PEDL073 Ayrshire

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Licence Area

PEDL073: 900km^2 – blocks ST40, ST41, ST42, ST50, ST51, ST52, ST61, ST62 and ST71

The licence area covers the central Ayrshire coalfield/Mauchline Basin, southern Ayrshire coalfield/ Dalmellington subbasin and Sanquhar basin (ST 71).

Regional Structural Setting

This area is the southwesternmost portion of central Scotland's Midland Valley, a relatively low-lying, 80km wide, northeast-southwest trending ancient rift valley that contains numerous Carboniferous formations that are prospective targets for CBM exploration and development. The Midland Valley lies between the Grampian Highlands in the north and the Southern Uplands. The Highland Boundary Fault delimits the northern boundary of this Devonian graben and the Southern Upland Fault marks the southern limit. Vertical displacement across the Southern Upland Fault began 400 m.y.b.p. and continued into the Carboniferous with a net downthrow to the northwest in excess of 900m.

Although the region is known as the Midland Valley, the term is appropriate only in a structural sense; physiographically the area is more diverse. Much of the area consists of farmland below 180m in elevation, but there are also many upland areas of rough pasture and moorland exceeding 400m in height. In PEDL073 higher areas include Benbain, Benbeoch, Benquhat and Cairn Table near Muirkirk.

The Ayrshire prospect consists of one large basin, Mauchline, and four smaller or subbasins situated along the southern and eastern perimeter. The central and northwestern licence regions encompass most of the Mauchline Basin, a broad syncline up to 1,500+m deep with a northwesterly axial orientation. The Mauchline Basin measures 30km east to west and 25km north to south and extends a few kilometers northwest of the licence. At the perimeter of the Mauchline Basin, several subbasins, Dalmellington, New Cumnock and Muirkirk, are situated to the southwest, south and east, respectively. These are 750 - 1,000m deep and no more than 15km^2 in areal extent within the licence. The Muirkirk syncline is larger but extends northeastward beyond the licence boundary. The Sanquhar Basin is located immediately south of the Southern Upland Fault on the eastern side of PEDL073 and is roughly 50 km^2 in area and up to 600m deep.

The Southern Upland Fault is accompanied by a group of associated faults subparallel to the main fault, including Kerse Loch Fault, Littlemill Fault, Leadhills Fault and Glenmuir Fault, all of which transect the PEDL073 region. The former two mark the southern edge of the deepest part of Mauchline Basin. A series of lesser normal faults subparallel to the axis of Mauchline Basin also transect the region. The intersection of the two fault trends has created a large number of discrete fault-bounded blocks within PEDL073, for example Sanquhar Basin which is delimited by the Southern Upland Fault to the north and by the crosscutting, northwest-trending Sanquhar Fault to the east.

For the purpose of CBM exploration, an individual fault block can be expected to have unique stress conditions and associated water and gas production characteristics since individual coal seams would be truncated and offset at block margins. Individual boundary faults could serve either as impermeable structural boundaries or as regions of enhanced permeability, depending on pore and stress conditions. Folding is generally associated with faulting in the Ayrshire prospect and locally the geology is structurally complex, such as in the Muirkirk syncline.

Geologic Target Formations

The target coal-bearing formations are all Carboniferous (master overlay and overlay 1). The sequence of prospective formations upwards is: Lower Carboniferous - Lower Limestone Group formation of the Carboniferous Limestone Series (secondary target); Upper Carboniferous Millstone Grit Series – Limestone Coal Group formation (primary target), Upper Limestone Group formation (secondary target) and Passage Group formation (tertiary target); and Upper Carboniferous Coal Measures Series – Lower Coal Measures and Middle Coal Measures formations (secondary targets). The latter two formations used to be collectively known as the Productive Coal Measures. The Upper Coal Measures formation is included within the Coal Measures Series but is not prospective for CBM in Ayrshire.

The target formations have been deposited on Ordovician to early Carboniferous sedimentary and igneous rocks in Ayrshire. Penecontemporaneous to target formation deposition, basic igneous rocks were deposited as sills, dikes and flows over a period of 70 million years during the middle Carboniferous through early Permian. This igneous activity was associated with continental rifting and crustal thinning that were precursors to development of the Atlantic Basin. In central Ayrshire, the youngest rocks are Permian aeolian sediments of New Red Sandstone formation which cap basalt flows and Upper Coal Measures sedimentary rocks. These sandstones reflect a major change of climate and environment from deposition of the earlier cyclic coal-bearing sequences under humid conditions in a fluvio-deltaic environment near sea level to more arid and continental conditions. A hiatus in deposition, or unconformity, associated with regional uplift and later deposition of Permian dune sandstones in a dry climate

resulted in deep oxidation of the upper part of the Carboniferous sequence in Ayrshire.

Target Coals Age: Upper Visean through Westphalian B/about 300-340 m.y.b.p.

Target Coal Depths: 0m - 1,600+m in central Mauchline Basin (overlay 1)

Except for the central Mauchline Basin and small areas of the subbasins, target formations are not mantled by younger non-prospective rocks. In central Mauchline Basin, borehole intersections of non-prospective rocks, including New Red Sandstone, basic lavas and Upper Coal Measure sediments, range in thickness from 600-800m. Where non-prospective rocks do not overlie target formations, the maximum composite thickness of prospective coal-bearing formations (and the maximum exploratory drilling depth) is less than 1,000m.

Prospective Part of Licence

Area with Target Coal Formations: 551km^2 total/61.2 % (overlay 1)
(508km^2 in the Mauchline Basin and contiguous subbasins and 42km^2 in the Sanquhar Basin)

(Block ST40: 34 km^2, Block ST41: 92 km^2, Block ST42: 100 km^2, Block ST50: 8 km^2, Block ST51: 97 km^2, Block ST52: 85 km^2, Block ST61: 51 km^2, Block ST62: 47 km^2 and Block ST71: 36 km^2)

Area of Underground Mining of one or more Coals: 188 km^2 total/20.9% (overlay 2)
(pre1960 162 km^2 in the Mauchline Basin and contiguous subbasins
- 26 km^2 in theSanquhar Basin)

(Block ST40: 21 km^2, Block ST41: 45.5 km^2, Block ST42, 21 km^2, Block ST50: 5.5 km^2, Block ST51: 27 km^2, Block ST52: 23 km^2, Block ST61: 6.75 km^2, Block ST62: 13 km^2 and Block ST71: 25.5 km^2)

The information noted above was based on review at the Coal Authority in Bretby of composite maps of individual coal seams plotted on 5 km X 5 km quarter sheets covering the licence area. These underground mine plan maps were updated through 1960. However, underground mining continued in this region into the 1980's and ceased sometime before 1991. A few opencast mines are also included if those mines were mapped on the 1:50,000 scale surface geologic maps used for this review.

Based on the level of mapping detail available for coal seams on the 1976 and 1999 geologic maps used as the basemap for this prospect review, new areas of

recent underground mining between 1960 and 1976 or 1960 and 1999 can be conjectured with some confidence:

New Areas of Underground Mining of one or more Coals: 11 km^2 total/1.2% (overlay 2)
(1960-1976 – Cumnock Geologic Sheet - 11 km^2 in the Mauchline Basin and 1960-1999 – New Cumnock Geologic Sheet contiguous subbasins
- 0 km^2 in Sanquhar Basin)

(Block ST51: 10.5 km^2, Block ST52: 0.5 km^2, Block ST61: <0.5 km^2, Block ST62: <0.5 km^2)

Total area with target formations above 150 m in depth: 60 km^2/6.7%
(overlay 1)
Total area a/a and not already excluded by underground mining: 53 km^2/ 5.9%

(Block ST40: 2 (1.5) km^2, Block ST41: 4 (2) km^2, Block ST42: <0.5 km^2, Block ST51: 1 km^2, Block ST52: 3.5 km^2, Block ST61: 23 (22) km^2, Block ST62: 15 (13) $km^2$and Block ST71: 12.5 (11) km^2)

Total area with target formations below 1,000m in depth: 106.5 km^2/11.8%
(overlay 1)
Total area a/a and not already excluded by underground mining: 93 km2/10.3%

(Block ST41: 13.5 (11) km^2, Block ST42: 59 (55) km^2, Block ST51: 7 (5) km^2 and Block ST52: 27 (22) km^2)

Net prospective area with target coals between 150 m and 1,000 m: 206 km^2/22.9%

Areas of Mined Coals

Coals, ironstones, fireclays, limestones and oil-shales have been extensively worked and formed the basis of industrialization of the Midland Valley in the 19th and first part of the 20th centuries. The mining, quarrying and sinking of boreholes associated with the exploration and exploitation of these minerals has resulted in a vast amount of detailed knowledge of the Carboniferous rocks in the region, particularly in coalfield areas.

Coal remains the single most valuable natural resource in the Midland Valley despite the decline in production since the early part of the century. Maximum production took place in 1913 when 42 million tons were mined and numerous collieries were in operation. Few collieries were still active in 1985 and the total annual production from subsurface and opencast sources for that year was about 12 million tons. In the early years of the coal mining industry, attention was concentrated on the more accessible seams at shallow depths. In many cases

plans of these workings are not available and possible subsidence is a major problem in relation to new construction projects. Large areas of the coalfields are now no longer worked, partly through exhaustion and partly because the remaining coal cannot be worked economically by the mechanized methods currently in use. Untapped reserves still exist and there are still seams suitable for opencast extraction.

Basic Intrusions and Coking of Coals

In areas where concordant igneous intrusions are present in coal-bearing strata it is common to find thin sills intruded along coal seams, as the latter have provided planes of minimum resistance to the lateral spread of magma. The Carboniferous rocks of southwest Ayrshire are cut by numerous small, mainly late Carboniferous-Permian, basic sills ranging in thickness from centimeters to 60m. (overlay 3)

Large areas in several of the mined seams, both in the Coal Measures and in the Limestone Coal Group, are intruded by masses of dolerite which have commonly been partly or completely altered to “white trap,” a pale white alteration product with abundant kaolinite. The coal adjoining the intrusions has been converted into economically useless natural coke, also known as “cinder coal” and fingerkohle. The coked coal adjoining the intrusions contains amygdales which are only just visible to the naked eye and may form up to 50% of the total volume of the coke. Most vesicles are filled with calcite and about 10% by silica.

It has been suggested that magma intruded into coals consolidates initially as pillows and sills of unaltered rock sheathed in burnt coal and after cooling is converted into white trap by gases distilled from the organic sediments. Residual fluids from conversion reactions concentrated in calcium bicarbonate result in later deposition of calcite in joints and vesicles. Altered basic intrusions are often described as “whin” on older borehole logs and mine plans of the Ayrshire coalfield.

The surface and subsurface occurrence of unaltered and altered basic intrusions is widespread in Ayrshire coalfield. Outcrops of igneous rocks and holes containing thermally altered coals have been identified in overlay 3. Coal alteration has been summarized in many borehole log rock descriptions. “Burnt” coals are completely coked. “Blind” coals have lost their volatiles due to heating. Both burnt and blind coals are non-prospective for CBM. Some logs lack sufficient descriptive detail to determine the condition of coals in wells with dolerite and whin logged adjacent to coal seams. Without an express description of coal alteration, a coal is assumed not to have lost gas. So, the overlay numbers present a “best case” for the condition of these coals. Certainly, additional coals have lost methane and have not been identified as such. The general condition of coals in a given hole is summarized in overlay 3 by the thickness-weighted percentage of coals that have lost gas.

Although the occurrence of intrusives is ubiquitous and widespread, the total volume of intrusives is not truly large and the presence of intrusives and conditions of coals can vary abruptly. Thinner intrusives in particular can be localized and their lateral extent and continuity difficult to predict. In areas where basic intrusives are thicker and more extensive and coalbeds have been properly identified in logs, extrapolation of coalbed conditions is possible. However, a cursory review of Ayrshire borehole coal alteration data suggests that coal alteration is not regionally mappable at the level of borehole sampling conducted for this review (50 borehole geologic logs covering an area of 550 km^2).

Reddening of Coal Measures and Replacement of Coal by Limestone

Red beds in the Upper Carboniferous originated as grey measures which were subsequently reddened by oxidation during the period represented by the Carboniferous-early Permian unconformity. The depth of reddening below the unconformity is broadly uniform, 1,300 to 1,500 ft, though the horizon of the base of the oxidized strata varies from 200 ft above the base of the Upper Coal Measures to the Upper Limestone Group. In detail, percolation of air and water was greater along certain fault planes and sandy beds. Other fault planes served as seals since they now separate reddened and non-reddened strata. (overlay 4)

The passage of coal to limestone in Ayrshire is usually associated with the reddening of the adjacent strata and it is assumed that the process of oxidation played an important role in such replacement. Replacement may have been dependent on the presence of salts of calcium and magnesium. Alteration appears to have taken place at a low temperature with coal commonly first replaced by calcite that may in turn have been replaced by dolomite. Alteration of coals to limestone has taken place within a vertically restricted belt in the lower part of the zone of reddening. Decomposition of Permian basic lavas seem to provide a suitable source of calcium and magnesium as the reckoned former extent of lavas roughly coincides with the distribution of limy coals and limestones in coal positions. In the Mauchline area, three main seams were worked. These Middle Coal Measures seams are, in descending order, Ell or McNaught, Tourha or Crawfordstone and Hurlford Main or Ayr Hard. Alteration is most widespread in the Ell and adjacent seams and decreases progressively with depth. Ayr Hard coal is normal in the greater part of the area.

The great depth and degree of oxidation below the Permian can be partly explained by the long period of nondeposition between the latest Coal Measures and the earliest Permian rocks. The main part of reddening appears to have taken place *before* the Permian basic lavas erupted. Subsequent weathering of the lavas provided solutions responsible for coal alteration near the lower limit of oxidation and above the permanent water table, which as a result of relief and low rainfall, lay in places as much as 1,950 ft below the desert landscape of that time.

If this interpretation of geologic history is correct, then Ayrshire Upper Coal Measures to Upper Limestone Group coals within 1,500-2,500 vertical feet of the Permian unconformity may have lost any adsorbed methane generated by coal maturation and burial prior to the early Permian.

Rank

Available records show Mauchline basin coals are high volatile bituminous, caking and noncaking coals.

Locally coals have been naturally coked and have completely lost their volatiles in proximity to basic intrusions. Some coals are also higher rank as a result of associated thermal metamorphism. With appropriate conditions, aureoles may have formed around intrusions where coals of higher rank have higher methane content but this is speculative and has not been studied in Ayrshire.

Gas Content Data

Data for Ayrshire are very sparse.

(Seam data from Creedy, 1986)
Killoch Colliery Middle Coal Measures:
Ayr Hard 2.8 m^3/ton 1982 4 samples
Main 2.0 m^3/ton 1982 5 samples
Depths: 500-600 m

The Killoch coals were sampled at the mining face and may have partially degassed during the Permian (overlay 4).

An average gas content for British high volatile bituminous coal is 5-6 m^3 methane/ton, according to charts in the 1988 International Journal of Coal Geology article, “Geological Controls on the Formation and Distribution of Gas in British Coal Measure Strata” by David Creedy. For the purpose of developing a best guess for gas reserves within select areas of PEDL073, 6 m^3 methane/ton will be the assumed gas content of all target formation coals.

Other methane-related information:

Kames mine firedamp explosion in 1957 killed 17 miners.
(Muirkirk, Limestone Coal Group)
Springhill (Ayrshire) mine firedamp explosion in 1917 killed 4 men.

Target Coal Thickness

Coal thickness data have been tabulated for PEDL073 in an Excel 97 spreadsheet file titled “Ayrshire coals” and are attached here as Appendix 1. Unlike for the Bristol/Somerset coalfield, Ayrshire borehole geologic logs have not been summarized by the BGS. Ayrshire hole records are mainly descriptive and lack such fundamental information as assignment of formation intervals. An attempt has been made to break out formations for the purpose of mapping the depth to the base of the lowest target formation, the Lower Limestone Group formation (overlay 1). Therefore, tabulated depths and thicknesses of formations for many holes are only best guesstimates based on geologic descriptions.

Because of structural problems and variations in borehole depths, aggregate coal thickness for each data point has been plotted on the master overlay both in meters and as a percent of section. This facilitated calculation of estimated gas reserves.

Brief descriptions about target formation thickness and coal percentage trends follow:

The Carboniferous System in Scotland is formed mainly by sequences of sediments laterally varying in thickness and locally intercalated with penecontemporaneous volcanic rocks. The sediments are coals, limestones, mudstones, siltstones, sandstones and fossils soils, such as seatearths and seatclays. They are arranged in rhythmic sequences described as cyclothems up to 30m or more thick but averaging about 10m. The relative proportions of each rock type within a cyclothem vary from place to place and from one part of the succession to another. The “cyclothem” concept forms the basis for Scottish lithostratigraphical division and is of continuing practical value.

The lowermost coal-bearing formation is the Strathclyde Group. It ranges in thickness from 75m in the Muirkirk area to 20m near New Cumnock and has been included as a prospective target formation on overlay 1 and the master overlay as little information is reported on the characteristics of these coals.

Above the Strathclyde is the Lower Limestone Group which ranges in thickness from 7-35m, being thickest near Muirkirk, absent around Sanquhar and about 10m thick near Coylton. Deposition of the Lower Limestone Group began a pattern of sedimentation which continued through deposition of the Upper Limestone Group in Ayrshire. Abrupt formation and bed thickening occur across northeasterly trending faults and testify to active growth of basins relative to shelf areas during this period. This is particularly notable across the Kerse Loch Fault at the south end of Mauchline Basin. Few holes in GeoMet’s 50 hole database were drilled deep enough to intersect a full section of Lower Limestone Group and none hit coals.

The primary target formation, Limestone Coal Group, ranges in thickness from 50m near Dalmellington to 130m near Cumnock and is absent around Sanquhar. Aggregate coal percentages commonly range from 5 to 10% with exceptional holes to 14% and a few holes with less than 2%. North of the Kerse Loch Fault and southwest of Coylton, on the west side of Mauchline Basin, this formation averages about 40m in thickness with 4 % coal. Mansfield No. 1 well, an exceptional hole, had over 16m of coal over a 116m interval near New Cumnock and 17m of coal in 127m of strata has been reported near Cumnock. No data are available for the deeper part of Mauchline Basin, but based on the sequences at Patna and Sorn on the southwest and east flanks, respectively, a significant amount of coal might be present under at least part of the deeper basin. The Limestone Coal Group is thick and its coals are well developed in a narrow belt lying to the south of Littlemill Fault at the west edge of the licence. Favorable coal development in the Limestone Coal Group may continue to the northeast to Cumnock and beyond.

The general increase in thickness from northwest to southeast across Kerse Loch Fault affects all groups of the Carboniferous Limestone Series, but most especially the Upper Limestone Group. Thickness of Upper Limestone Group south of the fault is not too variable, ranging from 150 to 200m near Dalmellington to 238m in Palquhairn Bore to 180m near Muirkirk and New Cumnock. North of the fault, this formation thins to 11 to 24m in Southcraig Bore and Whitehill (Old) Bore, respectively, south of Coylton. This formation is missing in Sanquhar basin. Coal percentages are usually low, 0-1%, but range up to 3% in the Mansfield No. 1 well.

The Passage Group is quite variable in both thickness and character. On the west side of Mauchline Basin it is absent in Dalmellington subbasin and mainly occurs as basalt flows up to150m thick near Patna. On the east side of the Mauchline Basin sedimentary sequences 50m to 75m thick make up Passage Group, with the thickest around New Cumnock and thinnest near Cumnock. This formation may be present as 30m of sandstones in Sanquhar Basin. Coal percentages are usually less than 1% in holes cutting through Passage Group sediments.

The earlier pattern of sedimentation along northeasterly faults in Ayrshire continued into the Coal Measures, but in diminished degree. The Lower Coal Measures vary in thickness from 170m near Cumnock to 330m near New Cumnock in Mauchline Basin with 110m in Sanquhar Basin. Aggregate coal percentages are also quite variable. A large number of holes intersect 5-7 % coal while other holes cluster around 2-3% and a third group contains less than 1%. The highest coal percentages are evident in holes near east-central Mauchline Basin and the central portions of New Cumnock and Dalmellington subbasins.

The Middle Coal Measures vary in thickness from 210m near Cumnock to 260m near Dalmellington in Mauchline Basin with 150m in the Sanquhar Basin.

Aggregate coal percentages are highest, 4-7%, in central Mauchline basin with 2-5% coal in Dalmellington, New Cumnock, Sanquhar and Muirkirk subbasins. Locally, percentages are less. Without mining and gas loss concerns, Middle Coal Measures strata would be a prime target for CBM exploration in this area. In Ayrshire complete successions of the Lower and Middle Coal Measures may contain as many as 20 coals of workable thickness (>2 feet) as well as many others too thin to have been named.

The Upper Coal Measures beds total more than 500m in thickness near the center of Mauchline Basin and are eroded away from most regions on the periphery. Small remnants are evident in the subbasins. The Sanquhar Basin contains a thicker sequence of Upper Coal Measures rocks, up to 300m. There are several coals near the base of Upper Coal Measures formation but these have degassed and are not prospective for CBM.

Potential Gas Reserves

First order gas reserve estimates have been calculated using average coal % for the interval below 150m and above 1,000m in five prospective areas outlined in overlay 5. In general, licence regions with the base of the target formations below 1,000m are considered less prospective because these are areas with thick sequences of non-prospective formations at the surface. Also, degassing of coals to significant depths below the Permian unconformity is associated with the deeper portions of the Mauchline Basin.

Area 1 is situated on the west side of the Mauchline Basin. It is a small area isolated by areas of previous mining to the east and south and by the basin margin and the licence boundary on the west.

Area: 10 km^2
Depth of base of target formations: 150-450m, averaging 300m thick (150 m net prospective)
Formations: Lower Coal Measures to Lower Limestone Group
Estimated % Coals: 2.5%
Best Case Gas Content: 6 m^3 methane/ton of coal
Worst Case Gas Content: 2 m^3 methane/ton of coal
Coal density: 1.35 tons/m^3 (for all areas)
Assume 100% methane content as composition of desorbed gas for all areas.
Assume the surface 150 m of rocks are not prospective for all areas.
Assume no coals are burned by intrusives for all areas.
Assume none of the target areas have lost gas during the Permian. (Selected areas generally avoid this problem.)

Best Case Area 1 calculated methane reserves:

10,000,000 m^2 X 15 m X 0.025 (% coal) X 1.35 t coal/m^3 X 6 m^3 methane/t coal=0.3 X 10^9 m^3 methane

Resource density: 0.03 X 10^9 m^3 methane/km^2

The maximum number of wells at 32 hectares/well is about 30. This area is too small and isolated and resource density is too low. It does not merit drilling a corehole.

Area 2 is situated west of Dalmellington subbasin in the southeast of PEDL073. It is also small and isolated. It is bounded by mined areas to the east and the basin margin to the south and west.

Area: 7 km^2
Depth of base of target formations: 150-600m, averaging 400m (250m net prospective)
Formations: Lower Coal Measures to Lower Limestone Group
Estimated % Coals: 2.5%
Best Case Gas Content: 6 m^3 methane/ton of coal
Worst Case Gas Content: 2 m^3 methane/ton of coal

Best Case Area 2 calculated methane reserves:

7,000,000 m^2 X 250 m X 0.025 (% coal) X 1.35 t coal/m^3 X 6 m^3 methane/t coal=0.35 X 10^9 m^3 methane

Resource density: 0.05 X 10^9 m^3 methane/km^2

The maximum number of wells at 32 hectares per well is about 20. This area is too small and isolated and does not merit drilling a corehole.

Area 3 is the primary target for a corehole because it is large, central and a simple rectangle in shape. Structural complications are minor and rock strata are not steeply dipping. The area is situated between the southeastern margin of Mauchline Basin and the northwestern margin of New Cumnock subbasin. One concern here is the extent of intrusives and burnt coals.

A number of *very prospective* contiguous areas have been assumed to be mined (overlay 2) and this will have to be confirmed before final siting of a corehole. This includes promising areas adjacent to New Cumnock subbasin with coals making up more than 5% of the stratigraphic section. Other “prospective-but-possibly-mined” areas include upper portions of Middle Coal Measures strata presently outside the limits of Area 3.

Area: 64 km^2

Depth of base of target formations: 150-800m, averaging 600m (450m net prospective)
Formations: Middle Coal Measures (minor), Lower Coal Measures to Lower Limestone Group
Estimated % Coals: 2 %
Best Case Gas Content: 6 m^3 methane/ton of coal
Worst Case Gas Content: 2 m^3 methane/ton of coal

Best Case Area 3 calculated methane reserves:

64,000,000 m^2 X 450 m X 0.02 (% coal) X 1.35 t coal/m^3 X 6 m^3 methane/t coal=4.7 X 10^9 m^3 methane

Resource density: 0.07 X 10^9 m^3 methane/km^2

The maximum number of wells at 32 hectares per well is 200. Although resource density is not much higher than the smaller areas to the west, total resource is much greater and drillhole siting has greater flexibility.

Area 4 is situated to the east of the Mauchline Basin and west of the Muirkirk subbasin. (Muirkirk is not prospective because the Limestone Coal Group coals have been extensively mined there.) The outline of this area is convoluted, skirting mined areas and villages while staying east of the deepest portion of Mauchline Basin. A hole situated in the north part of Area 4 could test a complete section of target formations at depths considered prospective (>150m in depth). However, this area has less flexibility in siting wells than Area 3 and would be more difficult to develop and, as a result, is considered a target for future consideration.

Area: 32.5 km^2
Depth of base of target formations: 150-800m, averaging 400m (250m net prospective)
Formations: Middle Coal Measures to Lower Limestone Group
Estimated % Coals: 2 %
Best Case Gas Content: 6 m^3 methane/ton of coal
Worst Case Gas Content: 2 m^3 methane/ton of coal

Best Case Area 4 calculated methane reserves:

32,500,000 m^2 X 250 m X 0.02 (% coal) X 1.35 t coal/m^3 X 6 m^3 methane/t coal=1.3 X 10^9 m^3 methane

Resource density: 0.04 X 10^9 m^3 methane/km^2

The maximum number of wells at 32 hectares per well is 100.

Area 5 is situated northeast of the New Cumnock subbasin. It is small but could be developed in conjunction with Area 4. Geologically it is very prospective with fairly simple block faulting and Limestone Coal Group coals at prospective depths.

Area: 6 km^2
Depth of base of target formations: 150-550m, averaging 350m (200m net prospective)
Formations: Lower Coal Measures (minor), Passage Group to Lower Limestone Group
Estimated % Coals: 5 %
Best Case Gas Content: 6 m^3 methane/ton of coal
Worst Case Gas Content: 2 m^3 methane/ton of coal

Best Case Area 5 calculated methane reserves:

6,000,000 m^2 X 200 m X 0.05 (% coal) X 1.35 t coal/m^3 X 6 m^3 methane/t coal=0.5 X 10^9 m^3 methane

Resource density: 0.08 X 10^9 m^3 methane/km^2

The maximum number of wells at 32 hectares per well is about 20.

Area 5 has the highest resource density of all unmined areas open to development in PEDL073. The possible exception is the untested deeps of the central Mauchline Basin which would require substantially deeper wells (1,500+m) to exploit any CBM resource that might be present.

Area 6 is the Sanquhar subbasin. Below 150m depth, only 3 km^2 of this basin has not been mined. Therefore, this area is not prospective.

The estimated total methane resource for Areas 1 through 5 is 7.2 X 10^9 m^3 methane. Over an aggregate area of 120 km2 resource density averages 0.06 X 10^9 m^3 methane/km^2. This assumes a best case average gas content of 6 m3 methane/ton of coal. If average gas content is 2.4 m3/t, as measured by Creedy, then the resource total drops to 2.9 X 10^9 m^3 methane and resource density decreases to 0.024 X 10^9 m^3 methane/km2. Because of uncertainty in the gas content of Ayrshire coals, coring needs to be conducted, primarily to collect desorption study coal samples but also to determine appropriate target seams for stimulation and to gain confidence that the Ayrshire CBM resource merits exploitation.

Recommended Corehole Location

The general area for a corehole would be at “Site A” in Area 3 of overlay 5, UK National Grid coordinates 252200 615600. This hole would be scheduled to drill

to 850m and would intersect all the target formations considered potentially prospective for this licence, except the upper portion of Middle Coal Measures. It is structurally the highest location within Area 3 and would intersect the target formations at the greatest depth possible, minimizing risk of geologically recent loss of methane due to shallow burial. There are volcanic flows in the vicinity and the hole is likely to intersect intrusives. This is a risk that cannot be mitigated at this prospect. The location is south of the zone of concern about Permian-related reddening and alteration of coals to limestone. It is situated in a larger, greater than 2 km^2, fault block where strata at the surface dip at a low angle to the north and east, toward central Mauchline Basin. A corehole at this location would be geologically representative of much of Area 3 and would be generally indicative of its CBM resource potential.