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The Geothermal Potential of Northern Ireland

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ABSTRACT

The *Geothermal Energy Review of Northern Ireland* study completed in *2005* modelled data from previously drilled oil and gas, mineral exploration and deep geothermal exploratory boreholes to develop temperature maps at selected depths in Northern Ireland. This study predicted suitable lithologies and reservoir characteristics in potential geothermal aquifers in areas where temperatures above the normal geothermal gradient were recognised in the subsurface.

Acquisition of airborne aeromagnetic data by the TELLUS project in 2007, in conjunction with existing geological data, has improved the understanding of deep geological structures throughout Northern Ireland. The new data allows identification of targets for deep geothermal energy development as a result of the Sherwood Sandstone and Lower Permian Sandstone targets being better defined.

Reservoir modelling and preliminary resource assessment based on newly acquired petrophysical and reservoir parameters of both targets shows that the Lower Permian Sandstone target has the highest geothermal potential in the Larne, Lough Neagh and Rathlin sedimentary basins.

A profile of Northern Ireland's energy usage shows that most electricity and heat requirements are met through the use of conventional fossil fuel technologies. Current government policy is focussed on the development of renewable energy solutions to reduce current CO_2 emissions. Deep geothermal energy in Northern Ireland could significantly contribute to the reduction of these emissions by providing a renewable heat source to both domestic and industrial sectors. Geothermal energy utilisation from Permo-Triassic basins should be considered as a suitable renewable energy alternative in these locations to supply heat to current and proposed future developments in order to meet the targets for the year 2020 set by Renewable Energy Directive through the national Renewable Energy Action Plans.

1. INTRODUCTION

Previous desktop studies on the geothermal potential of Northern Ireland focused on the assessments of temperature, porosity and related water flow in the Larne No.2 geothermal borehole completed in the 1980s. The findings of the study identified the reservoir petrophysical parameters were probably not representative due to damage to the formation caused during the drilling of the borehole.

The presence of the Sherwood Sandstone in relatively young sedimentary basins in Northern Ireland combined with an elevated geothermal gradient identified in a number of boreholes is comparable to other regions of Europe. Temperatures of between 70°C and 90°C have been recorded at depths of between 2km and 3km in a number of other boreholes.

Further analysis of logs from these boreholes in Northern Ireland has indicated an additional target in Lower Permian Sandstones below the Sherwood Sandstone which may constitute an additional reservoir target for deep geothermal energy development in the northern and eastern part of Northern Ireland. The basal Carboniferous sandstones of the North West Basin in southwest Fermanagh were also considered. Although the porosity and permeability recorded from oil exploration wells is low the data is limited and the hydro-geothermal potential cannot be ruled out.

The recently acquired airborne magnetic and gravity data in conjunction with existing seismic line data has been used to refine the parameters and semi-quantitatively estimate the total energy stored in a given reservoir volume by using a volumetric analysis method.

This paper focuses on the geothermal energy potential calculated using physical parameters from bedrock formations intersected in the oil and gas boreholes to a depth no greater than 2900m in Northern Ireland.

2. GEOLOGICAL REGIONS OF NORTHERN IRELAND

Northern Ireland has a number of sedimentary basins that have been explored in the past because of their potential to contain oil and gas reserves. The Rathlin, Larne and Lough Neagh basins in the east and northeast contain in excess of 3000m of Permo-Triassic sediments (Mitchell, 2004) whilst the North West Basin in the southwest of Northern Ireland contains a similar thickness of Carboniferous sandstones, shales and limestones (figure 1).

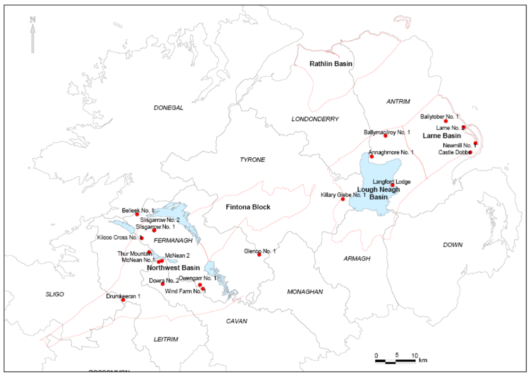

Figure 1: Sedimentary Basins and Oil and Gas Exploration Boreholes in Northern Ireland.

Exploration boreholes for oil and gas (figure 1) in these basins have improved the understanding of the depth to and thickness of permeable lithologies that could act as hydro-geothermal reservoirs. Core samples from these exploratory wells were used to determine the permeability and porosity values in the potential reservoir targets. Based on these data a series of representative sections showing the tops and bases of the target formations were generated (McCann, 1988 & 1990). No data currently exists for the northeastern and southwestern areas of Lough Neagh, which have been identified (Mitchell, 2004) as the main depocentres in the Lough Neagh Basin and are likely to contain thicker sedimentary sequences than the areas which have been tested to date. A summary stratigraphy of the Permo-Triassic basins is given in Table 1 below.

Table 1. Summary Stratigraphy of the Permo-Triassic Sequences in the Larne, Lough Neagh and Rathlin Basins.

Period	Group/Formation	Lithologies
Tertiary	Lough Neagh Group	Clays, lignites, minor sands and conglomerates
	Upper Antrim Basalts	Volcanics, pyroclastics and terrestrial sediments
	Interbasaltic Bed	Laterised basalts
	Lower Antrim Basalts	Volcanics, pyroclastics and terrestrial sediments
	Clay with Flints	Weathered Cretaceous and pyroclastics
Cretaceous	Ulster White Limestone Formation	Highly indurated chalks with flints
	Hibernian Greensand	Glauconitic sandstones
Jurassic	Waterloo Mudstone	Calcareous mudstone and thin limestones
Triassic	Penarth Group	Mudstone, siltstone and thin limestone
	Mercia Mudstone Group	Mudstones and thick evaporites ($CaSO_4$ and NaCl in Larne Basin)
	Sherwood Sandstone Group	Fluvial and aeolian sandstones
Permian	Belfast Group ("Permian Marl")	Mudstone, evaporites, Magnesian Limestone at base. Ur Perm. Sst. locally present
	Upper Permian Sandstone	Sandstone – only present in Lough Neagh Basin, replaces (in part) the Permian Marl
	Magnesian Limestone	Dolomitic limestones and dolomites
	Ballytober Sandstone Formation ("Lower Permian Sandstone")	Conglomerate and breccias passing up into sandstones
	Inver Volcanic Formation	Basaltic to trachytic volcanics and tuffaceous siltstones. Sandstone/conglomerate unit at base
Carboniferous	Coal Measures	Deltaic clastics and coals
	Carbonates, mixed clastics	Marine carbonates, passing up into sub-tidal to supra-tidal sequence, overlain by deltaics
Devonian	"Old Red Sandstone"	Terrestrial redbeds
Ordovician and Silurian	Lower Palaeozoics	Metamorphosed basement to basin

2.1 Sherwood Sandstone Group

The Sherwood Sandstone Group occurs in the Rathlin, Larne and Lough Neagh basins. The Sherwood Sandstone is typically overlain by thick Triassic mudstones and evaporites of the Mercia Mudstone group. This mudstone/evaporite succession acts as an insulating unit to the porous lithologies of the Sherwood Sandstone Group below. Typically, both of these are overlain by mudstones and thin limestones of the Triassic Penarth Group and Jurassic Waterloo Mudstone, the Cretaceous Ulster White Limestone, extrusive volcanics of the Antrim Basalt Group and Oligocene sediments in the Lough Neagh and Rathlin basins. Figure 3a shows the presence of the Sherwood Sandstone reservoir in the Rathlin basin based on the information recorded in the Portmore borehole.

The Sherwood Sandstone group is characterised by moderate to low porosity sandstones of fluvial and marine origin that have previously been explored for geothermal energy in the Larne basin (Larne No.2 Borehole) where it is recorded at a depth of 1800m with an approximate thickness of 800m. The Sherwood Sandstone group found in the Larne boreholes is shown in figure 2a.

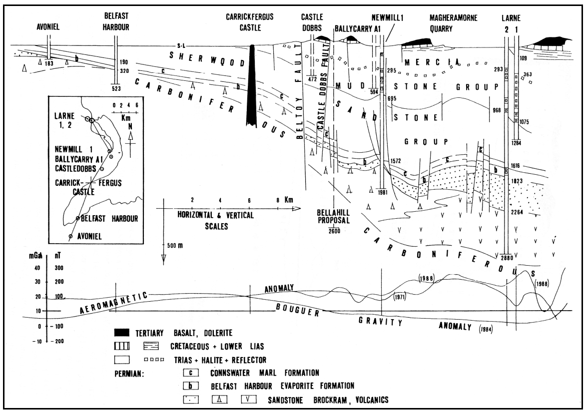

Figure 2a: Sherwood Sandstone Group and Permian Sandstone Group occurrences in the Larne & Lough Neagh Basins (McCann, 1990).

In the Rathlin Basin to the north, this group shows a maximum thickness of 600m and is present at a maximum depth of approximately 1900m.

2.2 Lower Permian Sandstones

This succession has been described from the drilling results in the Larne No.2 borehole as a sandstone ranging from very fine grained to very coarse grained units with a total thickness of approximately 440m. It was intersected at depths between 1800m and 2220m below ground level. It has also been encountered in the Portmore borehole at an approximate depth of 1890m where the base of the unit was not reached. However, seismic refraction studies on the edges of the Rathlin basin have shown that this formation may be thinner than in the Larne basin with thicknesses of the order of approximately 200m (figures 2b).

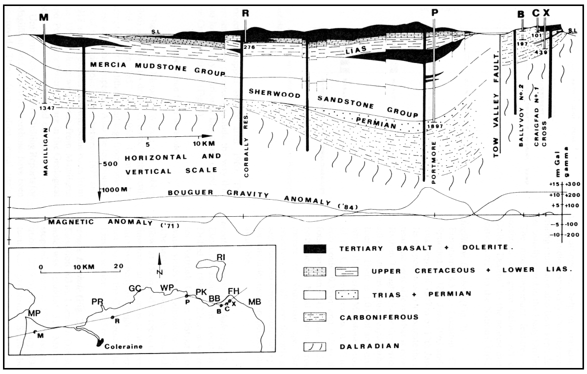

Figure 2b: Sherwood Sandstone Group and Permian Sandstone Group occurrences in the Rathlin Basin (McCann, 1988).

2.3 Carboniferous Sandstones

Carboniferous sandstones of Chadian age have been described in the Northwest Basin in the south Tyrone/Fermanagh region. These sandstones have moderate to low porosity and are terrestrially derived. The thickness of this succession is not as well known as the Boyle and Kilcoo Sandstones that have been frequently intersected by oil exploration boreholes. However they have been described as being up to possibly 150m thick at depths of between 1600 and 1800m in the Kilcoo Cross and Slisgarrow boreholes (figure 3).

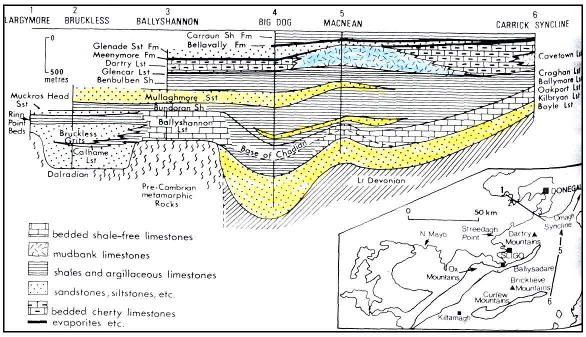

Figure 3: Carboniferous Sandstones (yellow) in the North West Basin (George et al, 1976).

The temperatures modelled in the 2005 CSA review have been used in this study to characterise the geothermal potential of target reservoir rocks in Northern Ireland in the vicinity of heat end-user markets.

3 ELEVATED TEMPERATURES:

Borehole temperature information from the hydrocarbon exploration and mineral exploration boreholes in Northern Ireland was modelled and assessed during a recent study. This showed high geothermal gradients and temperatures in some of the basins in Northern Ireland. Figure 4 shows the temperature modelled at a depth of 2500m based on measured borehole temperatures and calculated data.

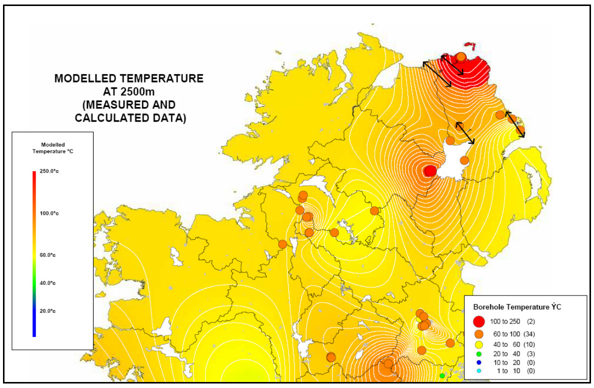

Figure 4: Modelled Temperature at 2,500m depth and seismic line locations in Northern Ireland (Goodman, 2004).

Based on the lithologies encountered in the hydrocarbon exploration boreholes and the temperature profiles recorded subsequent to the completion of the drilling a series of temperatures were modelled for a number of basins at depths of 1000m, 1500m, 2000m and 2500m. Table 2 below shows the modelled temperatures in a number of the boreholes where temperature gradients were measured.

The potential geothermal reservoir targets were intersected at depths of between 1500m and 2200m. The boreholes showing highest modelled temperatures at 2000m were Portmore with 82°C, Ballymacilroy with 74°C and Langford Lodge with 68°C. These temperatures coincide with the presence of Permian Sandstones and Sherwood Sandstone lithologies in the Rathlin and Lough Neagh basins.

These lithologies also occur in the Larne basin, which was drilled in the 1980s to evaluate geothermal potential, with similarly high temperatures. However, the recorded porosity and permeability of the Lower Permian sandstones in the Larne No. 2 borehole has been observed as anomalously low compared with other proximal boreholes like the Newmill No.1 borehole where much higher porosity and permeability and temperatures values in the Lower Permian Sandstones were observed. The temperature recorded in the Permian Sandstones in the Larne No. 2 borehole was 77.5°C at a depth of 2800m. For the purpose of this study a temperature of 83°C was used to characterise the reservoir.

Table 2. Modelled Temperatures in Hydrocarbon Boreholes (Goodman, 2004).

BOREHOLE NAME	T (°C) at 1000m	T (°C) at 1500m	T (°C) at 2000m	T (°C) at 2500m
Annaghmore No. 1	42.33	53.33	64.33	75.33
Ballymacilroy No. 1	49.28	62.00	74.00	85.00
Ballytober No. 1	37.50	51.50	66.00	80.00
Big Dog No. 1	33.89	45.60	57.40	69.20
Glenoo No. 1	33.50	43.00	52.50	61.50
Kilcoo Cross No. 1	35.00	46.50	57.00	68.00
Killary Glebe No. 1	39.60	51.00	61.00	71.50
Langford Lodge	43.00	56.00	68.00	80.00
Larne No. 2	43.00	51.00	60.50	70.00
Newmill No. 1	31.00	34.10	50.50	59.90
Owengarr No. 1	38.00	43.50	52.50	63.00
Port More No. 1	45.50	62.80	82.00	99.50
Slisgarrow No. 1	39.00	50.00	57.80	69.50
Wind Farm No. 1	27.00	40.50	54.50	68.50

Temperature values recorded in the Northwest basin in the Slisgarrow, Owengarr, Glenoo and Big Dog boreholes were noted in the 2005 CSA report as being partially inaccurate as very few temperature profiles were taken following the completion of the boreholes (one reading 9 hours after drilling at the end of the Slisgarrow No. 2 borehole was completed) and in some cases the time of the temperature log was not recorded. For this reason the temperatures observed in these boreholes in not believed to be the true stabilised formation temperature in the Lower Carboniferous targets. In this characterisation study a higher true stabilised formation temperature has been used.

4 TELLUS DATA:

The British Geological Survey (BGS) and the Geological Survey of Northern Ireland (GSNI), in partnership with the Geological Survey of Finland (GTK), flew a low-level airborne geophysical survey over Northern Ireland in 2005–6. The survey completed a total of 86,000 line km at a height of 56m and collected magnetic field, electrical conductivity and terrestrial gamma-radiation measurements.

The survey has permitted improved mapping of faults, dykes and the major volcanic complexes that are overprinted by late glacial and Quaternary sediments at the surface. The survey has aided the delineation and definition of the basins where geothermal reservoir targets are contained.

For the purpose of this study a combination of aeromagnetic data and previously acquired ground gravity data were reviewed by BGS and GSNI to refine the existing reservoir models previously established from older hydrocarbon seismic data.

Based on the geometry of the reservoir outlined in the seismic models, the magnetic intensity data collected during the TELLUS project in conjunction with the GSNI gravity data was superimposed to identify the correct density parameters of the reservoir formations and the geometry of the basin structures controlling the depths of the reservoir by using the individual modelled data for the seismic lines in figure 4.

The information gathered from this modelling exercise has refined the depth of the reservoir lithologies away from the exploration boreholes. Table 3 below shows the depth of the top and base of the Permo-Triassic reservoir rocks in three key areas where elevated temperatures have been modelled but where reservoir conditions have not yet been investigated.

Table 3. Estimated Geothermal Reservoir Thickness based on airborne geophysical data (TELLUS)..

	Sherwood Sandstone Group			Lower Permian Sandstones		
	Top of Reservoir Target (m)	*Base of Reservoir Target (m)*	**Estimated Thickness (m)**	*Top of reservoir Target (m)*	*Base of Reservoir Target (m)*	**Estimated Thickness (m)**
Antrim	1700	2100	**400**	2400	2600	**200**
Ballymoney	1400	1900	**500**	2000	2500	**500**
Magheramorne	900	1550	**650**	1650	1900	**250**

Data models have shown that the Sherwood Sandstone Group reservoir is sufficiently thick and occurs at depths up to 2km. The Lower Permian Sandstones are present at greater depths in the basin but are not as thick as the Sherwood Sandstone. Depth considerations indicate that the Lower Permian Sandstones should be considered as the primary geothermal reservoir target but it is worth noting that within the Permian Sandstone succession some non-porous tuffaceous sediments are also common and that the estimated thickness of the sandstone succession may be less than that observed in the models. However, as these units are generally quite thin (no more than about 10m to 30m thick) they were not included in the overall reservoir thickness models for this study.

The modelled data suggests that the estimated depths of both reservoirs at Antrim may be slightly underestimated, this is dependant on variations in the thickness of the strata overlying the Sherwood Sandstone Succession across the Lough Neagh basin.

Sherwood Sandstone and Permian Sandstone thickness at Ballymoney is in the region of 500m, where the latter of the two is estimated to be present at a depth of approximately 2500m. It is worth noting the presence of probable Carboniferous sandstone targets below the Permian Sandstones in these models. This would constitute a deeper additional reservoir target in this area. However, there is no deep borehole information to verify these models. During the course of 2008 a hydrocarbon exploration borehole located 15km north of Ballymoney will be drilled. Information gathered from this borehole may provide additional data on potential Carboniferous reservoir targets.

The granites of the Mourne area in Co. Down as well as probable buried granites in Northern Ireland, may have the potential for development of enhanced geothermal systems (EGS) such as Hot Dry Rock technology for the production of electricity. However, there is no information on the reservoir properties of these formations, and they were not assessed in this study. The Mourne granites have the potential for high radiogenic heat production. These may also constitute an important target for Hot Dry Rock type systems. At present there is insufficient information on the reservoir properties to be able to quantify their potential.

5 VOLUMETRIC ANALYSIS:

Reservoir calculations have been undertaken based on the volumetric method (Muffler, L. J. P. & Cataldi, R., 1978). This estimates the total thermal energy contained in a volume of rock based on basic rock property parameters such as mean temperature, porosity and specific heat capacity. These are converted into recoverable heat energy by estimating a load factor and a life time for a producing geothermal well doublet. For the purpose of this calculation, the volume of rock was assumed as being the thickness of the formation over a 22.5km^2 area which is considered the normal radius of influence of a geothermal well doublet over a period of 25 years of production.

The modelling exercise was carried out separately for the Sherwood Sandstone Group, the Lower Permian Sandstones and the Carboniferous Sandstones of the Northwest Basin. The potential of the Carboniferous lithologies previously described in this report in the Ballymoney area were not included as to date insufficient reservoir parameters are available. No modelling was possible for the Sherwood Sandstone Group or Lower Permian Sandstones in the main depocentres of the Lough Neagh Basin as no data is available for these areas.

Geological modelling of available data provided reservoir depths, petrological parameters and thicknesses of the reservoir targets used in the calculations. Additional information on the reservoir rock characteristics were obtained from hydrocarbon exploration boreholes in the vicinity of the modelled localities. In the absence of actual lithological properties of the formations below the selected localities, the adjacent borehole data provides a reasonable estimate of these parameters.

Only guideline geothermal resource estimates can be given for the specific sites selected, because specific heat capacities of the rock formations at the sites chosen are based on measurements acquired in generic laboratory tests. For this reason an analogous geothermal well doublet in Unterhaching (Germany) producing approximately 40MW$_{th}$ of heat using standard titanium heat exchanger technology, was included in the calculation for comparative purposes.

The results of the calculations are summarised in Table 4 below.

Table 4: Preliminary Reservoir Calculation for Total Heat Power stored in Geothermal Reservoirs formations in Northern Ireland.

Site Location	Lithology	Reservoir Thickness (m)	Base of Geothermal Target Formation (m)	Volume of Source Rock (V) (m^3)	Mean Calculated[a] or Measured (T) (°C)	Estimated Re-injection Temperature at the Surface (T_{ref}) (oC)	Load Factor[1] (% operational time)	Life Time[2] (years)	Energy Stored in the Reservoir (kJ$_{th}$)	Total Power Stored in the Reservoir (MW h)
Larne	Sherwood Sandstone	650	1615	14625000	80	40	0.75	25	1.58E+09	**439.53**
Ballymacilroy	Sherwood Sandstone	420	1870	26250000	84	40	0.75	25	3.54E+09	**983.50**
Langford	Sherwood Sandstone	270	1515	16875000	54	25	0.75	25	1.61E+09	**446.12**
Port More	Sherwood Sandstone	680	1830	42500000	78	40	0.75	25	5.24E+09	**1456.08**
Antrim	Sherwood Sandstone	400	1600	25000000	78	40	0.75	25	2.74E+09	**761.35**
Ballymoney	Sherwood Sandstone	500	1400	31250000	78	40	0.75	25	3.43E+09	**951.69**
Magheramorne	Sherwood Sandstone	650	1600	40625000	82	40	0.75	25	4.62E+09	**1281.96**
Larne	Lwr. Permian Sandstone	900	2800	56250000	83	40	0.75	25	8.19E+09	**2274.70**
Antrim	Lwr. Permian Sandstone	200	2200	12500000	77	40	0.75	25	1.36E+09	**378.22**
Ballymoney	Lwr. Permian Sandstone	500	2200	31250000	82	40	0.75	25	3.86E+09	**1073.33**
Magheramorne	Lwr Permian Sandstone	250	2200	15625000	83	40	0.75	25	1.90E+09	**528.84**
North West Basin	Carboniferous Basal Sandstone	150	2000	9375000	65	30	0.75	25	1.15E+09	**318.65**

The figures show initial estimates of total heat power contained in a rock reservoir. The original formulae for estimating the total energy contained in a given reservoir normally take into account the characteristics of both rocks and fluids present at depth. At present the only identified potential hot brine source of geothermal energy is in the Permo-Triassic basins in Northern Ireland. For this reason and the present incomplete geological dataset, a conservative case for the selected sites was adopted in this study and an assumption that geothermal energy that can be sourced from rock at depths of 1500m and 2500m depths only was made. Hence fluid specific heat capacities and fluid temperatures were omitted from the calculations.

The calculations of the total energy stored in reservoirs (Table 4), identifies the Lower Permian Sandstones in the Larne Basin as the reservoir with the highest geothermal potential. This is because these formations are thicker and occur at greater depth in the basin resulting in overall higher formation temperatures. A review of the hydrocarbon exploration data from these basins also indicates better porosity values in this formation where water flow potential is higher.

The Sherwood Sandstone Group in the same basins is located at shallower depths with lower temperatures and overall is slightly thinner than the Permian Sandstones below. Permeability and porosity may, however, be more favourable in the Sherwood Sandstone.

The potential of the Lower Permian Sandstone and the Sherwood Sandstone in the Lough Neagh Basin depocentres as outlined in Mitchell (2004) have not been assessed as only limited geophysical data and no exploration wells have been completed in these areas.

The availability of petrophysical properties for the Carboniferous limestones in Northern Ireland is limited to data from a single well in County Fermanagh. The TELLUS data has so far not been used to refine the depths of this target formation and it petrophysical properties. For this reason the reliability of the modelled energy stored in these formations is not as good.

Table 5 below shows an overall ranking of the potential for deep geothermal energy stored in the reservoirs in Northern Ireland with the Lower Permian Sandstones having the highest potential.

Table 5: Geothermal Reservoirs formations and Site Location Ranking in Northern Ireland.

Formation Ranking	Site Location Rank	Site Location	Lithology	Reservoir Thickness (m)	Base of Geothermal Target Formation (m)	Total Energy Stored in the Reservoir (MW h)
1	1	Larne	Lwr. Permian Sandstone	900	2800	2274.70
	2	Ballymoney	Lwr. Permian Sandstone	500	2200	1073.33
	3	Magheramorne	Lwr Permian Sandstone	250	2200	528.84
	4	Antrim	Lwr. Permian Sandstone	200	2200	378.22
2	1	Port More	Sherwood Sandstone	680	1830	1456.08
	2	Magheramorne	Sherwood Sandstone	650	1600	1281.96
	3	Ballymacilroy	Sherwood Sandstone	420	1870	983.50
	4	Ballymoney	Sherwood Sandstone	500	1400	951.69
	5	Antrim	Sherwood Sandstone	400	1600	761.35
	6	Langford Lodge	Sherwood Sandstone	270	1515	446.12
	7	Larne	Sherwood Sandstone	650	1615	439.53
3	1	North West Basin	Carboniferous Basal Sandstone	150	2000	318.65

The results show how depth and formation thickness control the potential for heat storage across all the basins. In localities where both the Lower Permian and Sherwood Sandstone targets are present, the thickness of the modelled formation is shown as the controlling factor. This is true of the Antrim and Magheramorne areas where the Lower Permian Sandstone formations are thinner compared to the overlying Sherwood Sandstone. Hydrocarbon well data shows that the porosity recorded in the Lower Permian formations is also slightly lower than that those of the Sherwood Sandstone. For this reason higher flow rates at lower temperatures in the shallower Sherwood Sandstone may yield more energy than in the Lower Permian Sandstones.

The Carboniferous Basal Sandstones encountered in the Northwest basin in Fermanagh have shown from the modelling to have the lowest stored energy values compared to the younger formation in other parts of Northern Ireland. However these are also very thin compared to some of the other modelled targets.

Figure 5 shows the distribution of geothermal potential of the given reservoir target formations in Northern Ireland.

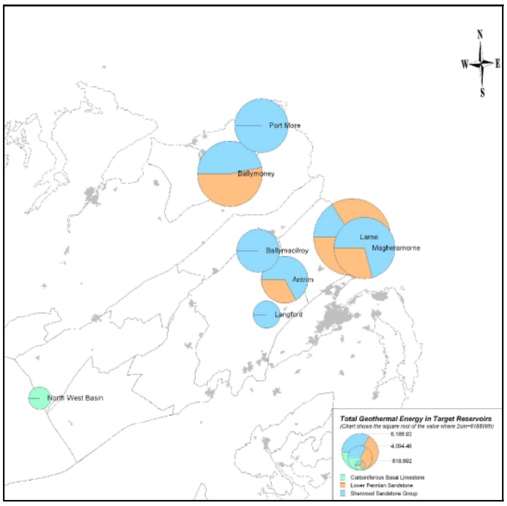

Figure 5: Claculated Geothermal Reservoir Potential in Northern Ireland.

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