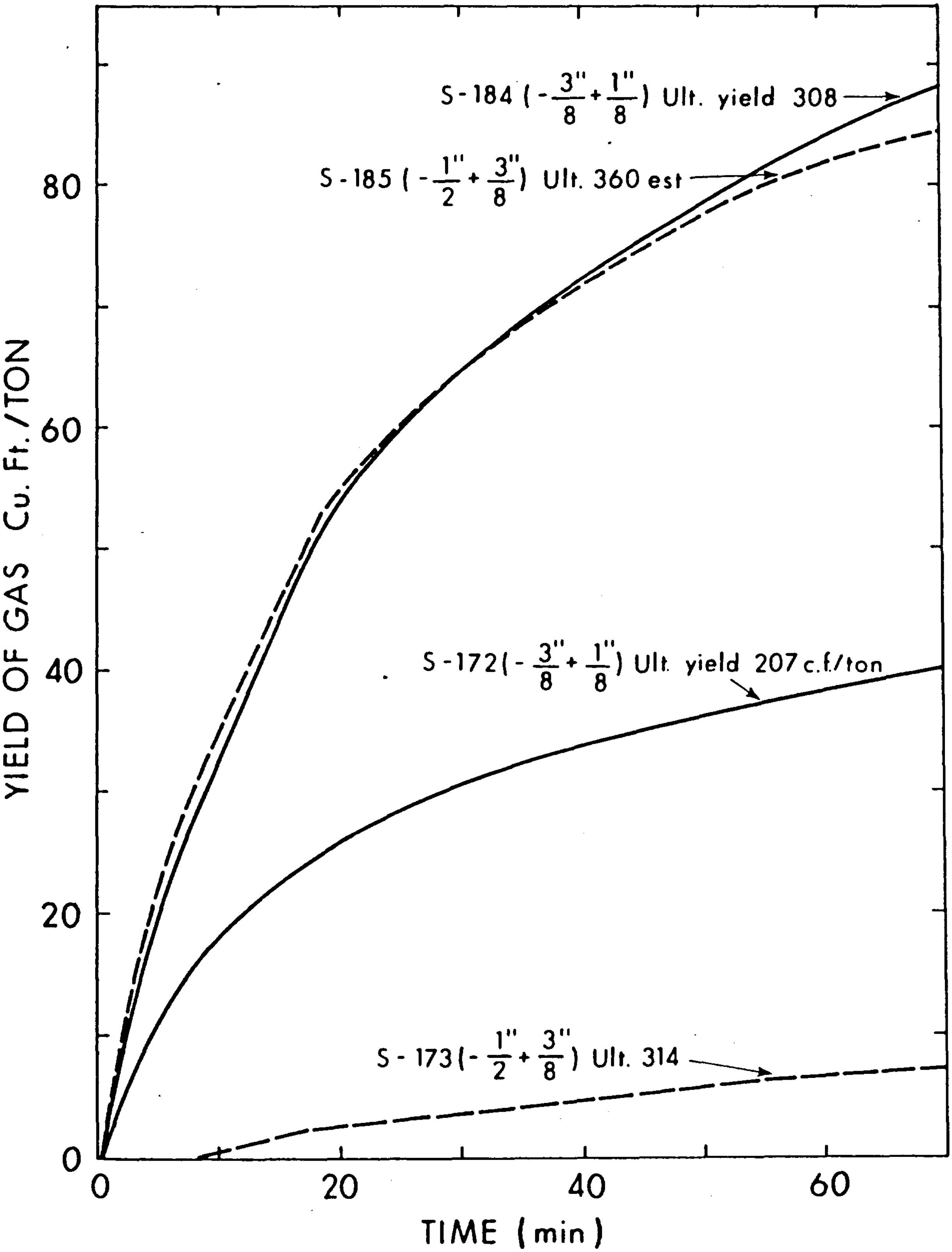



Fig. 7 - Rates of Gas Emission from Coal

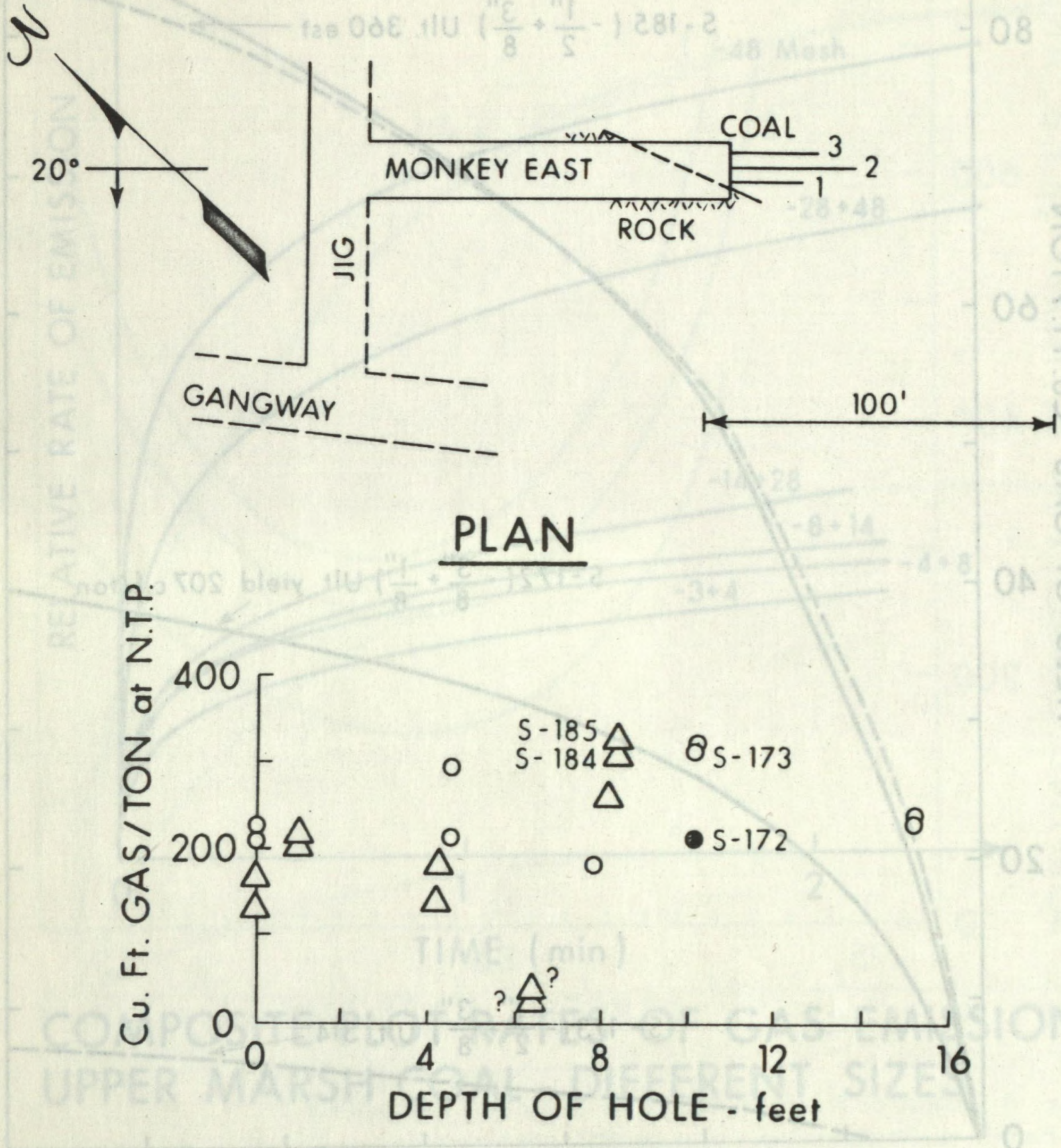



Fig. 6- Gas Content of Coal - Lower Marsh Seam
O Samples from No. 1 and 2 Holes
△ Samples from No. 3 Hole