Experience with well testing and in-situ stress measurement in the sydney basin for evaluation of coalbed methane prospectivity

by

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ABSTRACT

The invesitgation of coalbed methane prospects in the Sydney Basin, for Pacific Power and others, has routinely included the determination of insitu permeability of coal seams. This work has been undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Pacific Power using purpose built tools designed and constructued by the CSIRO. The methods employed provide for accurate test zone isolation and rapid test obsaervation, variation and repeat if desired.

This paper reviews the results of well testing from six such programmes and discusses the merits and limitations of the procedures utilised. The results of well testing have been found to be subject to test duration, history of sequential testing, test type - whether injection or production and differential pressures utilised. An understanding of the effects of these variables has permitted a clearer picture to emerge of the factors that influence the permeability of coal seams.

A broad range of permeability results have been determined for Sydney Basin coals. In wells tested to date results greater than 1 millidarcy are the exception rather than the rule. The wide range of results, for apparently similar coals led to an investigation of those factors that were considered to impact on in situ permeability. Secondary minerlisation is observed to reduce permeability. Coal seams with a high proportion of dull coal have unexpectedly high permeabiltiy in the Sydney Basin. The density of natural or induced fractures has been found to provide a strong correlation with measured permeability.

INTRODUCTION

Over the last three years, Pacific Power (formerly Electricity Commission of New South Wales) and others interested in coal seams and their hydrological behaviour have drilled and tested several wells distributed throughout the Sydney Basin (Figure 1). The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has developed a wireline well testing tool to measure important coal seam properties such as permeability and static reservoir pressure. Pacific Power has a similar tool that has complemented and supplemented the testing with the CSIRO tool. This paper discusses the well testing experience to date and seeks to relate the results to various geological conditions encountered in the Sydney Basin. In-situ permeability of the coal seams governs their gas production and well testing conveniently measures permeability.

Two types of test procedure, injection of water into or production of water from the coal seam, are possible with both tools. Both procedures theoretically should give the same results at the same horizon, but frequently they give different results. In some cases, the same procedure repeated with the same tool in the same horizon gives different results. These irregularities probably arise from a complex interaction of mechanisms inherent in coal seams that influence their response to pressure changes. Interpretation of well testing data in this unique environment consequently becomes a challenge. This paper presents the results of various tests on several seams to demonstrate the nature of some of these irregularities.

The paper also discusses the relationship of well testing results to geological factors including in-situ state of stress, secondary mineralisation, and coal type. Sydney Basin coals tested to date generally have low permeability, 100 to 500 µd, that secondary mineralisation can reduce or tectonic activity can increase significantly.

EQUIPMENT AND METHODS

CSIRO has developed a wireline well testing tool to measure intrinsic permeability and reservoir pressure, key properties needed to simulate flow of fluids in coal seams. The tool incorporates features that allow isolation of a target coal seam with inflatable packers and a downhole shut-in valve to eliminate nearly all wellbore storage effects. The construction of the tool permits its placement inside an HQ rod string with a straddle-packer assembly extending through the drill bit for seam isolation. The rod string serves not only to place the packers accurately but also as a conduit to inject water into the coal seam or as a storage chamber into which water from the coal seam can flow. Downhole shut-in to isolate a seam at depths up to 1000 metres and the ability to use the tool as drilling progresses make it an efficient exploration device. Efficiency increases because the test duration is short and one mobilisation of the drill rig is sufficient for both drilling and testing. Pacific Power has a similar wireline well testing tool that has provided complementary data in some horizons tested by both tools and supplementary data in horizons not tested by the CSIRO tool.

The transient pressure response to constant-rate water injection, or water production from the coal seam into the rod string under reduced pressure head, is the basis for analysis to determine the permeability and static reservoir pressure. The preferred analysis method uses the straight-line portion of the Horner plot showing shut-in pressure in the test horizon after injection or production. This analysis assumes single-phase radial flow in an infinite homogeneous reservoir. Typical Horner plots of test data appear in Figures 2 to 4. Some test horizons exhibit little or no wellbore damage (skin factor is near zero) as in Figure 2 (Koenig, *et al.*, 1990(b)), others appear severely damaged (skin factor is positive) as in Figure 3 (Casey, *et al.*, 1992), and still others show a degree of stimulation (skin factor is negative) as in Figure 4 (Koenig, *et al.*, 1991). The collection of recovery data after injection (or production) must continue for up to three times the duration of injection (or production) in many cases where damage or stimulation of the wellbore is evident. Otherwise, the recovery curve may not fully develop.

Much of the testing to date has used both injection and production tests in the same horizon to compare results for possible differences arising from stress sensitivity, gas desorption, fines migration, or other mechanisms that commonly occur in coal seams. Pressure differential between the reservoir and the wellbore has been varied in several instances to see whether the test results depend on the pressure differential. Tests in the same horizon with both "short" and "long" durations have been conducted to observe possible dependence of the results on test duration.

A production test employs the same procedure for either the CSIRO tool or the Pacific Power tool. With the tool positioned in the wellbore, compressed air applies pressure to the top of the rod string and forces water from the lower end of the rod string into the annulus between the wellbore and the rod string. After setting the packers and shutting the downhole valve, release of pressure on the rod string leaves a pressure head in the rod string lower than the pressure head in the reservoir. Opening the downhole valve after pressure in the reservoir stabilises allows natural production of water from the seam into the rod string. Measurement of pressure in the test interval and rod string allows calculation of the rate at which water flows from the seam since the volume in the rod string is known. The flow rate coupled with the pressure buildup after shut-in allows calculation of the permeability, and extrapolation of the pressure trend to infinite time gives the reservoir pressure.

Injection test procedures are different for the CSIRO tool and the Pacific Power tool. CSIRO uses a constant rate test and Pacific Power uses a constant head test. Both procedures begin with placement of the tool and inflation of the packers. While the pressure in the test interval stabilises, the rod string is filled with water. Simultaneous opening of the downhole valve and injection of water at a predetermined constant rate starts a CSIRO test. Pacific Power opens the downhole valve and measures the rate at which water must be added to keep the rod string full during the duration of injection. Measurement of the pressure during falloff completes the test cycle in both cases.

OBSERVATIONS FROM TESTING

Production Tests Compared to Injection Tests

Test horizons with repeated testing have yielded a variety of responses:

1. Production and injection test results differ probably because of alterations of the coal near the wellbore,

2. Hysteresis observed in reduction of permeability in some seams following repeated injection or production.

The Horner analysis used to compute permeability assumes that single phase, radial flow occurs in a homogeneous infinite reservoir. With these conditions prevailing, injection and production testing should yield similar estimates for permeability. In practice, however, production and injection testing at the same horizon have yielded permeabilities of different magnitudes.

In many instances the permeability determined from production tests has been greater than that from injection tests. In particular, during an exploration program near Robertson, 25 km south-west of Wollongong (Forster and others, 1988), permeabilities determined from production tests were as much as two orders of magnitude greater than injection permeabilities. In well EHKL 1, near Lisarow between Sydney and Newcastle, the production permeabilities were from 1.1 to 2.2 times greater than the injection permeabilities measured in the same horizon (Casey, *et al.*, 1992). An example of this phenomenon appears in Figure 5, which shows the Horner plots for an injection and a production test at the same horizon in borehole PHCY 1 (Forster, 1992(b)) near Rylstone on the western side of the Sydney Basin north of Lithgow. It is evident from the plots that the pressure response in the test section following the injection period is much different from the response following production. The response from the production buildup yields a straight line section of the Horner plot that yields a permeability of 1.9 md and a skin factor of 16.5 (indicating extreme borehole damage). In contrast, the straight line section of the injection Horner plot has a much higher gradient and yields a permeability of 0.011 md with a skin factor of -0.7.

The near-zero skin factor, as opposed to the skin factor of 16.5 determined in the production test, may suggest that the permeability measured in the injection test represents the permeability of a damaged zone near the wellface, and that the pressure transient has not penetrated the skin during the decay period. Clearly, however, there is a potential for confusion in deciding which permeability estimate more closely represents the true permeability of the coal seam. Since the prime reason for measuring the permeability is to evaluate the potential of the seam for coalbed methane production, the permeability determined from the production test may be more representative.

Several mechanisms are presumed to contribute to the observed differences between the production and injection permeabilities. An example of such a mechanism is fine particles in the borehole fluid forced into the coal-seam fractures and cleats during an injection test, hence reducing the permeability. Conversely, a production test may cause flow of uncontaminated ground water from the formation toward the borehole to dislodge some of the fines restricting flow and increase permeability. Another example of a possible mechanism is the excess pressure imposed on the test section during an injection test perhaps compressing the coal seam adjacent to the wellbore and partially close the fracture or cleat openings thereby lowering the permeability. Conversely, a production test might reduce pressure and relax the formation adjacent to the wellbore partially opening the water-bearing cleats or fractures to increase permeability. Either or both of these mechanisms could explain the test data.

The permeability derived from production testing of a given horizon does not always exceed that from injection testing. Two boreholes, EHL 1 (Llanillo) and EHRP 1 (Randwick Park) about 25 km south of Muswellbrook in the Hunter Valley, have yielded test results that do not follow a trend toward greater production permeabilities (Koenig, *et al.*, 1991). In these boreholes, the number of horizons in which the injection permeability is greater about equals the number in which the production permeability is greater.

Sensitivity of Test Results to Wellbore Damage

There is some suggestion from the test results that seams with a high skin factor (and therefore a low permeability zone adjacent to the borehole wall) are more likely to have a higher production permeability than injection permeability. Since many boreholes suffer some kind of formation damage during drilling, this would explain a tendency for production permeabilities to be greater than injection permeabilities. To investigate whether this trend is significant the ratio of production to injection permeability was plotted against the skin factor from the test that produced the higher permeability for twenty-six test horizons where both injection and production tests were performed. The resulting graph (Figure 6) shows some tendency for tests with a high skin factor to have a higher ratio of production permeability to injection permeability.

Hysteresis Effects

Hysteresis (dependence on testing history) is another interesting phenomenon observed in coal seams at some locations. At these locations, the results of testing seem to depend on previous testing history in a particular horizon regardless of the type of test conducted, whether production or injection. Borehole EHKL 1 near Lisarow shows hysteresis (Casey, *et al.*, 1992). CSIRO and Pacific Power conducted a total of six tests in the Wallarah Great Northern seam at an average depth of about 670 m (Figure 7). Three were production tests and three were injection. CSIRO conducted the first three tests with computed permeabilities apparently decreasing linearly from 0.069 to 0.013 md. Pacific Power conducted the latter three tests with computed permeabilities apparently decreasing from 0.14 to 0.019 md (Forster, 1992(a)). Production tests at this horizon generally preceded injection tests and yielded larger values of permeability. The same trend of decreasing computed permeability in subsequent testing occurred in the other horizons in borehole EHKL 1. Figure 8 shows the trends during CSIRO tests in seams at average depths of about 762 and 796 m (Casey, *et al.*, 1992). In this situation injection testing appears to damage the formation so that subsequent production testing yields lower permeability. Repeated injection testing appears to increase the damage.

Another example of hysteresis is apparent in Figure 9, which shows a total of four tests in the Hunter Valley that CSIRO and Pacific Power conducted in borehole EHRP 1 (Randwick Park) at the Bayswater seam (average depth about 445 m). The first two tests, conducted by CSIRO (Koenig, *et al.*, 1991), are examples of injection tests yielding greater permeability than production tests. The order of the tests rather than the type of test appears to control the result in this case. Pacific Power conducted a production test and a slug test (Forster, 1991). Once again, the first test conducted yielded the greater permeability.

Sensitivity to Differential Pressure

The calculated permeability for some coal seams appears to depend on the magnitude of the differential pressure (the difference in pressure between the reservoir pressure and the applied pressure to induce flow either into or out of the test horizon) used in test. To test the influence of this aspect, five production tests were performed on the Katoomba Seam in borehole PHCY 1 near Rylstone (Forster, 1992(b)) with differential pressures ranging from 175 to 871 kPa. The five production tests yielded flow rates directly proportional to the pressure. The calculated permeabilities ranged from 0.66 to 2.55 md, with the higher permeabilities derived from tests carried out at higher differential pressures. Hysteresis did not appear to influence the results in this seam. Figure 10 shows a plot of permeability versus the differential pressure, normalised to the static reservoir pressure. It shows an almost linear correlation between the two. Such differences in computed permeability could have significant impact on determining the production potential of a seam and the economic viability of a reservoir.

The calculated permeability for many other coal seams seems independent of the magnitude of the differential pressure. As an example of this behaviour, Figure 11 shows a sequence of four production tests in a coal seam at an average depth of 324 m at EMA 52 (Mt. Arthur) (Koenig *et al.*, 1990 (a)), which is about 7 km north of EHL 1 (Llanillo). The large flow rate during production and the extremely rapid recovery to the static reservoir pressure indicate a severely damaged, highly permeable coal seam. The flow rate during the first flow period was 2.04 l/min at a differential pressure of 1.1 MPa, which yields a permeability of 46 md and a skin of 20. The flow rate during the fourth flow period was 0.894 l/min at a differential pressure of 0.414 MPa, which yields a permeability of 47 md and a skin of 20.

There are also some indications from test data that differential pressure influences injection test results. In this case, higher injection pressures may lower permeabilities. However, controlled tests have not confirmed this phenomenon to date.

Influence of Test Duration

A test of longer duration generally represents a larger portion of a coal seam because the radius of investigation (the distance a pressure transient moves through a formation following injection or discharge at the wellbore) is directly proportional to the square root of test duration. A longer test would be more apt to detect possible permeability enhancement from fractures spaced on a larger scale.

In the Arrowfield seam at EHRP 1 (Randwick Park), a "short" test of one hour with the Pacific Power tool gave a permeability of 0.90 md and a "long" test of five hours with the Pacific Power tool gave 0.22 md. In the Bayswater seam (average depth of 444 m) at EHRP 1 (Randwick Park), a "short" test of one hour with the CSIRO tool over the test interval 441 to 448 m gave a permeability of 0.14 md and a "long" test of five hours with the Pacific Power tool over the test interval 438 to 449 m gave 0.46 md. Since the test intervals at the Bayswater seam were slightly different and the tools used to test the seam were different, a direct comparison is impossible at this horizon. In the Wallarah Great Northern seam (average depth of 670 m) at EHKL 1 (Lisarow), a "short" test of two hours with the Pacific Power tool gave a permeability of 0.13 md while a "long" test of six hours with the Pacific Power tool also gave 0.13 md (Forster, 1992(a)).

The results of "short" and "long" production tests at EHRP 1 (Randwick Park) and EHKL 1 (Lisarow) were inconclusive, therefore, regarding the influence of test duration on permeability results (Forster, 1991). In the exploration context, tests of one to six hours are likely to give comparable results. Tests of much longer duration may be necessary to investigate this phenomenon in the relatively low permeability coal seams encountered to date. This extended testing is beyond the exploration context, however, and into the realm of detailed site evaluation as a prelude to production activity.

GEOLOGICAL FACTORS THAT INFLUENCE TEST RESULTS

Primary and Secondary Permeability

In broad terms, permeability in coal can be thought of as primary or secondary. Primary permeability relates to matrix permeability in conventional reservoir rocks and to the microstructure and cleat development in coals. Coal petrography and the impact of secondary mineralisation influence primary permeability. Secondary permeability results from contemporary or post-coalification geological structures such as joints, faults, or shearing. Secondary permeability often may dominate apparent permeability. Fractures and shear zones intersecting coal seams can dramatically increase the gross permeability of a coal seam under test, without necessarily reflecting substantial access to the bulk of the coal matrix. Generally, significant secondary permeability indicates existence of paths created in the coal for water and gas to migrate to drainage wells.

Secondary permeability in coal seams broadly depends on sub-vertical or sub-horizontal features. Sub-vertical features, such as joints and high angle faults, are often thought of as a major source of secondary permeability in United States coal seams. The authors' experience with Australian coal seams to date has indicated that such features can significantly influence the permeability measured by well testing. However, experience has been that such features are often absent in the coals of the Sydney Basin. This presumably has a great deal to do with the difficulty of sampling sub-vertical features from vertical exploration holes.

The influence of sub-horizontal features on secondary permeability also has been obvious in the authors' experience. Anecdotal evidence from coal mining operations in the Bowen Basin suggests that gas production rate is related to the existence of low angle shear zones in the coal seams. Considerably more gas flows into the mine ventilation system when a shear zone is in the coal being mined. A program of in-situ rock stress measurement conducted throughout the Bowen Basin for coal mining purposes has provided an indication of the mechanism giving rise to low angle shears in coal seams. A sudden change in the magnitude and orientation of the horizontal stress field from above to below a coal seam in a sequence appears related to stress re-adjustment associated with low angle shearing occurring through the sequence.

An example of similar behaviour in the Sydney Basin occurs in the Hunter Valley. Figures 12 and 13 summarise in-situ stress measurements made in two holes, EHL 1 and EHRP 1, approximately 3.6 km apart in a stratigraphic sequence of coal seams (Singleton Coal Measures), sandstones, and finer-grained sediments. The measurements were made in sandstone units of various grain sizes using the hydraulic fracturing technique. The results in Figures 12 and 13 (Enever and Edgoose, 1991) represent the magnitudes of the horizontal secondary principal stresses as a function of depth, with respect to the corresponding vertical stress trend with depth estimated from overburden pressure. At EHL 1 (Figure 12) the horizontal stress field appeared to increase systematically with depth (Enever and others, in preparation). The corresponding profile of coal seam permeability with depth (Figure 14) in the same hole, suggests no obvious evidence for permeability depending on stress or depth. By contrast, at EHRP 1 (Figure 13) the profile of horizontal stress field with depth shows marked change at several points in the sequence, with the general magnitude increasing and decreasing across coal seams. These changes in the horizontal stress field appeared to correlate with zones of structural disturbance to the seams. As with the Bowen Basin, this is likely due to low angle shearing intersecting the sequence, associated with major episodes of thrusting in the region. An alternative explanation for the noted changes in the stress field could be differential slippage along coal seams in response to folding of the sequence. Whatever the cause of the observed changes in the stress field, the net effect seems to be enhanced permeability in the affected coal seams as shown by the profile of seam permeability with depth (Figure 15) in the same hole. Figure 15 indicates significant variation in permeability, with a low background permeability, enhanced by an order of magnitude in some seams.

The information summarised in Figures 12 and 13 provides a basis for developing strategies to guide exploration for higher permeability targets in preferred stress regimes.

In an attempt to quantify the effect of various significant geologic factors on permeability, the results of testing major coal seams in Pacific Power boreholes to date appear in Table 1. For each horizon an index has been defined to evaluate the influence of each of mineralisation, cleat development, and fracture development.

Primary Permeability and the Effect of Mineralisation

For each seam, the mineralisation index listed in Table 1 represents the percentage of coal plies containing visible mineralisation. In the Sydney Basin this usually consists of calcite and to a lesser extent siderite. It's presence is readily determined in the log of a drill core. The mineralisation usually occurs as off-white or brown infilling of the coal cleat, joints, or the fabric of the coal itself.

A plot of production results at EHRP 1 (Figure 16) suggests a tendency for permeability to decrease with increasing mineralisation index. A similar tendency appears in a plot of injection permeability for all holes versus mineralisation index (Figure 17). The effect of mineralisation in obstructing flow paths within the coal matrix, thereby reducing permeability, is evident.

Primary Permeability and the Effect of Cleat

For each seam listed in Table 1 the cleat index represents the total percentage of coal logged as dull with only minor bright laminae. The coals of the Sydney Basin vary from inertinite dominated coal to vitrinite dominated coals. Many seams alternate from layers high in vitrinite to layers where vitrinite is nearly absent. The inertinite rich coal is dull and blocky. It tends to fail with wider spaced major joints when subjected to stress. Vitrinite rich coal, on the other hand, is bright , brittle, and made up of finely-divided rectilinear components. It tends to fail with closely spaced, irregular, minor joints when subjected to stress. In effect, it crumbles and provides no major path for permeability. When subjected to further stress, the crushed coal or joints can be recompacted. The actual cleat faces are often very smooth and when compressed by lateral stress may provide only limited horizontal permeability.

The relationship evident from production tests at EHRP 1in Figure 18 and injection tests for all seams in Figure 19 is that in the Sydney Basin, with its high lateral stresses, the brighter the coal, the lower the permeability. On the other hand, the higher the inertinite content, the more dull the coal and the higher the permeability. This result contradicts the prevalent concept that greater permeability is associated with better cleat development. The explanation of this phenomenon may involve a complex interaction of mechanisms. Brighter coals tend to be more elastic and less susceptible than dull coals to fracturing with applied stress. On the other hand, the better developed cleat in brighter coals may make them more susceptible to secondary mineralisation.

Secondary Permeability and the Effect of Fractures.

For each seam listed in Table 1 a fracture index has been determined from either inspection of the core or core photographs and the actual geological and geotechnical logs. The fracture index represents the total length of joints per metre of coal drill core. As such it indicates the amount of jointing that may serve to act as conduits for permeability adjacent to the wellbore.

Near vertical fractures as are evident in EMA 52 (Mount Arthur) are believed to be the product of stress relief and act to enhance the permeability evident in the testing of that borehole (Koenig *et al.*, 1990; Allen et al., 1990(b); Forster, 1990). The western coalfield of the Sydney Basin contains dull coals that are consistently heavily fractured. Where tested (ELN 84 and PHCY 1) the coal seams have shown high permeability (Allen *et al.*, 1990(a); Odins and others, in preparation). In the Newcastle coalfield, borehole EHKL 1 intersected 7 m of relatively bright, clean coal. Mineralisation is sparse and joints are poorly developed (Rehfisch and others, 1992). The In-situ horizontal stress is high and relatively balanced and this together with the coal type appears to contribute to the lack of well developed fractures and hence the low level of permeability recorded.

A plot of production permeability versus fracture index at EHRP 1 (Figure 20) suggests a tendency for permeability to increase with increasing fracture index. A similar tendency appears in a plot of injection permeability versus fracture index for all boreholes (Figure 21).

CASE STUDY OF LLANILLO AND RANDWICK PARK

Almost all of the permeability values in coal seams at EHL 1 (Llanillo) are less than 100 d and the remaining few are between 100 and 200 d (Figure 14). Less than 4 km west at EHRP 1 (Randwick Park), in the same coal seams, which are generally 100 to 150 m shallower, permeability values mostly are between 100 and 500 d (Figure 15). Permeability values in four of the seams at EHRP 1 are below 100 d, and permeability is more than 1000 d in four other seams. Intense mineralisation readily explains the consistently low permeability at EHL 1 (Bocking *et al.*, 1992) compared to EHRP 1, where mineralisation is conspicuously less (Smith and others, 1992). The wide variation in permeability values at EHRP 1 correlates with changes in the stress field as discussed above and illustrated in Figure 13. Interestingly, large changes in the static water level occurred at EHRP 1 in horizons where the changes in stress field also occur. The static water level generally lies between 20 and 40 m below the ground surface. However, the static water level is from 5 m up to more than 100 m above the hydrostatic level in horizons where the changes in stress field occur.

Local conditions at EHL 1 and EHRP 1 vary widely and cause quite different responses during well testing. Effects of stress and mineralisation clearly act to enhance or reduce background permeability.

SUMMARY OVERVIEW OF THE SYDNEY BASIN

Permeability measurements from widely distributed locations in the Sydney Basin ordinarily are in the range of 100 to 500 d and suggest low inherent permeability. Lower or higher permeability has occurred at specific locations or coal horizons depending on local conditions of coal type, tectonism, or secondary mineralisation.

Reduction of permeability to very low values from 10 to 100 d can result from secondary mineralisation as observed at EHL 1 and at specific seams in many other locations throughout the Sydney Basin.

Permeability enhancement due to tectonism and stress relief has occurred in some locations like the western coalfields near Lithgow, where the dull, blocky coal with some open joints has permeability values from 1 to 6 md (Allen and Camp, 1990). Very large permeability values of 10 to 100 md occurred at EMA 52 (Mt. Arthur), which is about 7 km north of EHL 1 (Llanillo). Considerable stress relief, possibly associated with local faulting or intrusions, may explain the large permeability.

CONCLUSIONS

Results of exploration well testing to date have indicated that, in addition to various geological factors, testing methods and conditions influence the permeability value determined from a test in a slim hole. Further work is necessary to determine the relative importance of all the factors that can affect a well test result. Caution and experience are, therefore, valuable assets to interpret test data and to evaluate the potential of coal seams in the Sydney Basin for coalbed methane production.

The radius of investigation of a test conducted in a very low permeability (say less than 1 md) coal seam is quite small (a few metres or less) even if the test duration is several hours. It would seem prudent to investigate in some of these tight seams the effect of a small-scale hydraulic fracture stimulation or jetted completion to penetrate further into the coal seam. If the permeability is still low after the treatment, there is more confidence that the low permeability value correctly represents the bulk of the coal seam at that location.

In a test horizon where there is to be both an injection and a production test, the production test should precede the injection test to minimise the potential of moving coal fines or other particulate matter into the coal where it may become lodged and reduce permeability. However, production testing should be avoided in cases where reduction of the pressure in the coal seam possibly could bring about desorption of methane. A separation of several days between production and injection tests may reduce hysteresis effects that possibly would occur with an immediate succession of tests.

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Figure 1. [illegible]

Borehole	Seam	Depth (m)	k (μd) Inj	k (μd) Prod	Min. Index[1]	Cleat Index[2]	Frac. Index[3]
EHRP 1	Arrowfield	219.0-222.0	800	900	16	27	0.4
	Warkworth	298.8-303.9	-	64	43	18	0.5
	Mt. Arthur	331.3-336.3	560	160	33	16	0.4
	Broonie	429.3-434.0	1100	1500	6	59	0.5
	Bayswater	442.5-446.7	340	460	6	80	0.9
	Ramrod Ck	549.0-555.2	1000	1000	0	54	1.0
EHL 1	Arrowfield	324.4-327.3	94	31	84	16	0.4
	Warkworth	400.0-405.1	15	16	50	5	0.1
	Mt. Arthur	429.4-436.3	18	16	67	32	0.2
	Broonie	574.5-578.3	39	-	50	45	0.1
	Bayswater	583.3-589.7	13	4	58	52	0.4
	Ramrod Ck	715.6-717.7	96	-	27	61	0.5
PHCY 1	Katoomba	485.0-490.2	10	1630	5	78	1.0
ELN 84	Middle River	307.5-309.2	1480	-	25	91	0.4
	Irondale	387.1-388.4	1460	-	1	15	0.9
	Lithgow	412.1-417.4	5000	-	1	85	1.1
EMA 52	Glen Munro	84.3-87.4	15700	-	22	18	0.4
	Piercefield	323.8-326.2	1300	12000	6	45	0.8
	Bayswater	398.5-402.5	3900	10000	6	59	1.0
	Edinglassie	497.5-503.6	-	19000	0	8	1.0
EHKL 1	W. Gt. North.	666.3-673.4	42	69	9	6	0.2
	Fassifern	697.9-699.4	-	73	0	9	0.2
	F.J.Hily Hill	759.0-764.7	170	370	0	19	0.1
	Australasian	792.7-800.0	68	81	3	41	0.2

(1) Mineralisation index = percentage of coal plies containing visible mineralisation from examination of the coal core.

(2) Cleat index = percentage of dull coal plus percentage of dull, minor bright coal from examination of the coal core.

(3) Fracture index = total natural fracture length/coal seam thickness.

Table 1. Comparison of permeability results

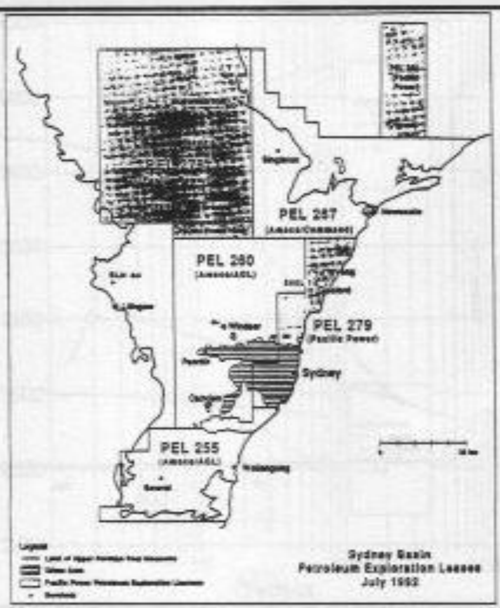

Figure 1. Sydney Basin exploration leases, July 1992.

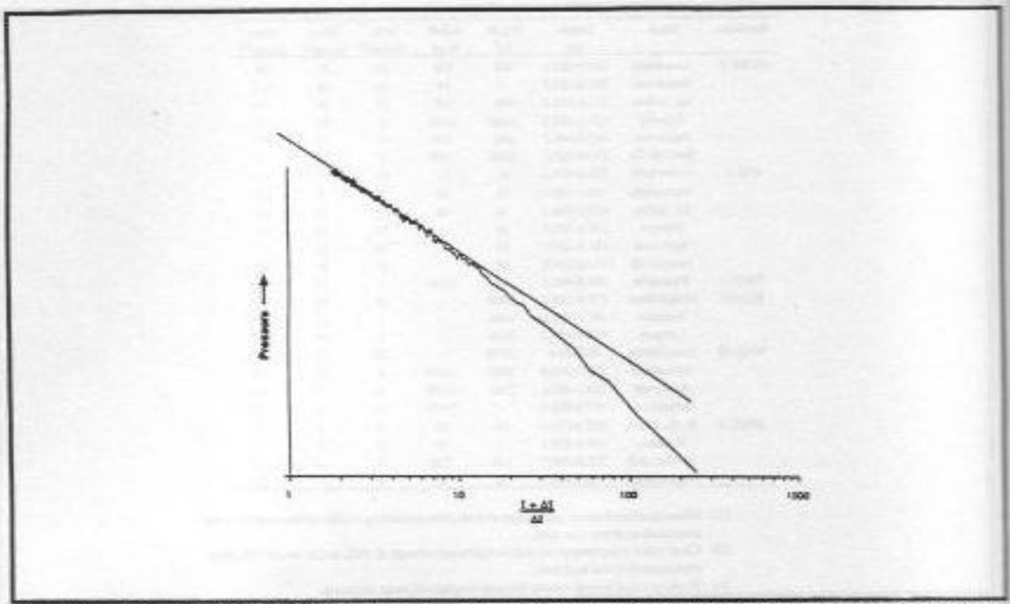

Figure 2. Horner plot of a typical production test in a well with insignificant wellbore damage (Bulli seam near Tahmoor).

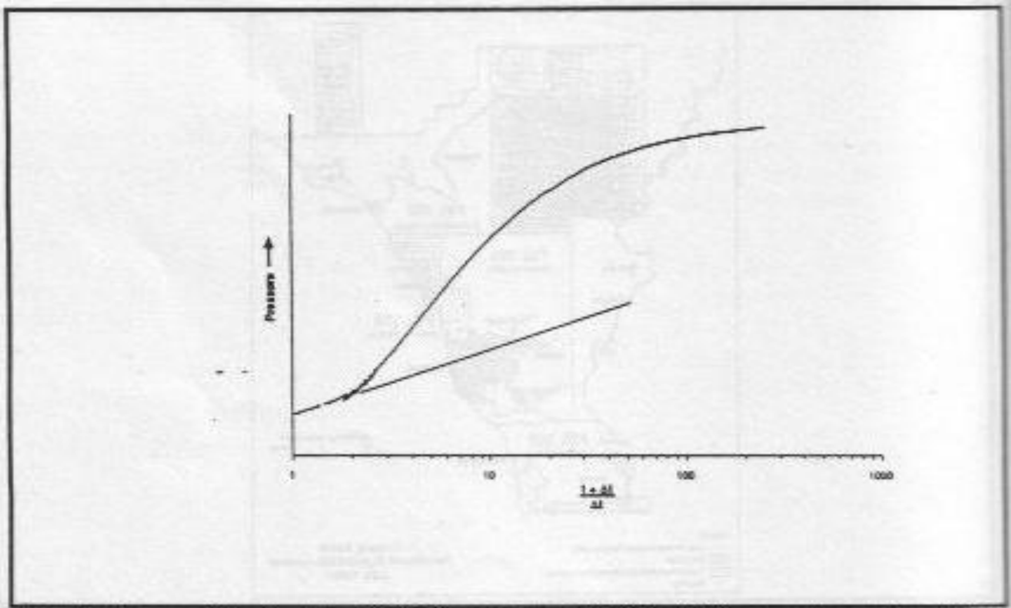

Figure 3. Horner plot of a typical injection test in a well with significant wellbore damage (F.J. Htly Hill seam near Lisarow).

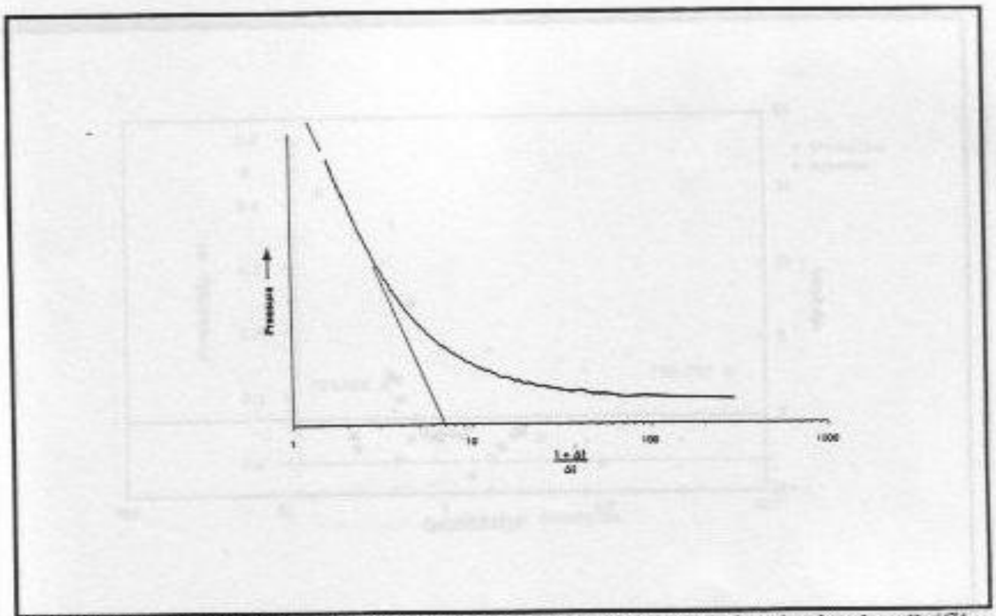

Figure 4. Horner plot of a typical production test in an apparently stimulated well (Glen Munro lower seam at EHPR 1).

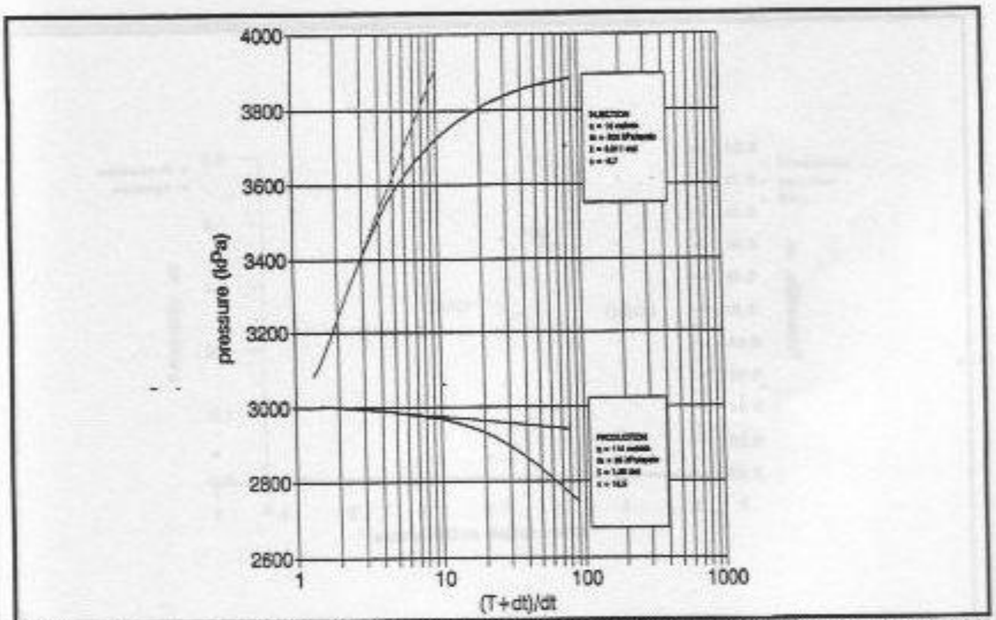

Figure 5. Horner plots for an injection and a production test in the Katoomba seam at PHCY 1.

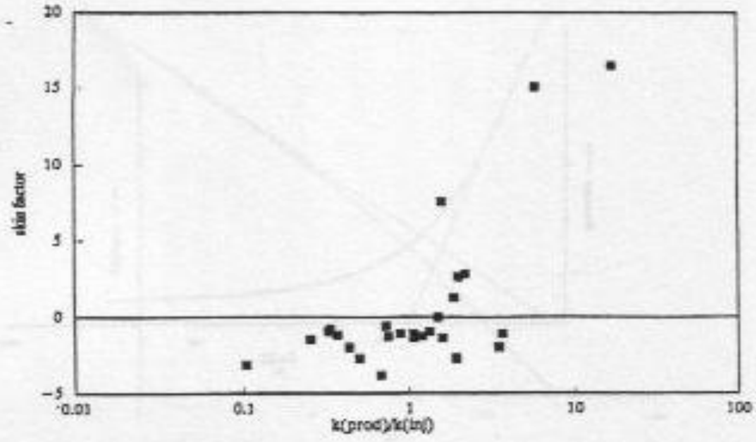

Figure 6. Ratio of production to injection permeability from twenty-six test horizons.

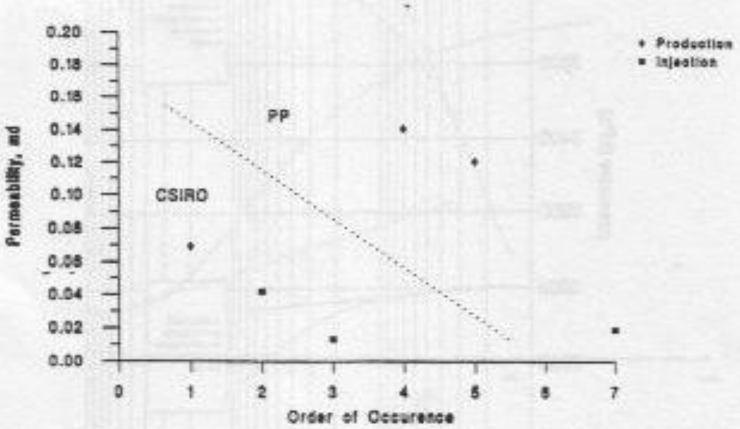

Figure 7. Permeability versus order of occurrence in the Wallarah Great Northern seam EHKL

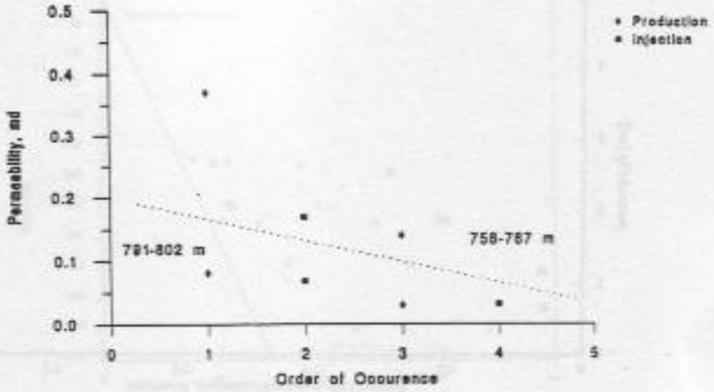

Figure 8. Permeability versus order of occurrence in two seams at EHKL 1.

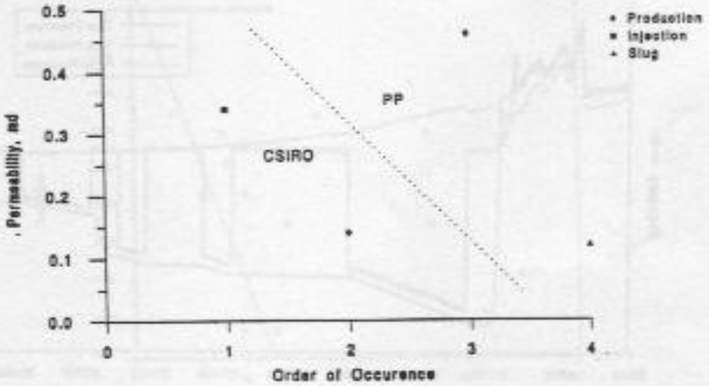

Figure 9. Permeability versus order of occurrence in Bayswater seam at EHPR 1.

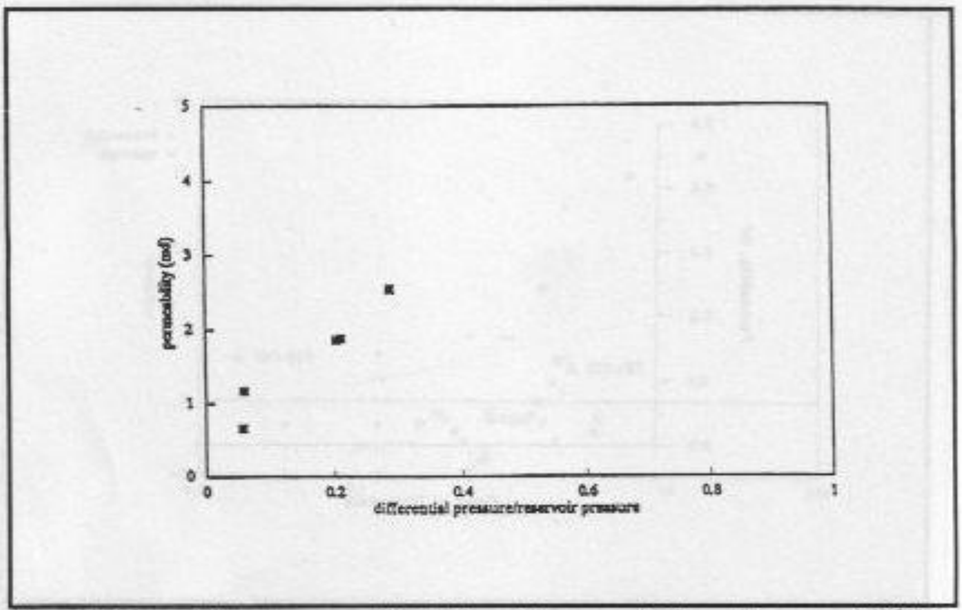

Figure 10. Permeability versus normalised differential pressure in Katoomba seam at PHCY 1

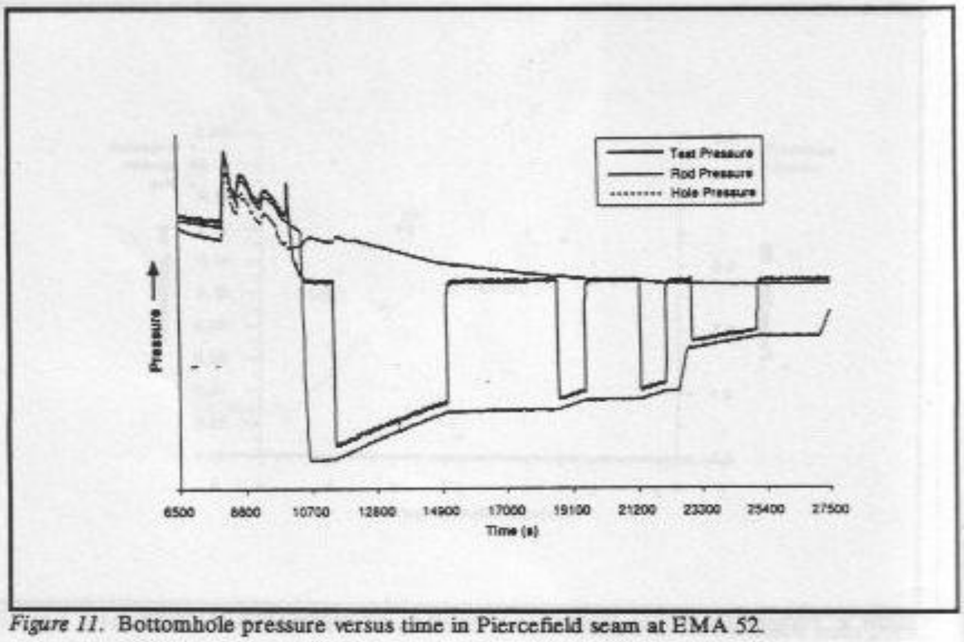

Figure 11. Bottomhole pressure versus time in Piercefield seam at EMA 52.

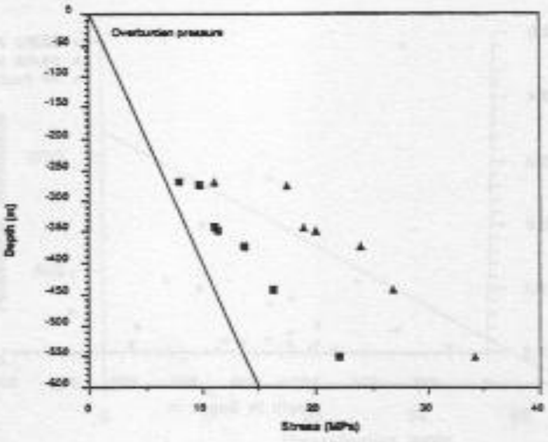

Figure 12. Horizontal stress at various depths at EHL 1.

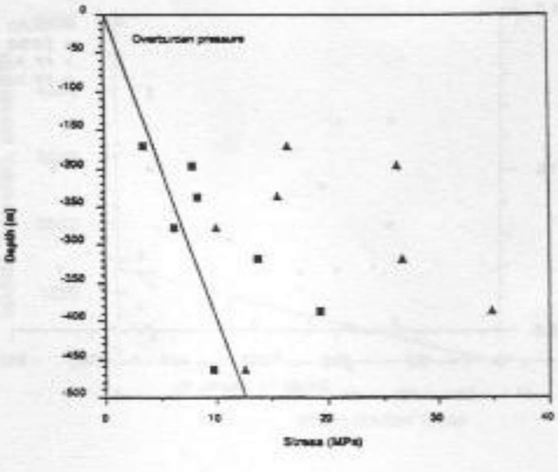

Figure 13. Horizontal stress at various depth at EHPR1.

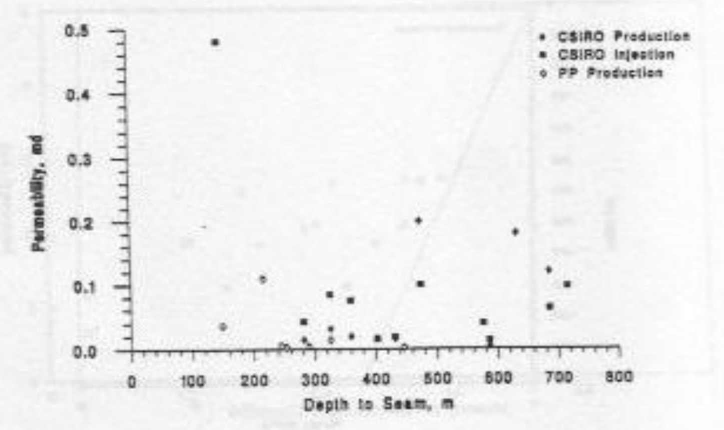

Figure 14. Permeability versus depth to seam at EHL 1.

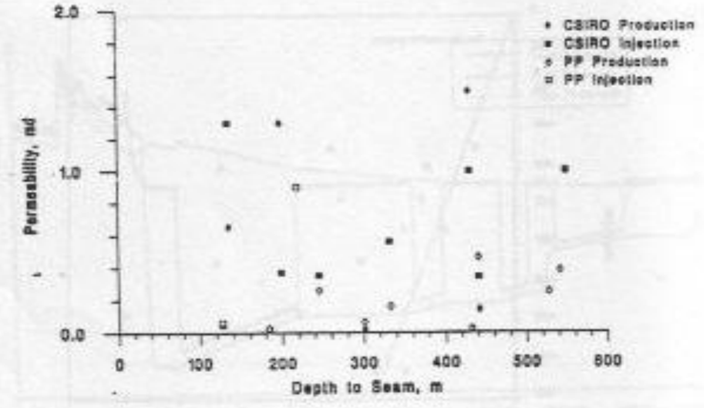

Figure 15. Permeability versus depth to seam at EHPR 1.

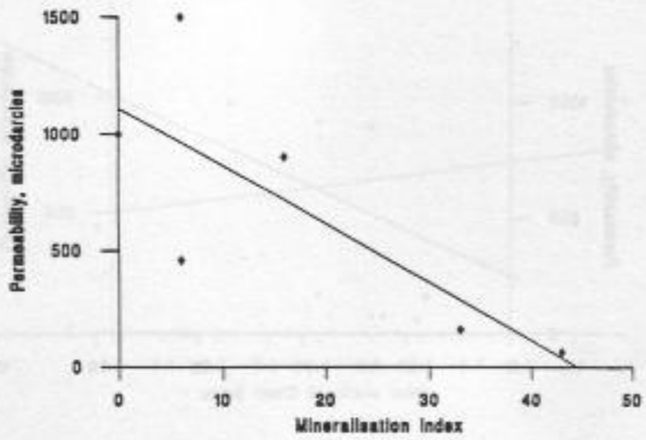

Figure 16. Permeability versus mineralisation index for six seams at EHRP 1.

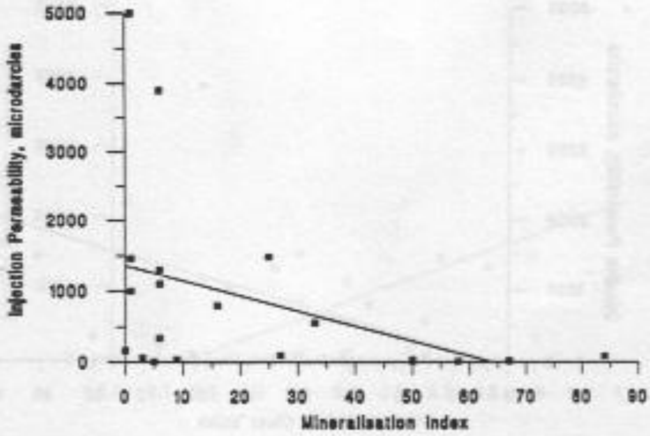

Figure 17. Permeability versus mineralisation index for all seams in Table 1.

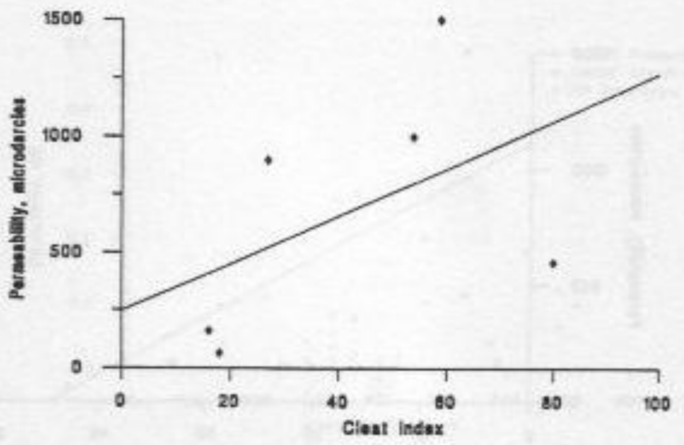

Figure 18. Permeability versus cleat index for six seams at EHRP 1.

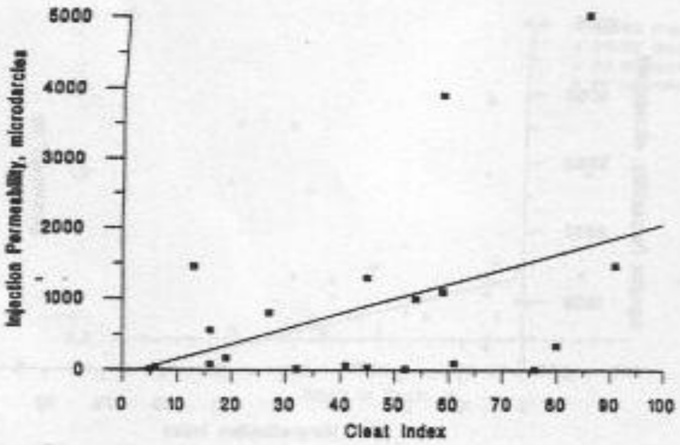

Figure 19. Permeability versus cleat index for all seams in Table. 1.

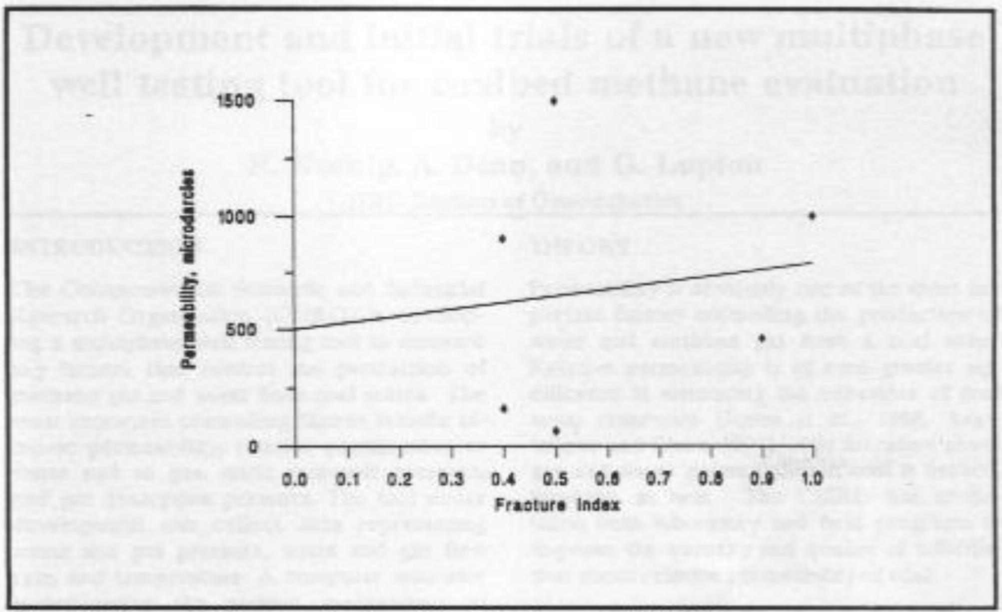

Figure 20. Permeability versus fracture index for six seams at EHRP 1.

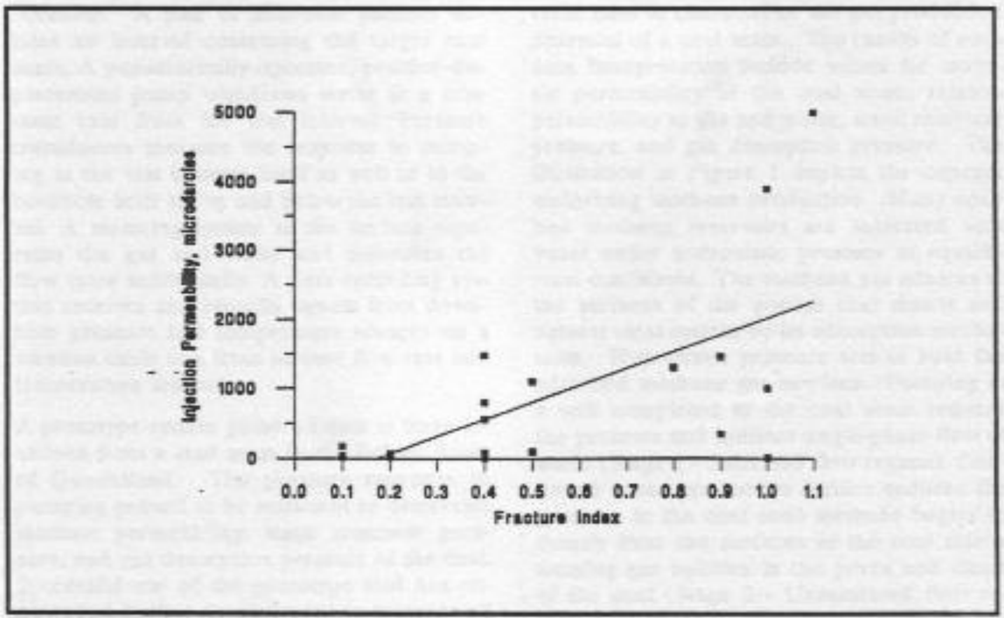

Figure 21. Permeability versus fracture index for all seams in Table 1.