HYDROCARBON PRODUCTION FROM PALAEOZOIC CLASTIC AND CARBONATE RESERVOIRS

INTRODUCTION

This is a compilation of public-domain information about commercial hydrocarbon reservoirs in fractured Palaeozoic formations from approximately 13 different countries.

It is a new compilation which closely relates to our fractured basements review but which looks specifically at reservoirs in Cambrian to Permian formations. As a 'Version 1' it is undoubtedly incomplete but we will aim to update and develop it on a regular basis. It is made available for personal interest and education only and should not be republished or distributed in any way. Data has not been cross-checked in detail against multiple references so use with care. In addition, some of the information, for example on production, may be out of date since it is based on historical sources.

Just as with the crystalline basements, most of the Palaeozoic formations have a pretty tight matrix and therefore sustainable production relies on the presence of secondary porosity in the form of well connected fracture systems and/or alteration effects such as weathering dissolution in carbonates

Information updates, corrections and comments are welcome. We know from our own work that there are several fields that are not included here because no information has been released in the public domain. If you can provide information or examples that we can use in the compilation we will be delighted to continue developing the resource.

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Updated December 2013

Algeria

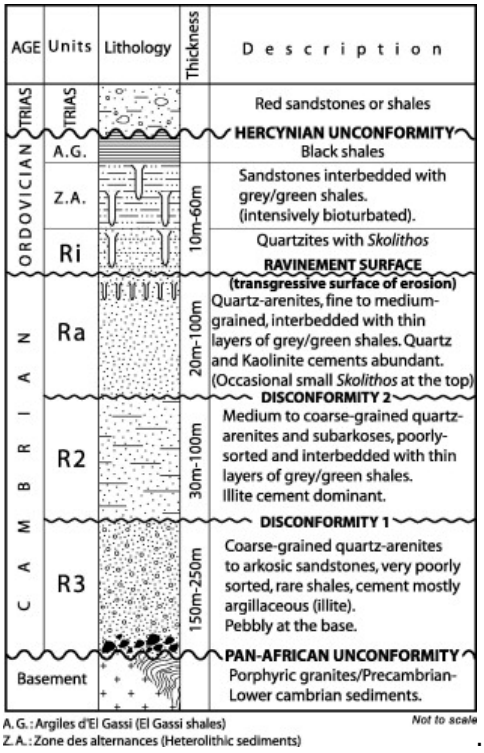
El Gassi

El Gassi is located 60 miles south west of Hassi Messaoud in central Algeria and is closely linked in with neighbouring fields El Agreb and Zotti. As found in the Rhourde el Baguel field the predominant reservoir rock of the area is Cambrian quartzite sandstone. This tends to have low permeability, be diagenetically modified and characterised by a complicated network of faults and fractures Sonatrach joined with Amerada Hess in 2000 to exploit the estimated remaining 300 million barrels of oil with the hope of reaching a production rate of 45,000 barrels of oil per day (Amerada Hess, 2000).

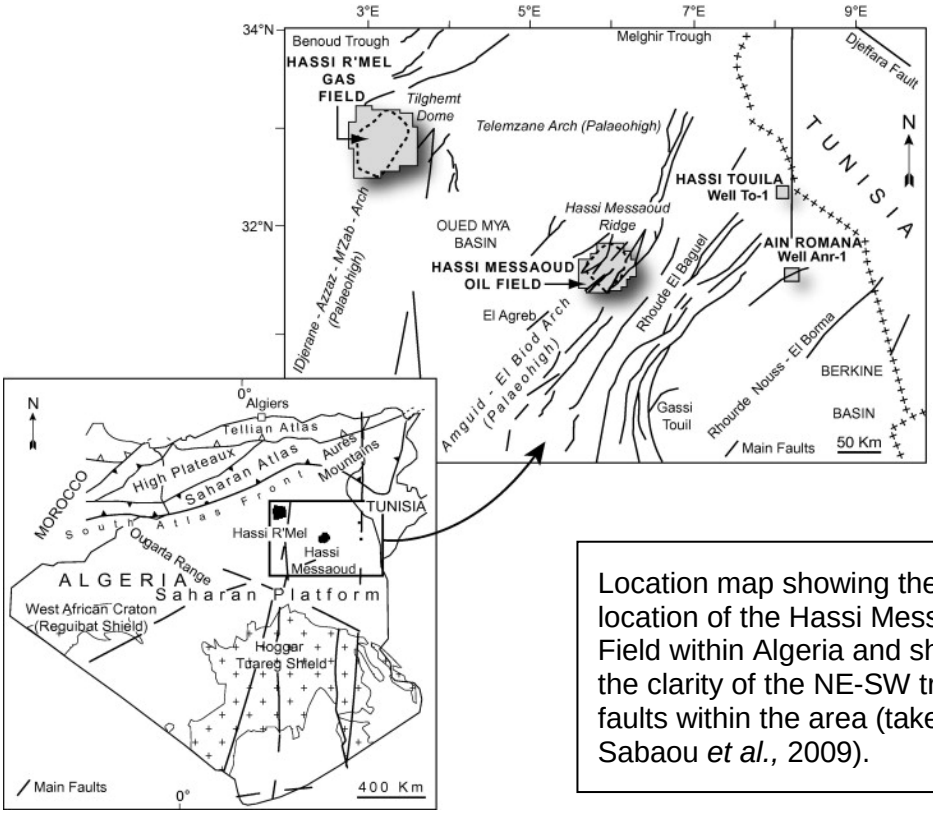
Hassi Messaoud

Hassi Messaoud is the largest oil producing reservoir (categorised as a Super Giant reservoir) in Algeria with total proven reserves of 6.4 billion barrels of oil. Production in 2008 had reached 400,000bbls/d, a figure which Sonatrach (field operator) is hoping to increase within the next few years (Oil and Gas Directory, Middle East, 2011). A series of Cambro-Ordovician sandstones serve as the predominant reservoir rock of the field which are commonly subdivided into four separated divisions; R3, R2, Ra and Ri (See figures, taken from Sabaou *et al.,* 2009). “Ra” is the most productive Cambrian reservoir of Hassi Messaoud. The sandstones are deposited on top of igneous and metamorphic basement rocks and are said to be characteristic of cratonic environments which were unstable during the Cambrian due to phases of extension and compression from the Pan African Orogeny (Sabaou *et al.,* 2009).

Faulting within the area follows a NE-SW or E-W trending pattern. Wells MD 251, MD 264, and MD 340 were based around one of these NE-SW trending faults in order to test fracture intensity. Well MD 251 was situated 0.5km south of the chosen fault and displayed a low fracture intensity which was mainly stratabound. Well MD 264 was located 0.1km south of the fault line, open fractures here were rare but porous fractures were more common with a fracture intensity of $1.5m^{-1}$. Finally, well MD 340, only 0.1km north of the NE-SW fault line contained both open and porous fractures and a high fracture intensity of $>5m^{-1}$. The figures show the exact location of Hassi Messaoud field with respect to the rest of Algeria but also the nature and scale of the NE-SW trending faults (taken from Sabaou *et al.,* 2009)



Lithostratigraphical column showing the four divisions of the Cambrian reservoir rock (figure taken from Sabaou *et al.,* 2009).



Location map showing the exact location of the Hassi Messaoud Field within Algeria and showing the clarity of the NE-SW trending faults within the area (taken from Sabaou *et al.,* 2009).

Rhourde el Baguel Field

Discovered in 1962, the Rhourde el Baguel Field is situated in the Ouargla Province in Eastern Algeria. ARCO (now part of BP) started development in the field in 1997 and by December 2000, 37 new wells had been drilled and 38 producers were active in the region. By the time the redevelopment phase had begun, Sonatrach and ARCO had produced 430 MMBO (15% of oil in place) (Robinson *et al.,* 2000). The reservoir contains an estimated 3 billion barrels of undersaturated light oil within a 550m succession of Cambrian sandstones (occasionally interbedded with small portions of shale). With increasing depth the matrix porosity of the reservoir increases and the matrix permeability decreases. The lower 2/3 of the reservoir (zone 1) consists of "strong sandstones" with 11% porosity and an average permeability of 0.25-0.4 md, contributing to 15% of total recovered oil; whilst the upper 1/3 (top 170m) of the reservoir includes "very strong" quartz rich sandstones with 8% average porosity and 13 md permeability. The upper zones (2-6) therefore account for the most productive reservoirs, in particular zones 6A, 5B and 5A which contain the most interconnected fractures.

A noticeable divide can also be seen between the southwest and central parts of the field (containing more open fractures) and the northern part of the field (containing no open fractures). Faults as well as fractures also influence productivity within the field as they increase permeability, therefore wells that intersect these fault lines yield higher productivity than cross strike fractures (Wilkins and Belfield, 1998).

Tiguentourine Field , In Amenas

Situated in Eastern Algeria, in the southern part of the Illizi Basin, the Tiguentourine field is a gas condensate deposit in a Cambrian and Ordovician glaciogenic sandstone reservoir. Well connected natural open fractures make this reservoir viable for drilling and the area has been taken on as a joint venture between Statoil, BP and Sonatrach (EAGE Conference and Exhibition, 2007). Since the 1950's, approximately 40 wells have been drilled by the above enterprises for "exploration, appraisal and development purposes" (North African/Mediterranean Petroleum and Geosciences Conference and Exhibitions, 2007). Production rates and total reserve values are unavailable

Argentina

Tarija Basin

Situated in northern Argentina, the Tarija Basin has a network of natural fractures contributing to high secondary porosity and enhancing the potential reservoir volume of this mostly unexplored hydrocarbon play. Oil and gas migration and generation in this area coincide with the formation of a serious of recent (9Ma-present) anticlinal structures. The Tuyunti structure within the Tarija Basin is owned by Pan-American Energy (52%), Shell Capsa(22.5%), Repsol-YPF (22.5%), Apco (1.5%) and Northwest(1.5%) – ownership details from figures published in 2004. Palaeozoic, Silurian and Devonian quartzite sandstone units are strongly lithified, forming the fractured gas reservoirs. Further exploration of the area is due to take place (Sanders *et al.,* 2004*).*

China

Junggar Basin-Karamary Oilfield

Situated in the Northwest of China, the Junggar basin covers an area of 130,000km^2 and has gained commercial success along the Karamary thrust belt since 1955. Exploration of the Karamary Oil field is permitted by the Karamary Oil Company (KOC) and in 1990 they estimated reserves at 200-300 million barrels. The most productive source rocks within the basin are primarily Permian lacustrine sediments; hydrocarbons migrate north-westwards out of these deep Permian source rocks and accumulate in Permian and Carboniferous reservoirs. Current production values of the area are unavailable, however in 1984, "Karamary was producing 75000 barrels a day" (Lawrence, 1990).

Tarim Basin- Manjiaer Sag

The Tarim basin is of the same origin and evolution as the Junggar Basin, only larger, 906,500km^2 (Lawrence, 1990). Three main source rocks of different ages (Mid-lower Cambrian, Mid-lower Ordovician and Upper Ordovician) are found within the Manjiaer Sag. Mid-lower Cambrian source rocks include both a muddy and a limey rock with thicknesses of 50-150m and 100-200m respectively, these produce high temperature pyrolysis dry gas. Mid-Lower Ordovician black siliceous rocks dominate the eastern part of the Manjiaer Sag and produce commercial amounts of oil and gas, type I and II. Upper Ordovician source rocks occur in laminated band deposits or troughs and contain types I, II and III prone oil, this source is not exploited commercially (Meng-jun *et al.,2008*).

With regard to possible future production within the area, PetroChina claim that recent "strategic discoveries in major exploration areas such as the Tarim Basin, lay solid foundations for the 17th Peak Growth Oil and Gas Reserves Program" (PetroChina, 2008).

Shanxi Formation – Ordos Basin

Situated in the north-west of China, the lower Permian sandstone reservoirs in the north-eastern part of the Ordos Basin are a prolific Palaeozoic hydrocarbon reserve which covers an area of 320,000 km^2. The main source rock comes from Upper Palaeozoic coal seams in dark mudstone found within the Upper Carboniferous and Lower Permian Strata. Although the reservoir rocks are typically 'tight Permian sandstones' there are three combinations of reservoir-cap rocks in which gas pools have been found: Upper Carboniferous Taiyan formation carbonate and argillaceous carbonate; Lower Permian Shanxi formation interbedded sandstone & mudstone and Lower Permian Xiashihezi formation sandstone and Upper Permian Shangshihezi formation interbedded mudstone & mudsiltstone. Combinations 2 and 3 are the most important in terms of gas reserves (Xiao *et al.,* 2005). Exploration of this area commenced in 1907 (Zhu *et al.,* 2008).

Czech Republic

The Liten formation in the Barrandian basin, Czech Republic, contains 2.4% total organic carbon content and is considered a potential petroleum source rock. There are three

distinguishable phases of hydrogen migration which occur within quartz and calcite veins, cross cutting dolerite dykes. These are represented by solid bitumen (oldest phase), "liquid petroleum within fluid inclusions" (second phase) and a semi solid wax blanketing the veins (youngest phase) (Suchy et al., 2010). The source of the oil is thought to originate from multiple Silurian source rocks; although the potential reservoir rock of Cambrian arkoses and sandstones has been identified, it is yet to be exploited.

Iraq

The western deserts of Iraq remain a largely under-explored area, however they are thought to hold significant hydrocarbon potential. There are two ages of Palaeozoic source rocks within the area; lower marine "hot" shales and Upper Ordovician black shales of the Khabour formation. Reservoir rocks vary in age and include Cambrian, Ordovician and Early Silurian Sandstones, reservoir quality however is a major exploration risk as some of the reservoir rocks may have been affected by quartz overgrowth (Aqrawi *et al.,* 2012).

In Kurdistan, current exploration and appraisal drilling is proving reservoirs hosted in Triassic sequences formed by carbonates, dolomites, shales and anhydrites.

Libya

Libya is Africa's largest distributor of oil, having produced approximately 20 billion barrels of oil to date. Although much of this has come from Mesozoic and Cenozoic reservoirs, Palaeozoic reservoirs also present an equally large potential resource for Africa.

<u>The Murzuq Basin</u>

The Murzuq Basin is an example of an Ordovician glaciogenic reservoir in western Libya, approximately 350, 000 squared kilometres. Until the 1980's the search for hydrocarbons within this basin was unproven. Since then, large discoveries in Upper Ordovician (Hirantian) sediments have been made, including the Elephant and El Shahara fields containing 1-1.5 billion barrels of potential reserves (Le Heron *et al.* 2005). These discoveries were subject to a "successful European exploration programme" 25 years ago (Le Heron, 2007).

<u>Al Kufrah Basin</u>

The Al Kufrah Basin is the most easterly of the great Palaeozoic sedimentary basins in North Africa. It covers a vast area of 400,000 km^2 which is largely yet to be exploited, however exploration of the region did commence in 2005. Holes are due to be sunk following the country's civil unrest by Germany's largest producer of crude oil and natural gas, Wintershall (who have been working in Libya since 1958) and Italian company ENI (Le Heron and Howard, 2011). The source and seal rocks of these Ordovician glaciogenic traps are the "hot shales" of the lower Silurian, whilst the reservoir rocks are comprised of Cambro-Ordovician sandstones. Factors making this region such a major potential reservoir include the thickness of the Hawaz Formation at the base of the succession (300m), the lack of shale;

unconformities, indicating a “well connected reservoir with few barriers prohibiting fluid flow” and significant faulting (Le Heron and Howard, 2011).

The Jebel Hadrid structure within the Kufrah basin is a circular structure measuring approximately 4.7 km in diameter. It was originally thought to have formed from endogenic processes, however recent research has led to the conclusion that it could be an impact crater. Two other craters have also been identified in Libya. This, in turn has sparked an interest for further exploration within the crater as there are many highly productive reservoirs formed from impact throughout the world. For example the Cantarell oil field within the Chicxulub crater (Mexico) produces 1.3 million barrels of oil per day, of which, 60% comes from the K-T breccia (Grajales-Nishimura *et al,* 2000). Two potential major plays have been identified within the Jebel Hadrid crater (Schmieder *et al.,* 2009):

1. A Palaeozoic play with a source rock of “hot shales” from the Tanezzuft Formation and a reservoir rock of Cambro/Ordovician sandstones.
2. An Infracambrian play with source rocks of black shales and organic rich limestones and reservoir rocks of sandstones and fractured limestones.

North Africa

Exploration for petroleum from Palaeozoic reservoirs in North Africa began in the early 1950’s throughout Libya, Algeria, Tunisia and Morocco. In 1952 the first well was sunk in the Sahara Desert, Algeria and since then a further 330 hydrocarbon accumulations from Palaeozoic reservoirs have been found with an estimated recovery of 46 billion barrels of oil (Traut *et al., 1998)*. Glaciogenic reservoirs, in particular Hirnantian deposits hold great economic significance over central North Africa with Palaeozoic, Early Silurian shales as the predominant source rock (TOC values measured 4.5% in eastern Marocco) (Le Heren *et al.*, 2009).

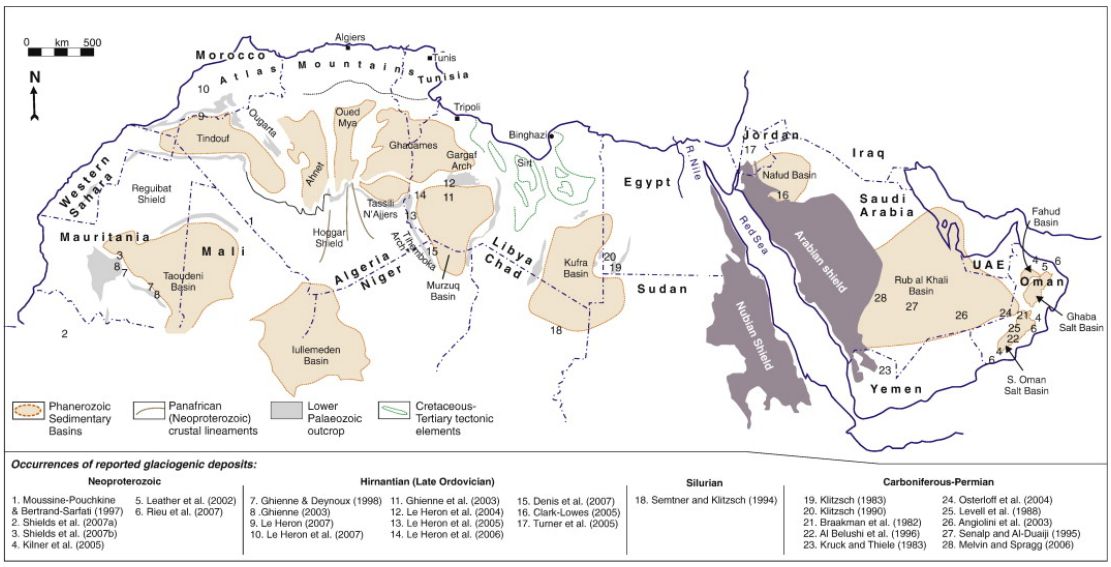


Figure from Le Heren *et al,* 2009 – Map showing glacially related deposits of Paleozoic and Phanerozoic age.

Ghadames Basin

An intra-cratonic basin covering 350,000 km^2 including portions of Algeria, Libya and Tunisia. Over 700 exploratory wells have been drilled within the basin, discovering approximately 160 oil pools from Ordovician, Silurian and Devonian Palaeozoic source rocks. The basin is bounded by the Dahar Naffusah high in the north and the Qarqaf Uplift in the south.

Total oil in place within the Ghadames basin for Algeria is 5758 STOIIP whilst the total number of fields is 57. These figures for Libya and Tunisia are slightly lower: 3347 STOIIP with 61 fields and 550 STOIIP with 5 fields respectively. Production from Ordovician and Devonian reservoirs comes from the southern flank of the Ghadames basin because of the sandier facies and improved petrological features. Oil production from these reservoirs is more prolific in Algeria. For example the Ordovician quartzite sands found by AGOCO and AGIP in the Hamra High and the Devonian sandstone oil fields of Bir Rebaa, Rhourda, Messoud and Bir Berkine on the western flank of the Ghadames Basin (Echikh, 1998).

Silurian source rocks in the north-western part of the basin, in the lower Acacus provide a lucrative region of oil in Libya, including 22 oil fields and 3 gas fields. Although major new discoveries have already been made throughout this region “studies obtained by foreign companies” (Echikh, 1998) in partnership with Sonatrach have found evidence for further untapped potential in Silurian and Devonian source rocks in Algeria and the Illizi region in Libya.

Oman

Salt basins in Oman were formed from rifting during the late Precambrian and were preserved by uplift during the Hercynian. They host Precambrian, Palaeozoic and Meosozoic reservoirs which are charged by Precambrian source rocks as a result of the Hercynian uplift (Afifi, 2005). The Al Khlata Formation is a major productive hydrocarbon bearing province in Oman, with an estimated 3 bbl of oil in 1998. Palaeozoic glaciogenic reservoirs play a key role in the preservation of oil in many active basins throughout North Africa, including in the Al Khalata Formation. Hence, approximately 20 fields in the Ghaba and Nafud salt basins are accounted for by “glacial fluvial and glacial-lacustrine sandstones” (Le Heren *et al.,* 2009).

Eastern Flank Hydrocarbon Province

Situated on the south-eastern edge of south Oman, the Eastern Flank Hydrocarbon Province defines a belt of oil zones measuring 30-70km wide and 300km long which was discovered by PDO in the 1970’s. By 1986 a total of $2x10^9m^3$ of oil had been discovered and there were 6 producing oil fields found in low relief anticlines. Although primary recoveries were low (5-7%) the success rate of oil finding was high (60-70%) due to hydrocarbons migrating beneath the salt traps. Enhanced oil recovery techniques were due to take place in south Oman to improve the low recovery rates (Al-Marjeby and Nash, 1986).

Khazzan Makarem

The Kazzan Makarem field is situated in block 61 in the centre of Oman. The reservoir rock

is composed of PreCambrian and Palaeozoic clastic sedimentary formations (GeoScience Report) and covers a vast area of 2800km^2, containing an estimated 20-30 trillion cubic feet of natural gas. BP is the main operator of the area with 100% working interest as the company has the required technology to deal with the type of "tight gas" found in this area (BP, Upstream major projects – Middle East, 2012). Gas production from the Khazzan Makarem field is due to commence at the end of 2016, this was announced in July 2012, by Shaikh Ali Bin Thabit al Battashi, advisor to the Ministry of Oil and Gas.

Poland

Zechstein Plays

Located in the central lowlands of Poland the Zechstein Plays are composed of Permian reservoirs of sandstone or dolomite which host hydrocarbons sourced from shales formed approximately 250-270 Ma. These formations are sealed by Zechstein rock salt and contain both oil and gas. Aurelian Oil and Gas is a major producer in this region and holds a 35% interest in the Cybinka/Torzym basin, including the Meidzychod and Lubiatow fields which contain 7 billion m^3 of gas and 30 million barrels of oil (discovered 2003). Aurelian also holds a 50% interest in block 249, Kalisz and a 90% interest in blocks 207, 208 and 206 in the East and North Pozan regions (AurelianOil, 2012).

Russia

Pechora Platform

Exploration of the Timan-Pechora basin has been carried out onshore throughout the past 50 years, revealing one of Russia's most productive hydrocarbon basins. However offshore exploration in this area is still in its infancy with only five commercial discoveries of oil and gas between 1988 and 1998. The basin harbours two main source and reservoir rocks. Firstly, the Domanik shale source rock (average thickness – 20-60m) hosted by Permo-Carboniferous reservoir rocks and secondly: Silurian-Lower Devonian source rocks, found in Lower-Mid. Devonian carbonates. Reservoir rocks vary in thickness from 9-19m. The Permo-Carboniferous reservoir rocks have enhanced porosities of up to 16-17% from dolomitization (Martirosyan *et al.,* 1998).

90% of recoverable oil offshore from the Pechora Platform is found in Permo-Carboniferous carbonates with a further estimated 30% of undiscovered reserves expected in both the Permo-Carboniferous and the Siliurian-Devonian reservoirs. Figures published by Martirosyan *et al.,* 1998, show the recoverable amount of offshore oil to be 111 x 10^{12} BBLS and gas to be 96 x 10^{12} SCF. Furthermore, operations from Gazprom are scheduled to start in the Prirazlomnoye oil field of the Pechora Basin later this year (2012). This field contains an estimated 72 million tons of oil reserves which would result in an annual production of 6.6 million tons (Gazprom, 2011).

Porosity and permeability in the Pechora Platform vary according to the reservoir rock. Sandstone reservoirs of the Lower Palaeozoic have an average porosity of 11.5% and an average permeability of 15md. Carbonate reservoirs have a low average porosity of 9% in the Lower Palaeozoic rocks and a high average porosity of 15.8% in the Lower Carboniferous reservoir rocks. The carbonate reservoirs contain a range of permeability's from 63-930md. These significant carbonate plays were formed by tectonically controlled Upper Devonian and Lower Permian shelf edge reefs.

Within the Pechora-Barents basin, 3 types of carbonate reservoir have been identified. These are the "Upper Moscovian – Lower Sakmarian warm water carbonates, Upper Sakmarian – lower Artinskian cool water carbonates and Upper Artinskian –Kazanian cold water carbonates" (Mironcheva *et al.,* 2007). Although these reservoirs have been identified as a future prospect for hydrocarbon exploration, the amount which they yield is yet to be confirmed.

Chuzik-Chizhapka

Situated in West Siberia, Chuzik-Chizhapka is a region of oil and gas accumulation within the Parabel District. Host rocks vary in age from pre-Jurassic basement rocks to limestones on the Palaeozoic-Mesozoic boundary. Potential petroleum bearing reservoir rocks from pre-Jurassic lithologies include volcanics and Late Devonian argillites. These form the Sel'veika field and the Chaga formation, contributing to the "largest accumulation of Palaeozoic oil" in Siberia (Kontorovich, 2007). The most favourable reservoir rocks in this area include organic limestones found in regions of low uplift. Although these potential Palaeozoic reservoirs have been identified, they are yet to be exploited.

Thailand

The Khorat Basin

The Khorat Basin has a total area of 200,000km^2, covering major parts of northeast Thailand and western Laos. The basin includes three main areas of exploration (started by Exxon 1981) Phu Horm, Nom Pong and Dong Mun. Developed Permian carbonates of Late Wolfcampian-Early Guadalupian age account for the predominant reservoir rocks which are reputed for having low permeability, therefore the presence of any microfractures leads to good productivity (Kozar *et al.,* 1992). Phu Horm is currently the only gas producing field in the basin; however several other potential gas fields have been discovered (Smith and Stokes, 1997).

Phu Horm

Phu Horm is a deep gas development in the north-eastern corner of Thailand above the Khorat Plateau. The field is located close to the borders of Laos and Cambodia approximately 45km north of the Nam Phong gas field and has an area of 231.6km^2. Exploration of the area has been carried out since 1983 when the first well Phu Horm-1 was drilled in the northern end of the Phu Horm anticline. In May 2002 drilling commenced for well Phu Horm-3 (carried out by Amerada Hess) with the target depth of 2,900m and the aim to intersect the Permian Pha Nok Khao Dolomite. The carbonate reservoir rock consists of heavily dolomitised skeletal wackestones and packstones with only a fair matrix permeability and an average porosity of 4.2%, macro and micro features increase the productivity potential of this area. Initial rates of production were calculated at 6 million cubic feet per day with the intention of raising this to 100 million cubic feet per day (PTTEP, 2006). By 2011 production from Phu Horm averaged at 85.91 million cubic feet per day of natural gas and 392.22 Bbls per day of condensate (Gulfport Energy Corporation, 2012). Estimated reserves for the Phu Horm field stand at 300-500BCF (Smith and Stokes, 1997).

United States

Alaska

Lisburne Group

The Lisburne group is situated in the north eastern corner of Alaska, next to Prudhoe Bay and was discovered in 1968, with peak developments in the mid-1980's. The Lisburne group is the "only carbonate field developed in Alaska" (BP, 2007) and is composed of interbedded dolomite mudstones and grainstones. The fractured carbonate reservoir spans an area of 100 square miles and is Mississipian- Pennsylvanian in age. Estimated original oil in place has been calculated at 3 billion bbls with a 15% recovery factor of around 450 million barrels. There are two sets of fractures which play an imperative role in the porosity (2-18%) and permeability (1md) of the group; these are E-W fractures parallel to the fold axes which formed late during folding and N-S fractures, perpendicular to the fold axes which formed post folding. The N-S fractures tend to be much larger than the E-W fractures and have a greater possibility of interconnecting, therefore wellbores perpendicular to the N-S set strike hold the most potential for oil recovery. Stratigraphy also influences fracture density as the dolomites are more heavily fractured than the grainstones, hence the best developed reservoir is in the dolomites.

Nevada

Blackburn Oil Field

The Blackburn Oil Field in Pine Valley, Eureka Country, Nevada was discovered in 1982 by Amoco Production Company. Heavily fractured Devonian dolomite serves as the principle reservoir rock as petroleum here is found in "fractured, locally brecciated, microcrystalline to finely crystalline dolomites of the Devonian Nevada Group" (Hulen *et al.,* (1990). Other fields within the area are hosted by fractured carbonates, for example the Grand Canyon field (produced over 6 M bbls/day, 1990). Hydrothermal fracturing of the reservoir rocks is thought to have originated from magmatic activity beneath the Blackburn Oil Field increasing the porosity (5.3%) and permeability (21 md) of the area (Hulen *et al.,* 1990).

New Mexico

Sin Nombre Area

The Sin Nombre area in New Mexico is located north of the Permian Basin and south of the Tucumcari Basin, covering an area of approximately 7000 m^2. In the south east and south-central parts of the area, 100 BCF gas and 6 million barrels of oil have been produced from 17 oil pools, however the Sin Nombre is not well explored and there is significant potential for greater reserves. Permian sandstone from the Abo Formation serve as reservoir rocks hosting gas, whilst Silurian Fusselman dolostones and Pennsylvanian limestones are the predominant reservoir rocks for oil. Hydrocarbon production surrounding Sin Nombre has

been very lucrative, for example during 2000 “63.8 million bbls of oil and 553 billion ft^3 (BCF) gas were produced” (Broadhead, 2003) suggesting that further exploration of this area would be beneficial.

Texas

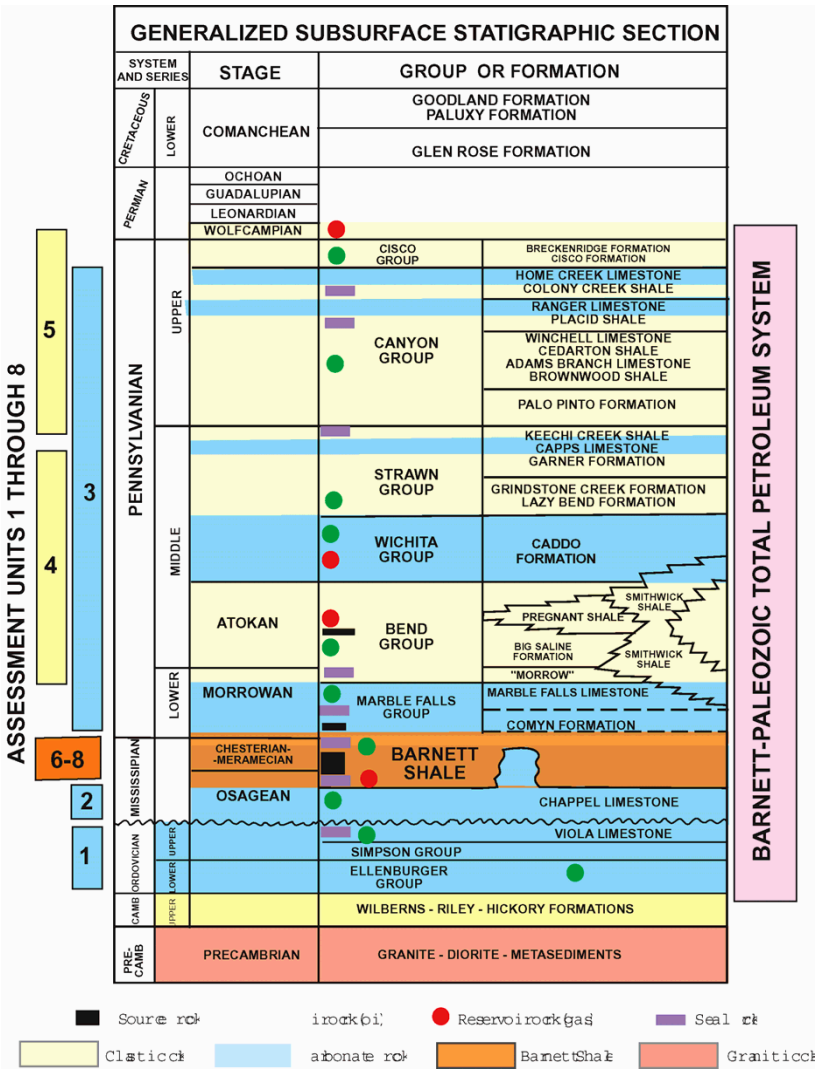
Texas is the main petroleum producing state of the Palaeozoic dolomite reservoirs of the Permian Basin in the USA. The basin extends into the south east of New Mexico, contributing to the production of over 26 billion barrels of oil since the 1920’s. Texas contains 120 major fields of Palaeozoic reservoirs, divided into four main groups by age.

1) The San Andreas/Grayburg dolomite reservoirs, Upper – Middle Permian in age. These reservoirs include the “largest in the Permian Basin” (Saller, 2004). Production forecasts indicate that a combination of three of the reservoir fields will recover more than 1 billion barrels of oil.
2) Abo, Clear Fork and Glorietta reservoirs, Lower-Middle Permian, dolomite. These reservoirs vary in size, retrieving anything from 10-220 million barrels.
3) Siluro-Devonian reservoirs. Dolomite reservoirs with a small area and a low porosity.
4) The Ellenburg carbonate reservoir, Ordovician in age. The oldest and deepest in the Permian Basin, a well connected fractured dolomite reservoir, owing its porosity to the collapse of an intricate cave system.

Oxy is the number one oil producer in the Permian Basin of South Texas, owning 138,000 net acres and over 1000 active wells in the area (Oxy, 2012).

Barnett Total Petroleum System

Within the Barnett system, five conventional hydrocarbon plays have been identified and one unconventional play. The five conventional plays have been assessed to contain as much as “381 million barrels of oil, 103.6 million barrels of natural gas liquids, 479 billion cubic feet of associated gas and 1,029 BCF of non-associated gas” (Pollastro *et al.,* 2003). Reservoir rocks range from Ordovician to Permian in age and compositions vary accordingly. Ordovician, Mississippian and Early Pensylvanian ages are represented by carbonate reefs, predominantly limestone pinnacle reefs. The more productive clastic reservoirs of Middle Pensylvanian to Lower Permian age are composed of sandstones and Band Group Conglomerates, this sequence is also thinly bedded with limestone and holds a cumulative production of 3TCFC. Cumulative production of these conventional reservoirs had reached 2 billion barrels of oil and 7 trillion cubic feet of gas by 1995. The Mississippian-Pensylvanian Barnett Shale is the one source rock of the area and is also the one unconventional hydrocarbon play (fractured Barnett Shale). It produces high quality oil (35-50°API gravity, low sulphur) and shows the greatest promise for future exploration (Pollastro *et al.,* 2003).



Generalized stratigraphic subsurface section of USGS Bend Arch-Fort Worth Basin Province showing stratigraphic extent of Barnett-Paleozoic Total Petroleum System, source rocks, producing oil and gas reservoir units, seal rocks, and proposed assessment units. Taken from http://www.searchanddiscovery.com/documents/pollastro/images/article.pdf [accessed 27/07/2012]

San Andreas Reservoir at Keystone Field

Keystone Field is situated in Winkler Country, Texas. The Permian San Andreas Reservoir is the predominant hydrocarbon bearing unit in the area and is part of the San Andreas platform carbonate from the Central Basin platform play. The shallow marine to tidal flat carbonate facies reservoir is heavily dolomitized inducing low permeabilities of less than 1md, despite this, productivity has been relatively high from northeast-southwest natural fractures. Anhydrite and gypsum nodules and cements are also common within the reservoir rock. Initial production rates reached 120bbls oil per day, however this decreased by 75% within 6 months. Cumulative production from the field since then has reached an estimated 2.8 miillion stock tank barrels (MSTB) (Major and Holtz, 1997).

Pakenham Field Area

Located in the Val Verde Basin, in south-western Texas, the Pakenham field is a recently discovered (1993) gas and condensate deposit of Pennsylvanian (Desmoinesian) age. The reservoir is composed of Strawn carbonates.

Thrusting along the edge of the Ouachita front has played a key role in the preservation of these reservoirs and the rate of production often depends on the nature of fracturing. Reservoir quality is also controlled by structure: “multiple reservoirs and single reservoirs are structurally divided into multiple potential pools” (Montgomery, 1996). Discovery well 49-1ACU was drilled in 1993 by Tom Brown Inc., followed by a secondary well (49-2ACU) 0.5 miles to the east in 1994. Since then a number of major oil companies (Conoco, Chevron USA, Union Pacific Resources Corporation and Mobil Oil) and a few smaller independent companies have put drilling programs in place, looking for further exploratory prospects within the region.

The Val Verde Basin is already a well known gas rich province and includes the discovery of several giant fields, for example the Brown Bassett, Grey Ranch and Pukett fields in the fractured Ordovician Ellenburger dolomites. These occur in the hydrocarbon producing Val Verde fault zone (Montgomery, 1996).

Virginia

Eastern Devonian Shales

Eastern Devonian Shales are a highly productive reservoir rock in the west-central part of the Appalachian Basin. Current production from this region is estimated at more than 2.7 trillion cubic feet of natural gas from 9600 producing wells (Nearing and Startzman, 1988).

Trenton Limestone Reservoirs

The Trenton Limestone can be found in Lee Country, south-western Virginia. The carbonate reservoir rocks have largely been destroyed through diagenesis and are therefore mostly impermeable; however, fractures have increased the porosity and permeability of the rock

making it a viable reservoir. Exploration of the area commenced in 1910 with the most productive years occurring between 1981-1983, during this period 35 wells produced 128,112 bbl of oil (Bartlett).

UK

London-Brabant Massif

Situated between the United Kingdom and the Netherlands, the London-Brabant Massif represents sub Permian potential reservoirs from Carboniferous sediments and Millstone Grit sandstones. Exploration of this area was led by ECL in 1984 uncovering several hydrocarbon plays through seismic data. The Barren Measures sandstone (well 53/12-3) proved to be a very promising reservoir rock with porosity values ranging from 14-28% inducing good permeability, whilst Mesozoic block faulting provides a solid structural trap. A further proven gas source could be found in the Westphalian A and B coal measures (Tubb *et al.,* 1986).

NW Europe – The Northern Permian Basin

Exploration for potential petroleum reserves of Palaeozoic age in the Northern Permian Basin has been fairly restricted. To date, only a few fields are active offshore Scotland, one of them being the Beatrice field which produces commercial quantities of oil from Palaeozoic rocks (Devonian lacustrine shales) in the North Sea Basin (Pedersen *et al.,*2006). The Alum shale in the Norwegian Sea is the most promising Palaeozoic source rock in the Norwegian area, producing commercial amounts of oil offshore western Sweden. UK wells 15/19-2 and 20/10-a3 show oil prone characteristics within the offshore lower Carboniferous shales, whilst onshore Carboniferous lacustrine shales in Scotland reveal a super rich, type I oil prone source. Further exploration (well 25/10-2) off the coast of Norway exposed high petroleum potential of oil prone type II in Permian marine Kupferschiefer.

Buchan Field

Situated 55km WNW of the Forties Field and 160km ENE of Aberdeen (Mieras, 1984) the Buchan Field lies on the southern edge of the Witch Grand Graben (Edwards, 1991). The predominant reservoir rocks are found in the central horst structure of the field and are composed of Upper Devonian and Carboniferous Red Sandstones and Mudstones representing a typical alluvial sequence. The reservoir is extremely complex and fractured as it is located on an old fault line, however it holds an estimated 90MMBBL of oil within a 585m oil column. Poorer reservoir quality is found down flank due to increasing depth and mineralisation of the fractures (Edwards, 1991).

Clair Field

The Clair Field was discovered in 1977 by the exploration well 206/8-1a (BP, 2003), since then it has been declared the largest known hydrocarbon reserve on the UK continental shelf

(Sheehan, 2011). Hydrocarbons sourced from Palaeozoic reservoirs in the Clair Field are found in fractured Devonian Carboniferous red sandstone beds, much like in the Buchan Field. The Clair field is located 75km off the west coast of the Shetlands and lies in approximately 150m of water. Thesequence of Devonian-Carboniferous sediments have an average thickness of 700m and accommodate an oil column of 568m (Coney *et al.,* 1993). The uppermost Devonian-Carboniferous sequence includes grey argillaceous siltstones with interbedded fine-grained sandstones. Recoverable reserves from phase 1 of the Clair Development are estimated at 250 million barrels of oil. Production started in February, 2005 and the field has so far produced approximately 80 million barrels of oil (BP, 2011). Structural constraints play an important role in the nature of this important hydrocarbon reservoir and oil can be found within 9 fault bounded segments. There are two sets of faulting: NNE-SSW oblique faults, truncating the Rona Ridge and NE-SW to ENE-WSW normal fault segments (Baron *et al.,* 2008) it is thought that the faulting occurred during the late Cretaceous period. The Clair Field contains 6 co-venturers, each with a fixed equity share holding (BP, 2011):

BP Exploration Operating Co. 27.6215%

Britoil plc (BP) 0.98%

ConocoPhillips (UK) Limited 24.0029%

Chevron North Sea Limited 19.4225%

Enterprise Oil Limited (Shell) 18.6831%

Shell Clair UK Limited (Shell) 9.2900%

The Second Phase of the Clair Development is situated to the north east of Phase One; the field has an expected recovery of 640 million barrels of oil over a 40 year period and production is due to start in 2016 (Sheehan, 2011).

Ukraine

The Rudenkovstoye Field

The Rudenkovskoye field is located in the southeast of the Poltava region in the Ukraine with a predominant reservoir rock of Devonian Sandstone and a complex fracture system. The field is operated by JKX, who claim to have a total of 21.6MMboe of reserves in the Rudenkovskoye field. Their most successful well in the area to date is well R103, drilled in December 2010 to a depth of 4641m; it exploits tight gas reservoirs within the Devonian sandstone, yielding 8.1MMcfd and 18 barrels of oil per day (JKX, 2010).

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Table of Production from Palaeozoic Reservoirs in South America, Europe and Africa:

Company	Country	Reservoir Name	Reservoir Rock	Production Oil/Gas	Comment	Status
Pan American Energy (52%) Shell Capsa (22.5%) Repsol-YPF (22.5%) Apco (1.5%) Northwest (1.5%)	Argentina	The Tuyunti structure in the Tarija Basin.	Palaeozoic Silurian and Devonian quartzite sandstone.	Gas reservoirs have been identified.	Still in the exploration stage of development.	Exploration
Aurelian (35% - Now merged with San Leon Energy)	Poland	The Zechstein Plays, the Cybinka/Torzym Basin.	Permian reservoirs of sandstone or dolomite.	In the Meidzychod and Lubiatow fields there is an estimated 7Bm^3 of gas and 30M barrels of oil.	Aurelian and San Leon Energy are two key players in the European unconventional gas sector. "The combined entity will be that creates the largest foreign holder of unconventional gas concessions in Poland". (naturalgaseurope.com – accessed 28/12/13).	Exploration
Gazprom	Russia	The Pechora Platform – Prirazlomnye oil field	Permo-Carboniferous Carbonate reservoir rocks.	Contains 72 million tons of oil reserves – an estimated 6.6 million tons of	This development has had a lot of coverage in the press recently regarding the	Ready to produce but suspended due to legal reasons – the activists are still being

				annual production due to start in Spring 2013.	Greenpeace "piracy" arrests. It is to be the first commercial offshore oil development in the Arctic.	detained in a Russian Prison (Oct. 2013).
BP (Exploration Operating Co. 27.6%) Britoil plc (BP) (0.98%) Conoco Phillips (UK) Ltd. (24%) Chevron North Sea Ltd. (19.4%) Enterprise Oil Ltd. (Shell) (18.7%) Shell Clair UK Ltd. (9.3%)	UK (75km offshore from the Shetland islands.	The Clair Field	Devonian-Carboniferous grey argillaceous siltstones with interbedded fine grained sandstones.	From 2005-2011 the Clair Field produced 80M barrels of oil from an estimated reserve total of 250M barrels.	There is a second phase of development north east of phase one, due to start in 2016. This has an expected recovery of 640M barrels of recoverable oil over a 40 year period.	Phase one – in production. Phase two – due to start 2016.
JKX	The Ukraine	The Rudenkovstoye Field	Devonian sandstone	An estimated reserve of 21.6M barrels of oil. Well R103 produces 18bbl/d.		Producing
Sonatrach and Amerada Hess (Since 2000)	Algeria	Hassi Messaoud	A series of Cambro-Ordovician sandstones	440,000bbl/d (70,000m^3/d of gas)		Producing
Sonatrach and ARCO (now part of	Algeria – The Ovargla	Rhoude el Baguel Field	Cambrian sandstones (occasionally	Out of an estimated 3Bbls,		Producing

BP)	Province		interbedded with portions of shale)	430Mbls (15% of oil in place has been produced since 2000).		
Statoil, BP and Sonatrach	Algeria, southern part of the Illizi Basin	The Tiguentourine Field in Amenas	Cambrian and Ordovician glaciogenic sandstone	Gas condensate deposit	Production rates and total reserve values are unavailable.	“wells drilled for exploration, appraisal and development purposes”.
Wintershall and ENI	Libya	Al Kufrah Basin	Cambro-Ordovician sandstones	Still in exploration stage but said to be a “major potential reservoir”.	Recent research has led scientists to believe that the oil producing structure (Jebel Hadrid structure) within the basin is the result of an impact crater.	Exploration

Table of Production from Palaeozoic Reservoirs in The Middle East, South East Asia and North America:

Company	Country	Reservoir name	Reservoir rock	Production Oil/Gas	Comments	Status
BP	Oman	Khazzan Makarem	Pre-Cambrian and Palaeozoic clastic sedimentary formations.	Reserve contains an estimated 20-30 Trillion cubic feet of natural gas. Production goal – 1 Billion cubic feet of gas per day. (www.bp.com-accessed 29/10/13)	Gas production due to commence 2017.	Development
Petrochina	China	Junggar Basin – Karamay Oilfield	Permian lacustrine sediments	Production rates are unavailable. The field is said to have an estimated reserve of 200-300Mbls.	In 1984 – the field was producing 75,000bls/d, this was the last figure made public.	Producing
Petrochina	China	Tarim Basin – Marijiaer Sag	Mid-Lower Cambrian muddy limey rocks. Mid-Lower Ordovician siliceous rocks. Upper Ordovician laminated band deposits.	Reserve estimated at 100Bbls of oil equivalent. Petrochina's target to produce 1Mbdoe by 2020 (theoildrum.com – accessed 29/10/2013).		Development
Hess Thailand Ltd. (operator – 35%) Apico LLC. (35%) PPTEP	Thailand	Phu Horm	The Permian Pha Nok Khao Dolomite – a carbonate reservoir rock of dolomitized skeletal wackestones and packstones.	Reserves estimated at 300-500 BCF. Figures produced in 2012 showed a production level of 93MMcf per day of natural gas and 428Bbls per day of condensate)		Producing

(20%) Exxon Mobil Exploration (10%)				figures from gulfportenergy.com/thailand – accessed 29/10/2013).		
BP Exploration (Alaska) Inc.	United States – Alaska	The Lisburne Group	A carbonate reservoir of interbedded dolomite mudstones and grainstones – Mississippian/ Pennsylvanian in age.	Estimated reserve of 3Bbls of which 450Mbls are recoverable. There are no figures available for current production rates.	Peak production was achieved in 1986 at a rate of 45,000bls/d	Producing
Devon Energy Chesapeake Energy XTO Energy Enervest Operating LLC. Quicksilver Resources Carrizo Oil and Gas, Inc. Legend Natural Gas IV Premier Natural Resources II Barnett Shale Operating	United States – Texas	The Barnett Shale	Ordovician, Mississippian and Early Pennsylvanian carbonate reefs. Mid Pennsylvanian – Lower Permian sandstones and Band Group conglomerates.	Cumulative production by 1995 – 2Bbls oil and 7 Trillion cubic feet of gas.	It produces high quality oil and holds great promise for further exploration.	Producing and Exploring.

References:

Afifi, A. M. (2005). Palaeozoic hydrocarbon habitat in the Arabian Plate. Search and Discovery Article #10075. Accessed 11/07/2012 http://www.searchanddiscovery.com/documents/2004/afifi02/index.htm.

Al-Marjeby, A. and Nash, D. (1986). A summary of the geology and oil habitat of the Eastern Flank Hydrocarbon Province of South Oman. Marine and Petroleum Geology. Vol 3. Pp.306-314.

Alsharhan, A. S. Nairn, A. E. M. and Mohammed, A. A. (1993). Late Palaeozoic glacial sediments of the southern Arabian Peninsula: their lithofacies and hydrocarbon potential. Marine and Petroleum Geology. Vol 10. Pp71-78.

Aqrawi, A. A. M. Skarpnes, O. Scotchmer, J. and Masri, A. (2012). Lower Palaeozoic Petroleum Systems of Western Iraq with Reference to Jordan. Search and discovery article #50590. Accessed 26/07/2012 http://www.searchanddiscovery.com/documents/2012/50590aqrawi/ndx_aqrawi.pdf

Bartlett, C. S. Trenton Limestone Fracture Reservoirs in Lee Country, Southwestern Virginia. Bartlett Geological Consultants, Abingdon, Virginial. Chapter 3. Pp. 27-35.

Baron, M. Parnell, J. Mark, D. Carr, A. Przyjalgowski, M. and Feely, M. (2008). Evolution of hydrocarbon migration style in a fractured reservoir deduced from fluid inclusion data, Clair Field, west of Shetland, UK. Marine and Petroleum Geology. Vol 25. Pp. 153-172.

BP. (2003). Asset Portfolio, The Clair Reservoir. BP Exploration Farburn Industrial Estate.

Broadhead, R. F. (2003). Petroleum Potential of the Sin Nombre Area, East-Central New Mexico. Search and Discovery Article #10036. Accessed 27/07/2012 http://www.searchanddiscovery.com/documents/broadhead/images/article.pdf

Coney, D. Fyfe, T. B. Retail, P. and Smith, p. J. (1993). Clair appraisal: the benefits of a co-operative approach. Petroleum Geology of Northwest Europe: Proceedings of the 4th conference. The Geological Society, London. Pp. 1409-1420.

Crossley, R. and McDougall, N. (1998). Lower Palaeozoic reservoirs of North Africa. Geological Society, London, Special Publications. Vol132. Pp 157-166.

Echikh, K. (1998). Geology and hydrocarbon occurrences in the Ghadames Basin Algeria, Tunisia, Libya. Geological Society, London, Special Publications. Vol 132. Pp. 109-129.

Edwards, C. W. (1991). The Buchan Field, Blocks 20/5a and 21/1a, UK North Sea. Geological Society Memoirs. Vol 14. Pp. 253-259.

Grajales-Nishimura, j. M. Cedillo-Pardo, E. Rosales-Dominguez, C. Moran-Zenteno, D. J. Alvarez, W. Claeys, P. Ruiz-Morales, J. Garcia-Hernandez, J. Padilla-Avila, P. and Sanchez-Rios, A. (2000). Chicxulub impact: The origin of reservoir and seal facies in the southeastern Mexico oil fields. Geology. Vol 28 (4). Pp. 307-310.

Hulen, J. B. Bereskin, R. and Bortz, L. C. (1990). High-Temperature Hydrothermal Origin for Fractured Carbonate Reservoirs in the Blackburn Oil Field, Nevada. Geological Note. The American Association of Petroleum Geologists Bulletin. Vol 74. No. 8. Pp. 1262-1272.

Kontorovich, V. A. (2007). Petroleum potential of reservoirs at the Paleozoic-Mesozoic boundary in West Siberia: seismological criteria *(example of the Chuzik-Chizhapka regional oil-gas accumulation).* Russian Geologu and Geophysics. Vol48. Pp. 422-428.

Kozar, M. G. Crandall, G. F. and hall, S. E. (1992). Integrated Structural and Stratigraphic Study of the Khorat Basin, Rat Buri Limestone (Permian), Thailand. National Conference on “Geologic Resources of Thailand: Potential for Future Development. Pp 692-736.

Lawrence, S. R. (1990). Aspects of the petroleum geology of the Junggar Basin, Northwest China. Geological Society, Special Publications. No. 50. Pp. 545-557.

Le Here, D. P. Craig, J. and Etienne, J. L. (2009). Ancient glaciations and hydrocarbon accumulations in North Africa and the Middle East. Earth-Science Reviews. Vol 93. Pp. 47-76.

Le Heren, D. P. Craig, J. Sutcliffe, O. E. and Whittington, R. (2006). Late Odovician glaciogenic reservoir heterogeneity: An example from the Murzuq Basin, Libya. Marine and Petroleum Geology. Vol 23. Pp. 655-677.

Le Heren, D. P. Howard, J. P. (2012). Sandstones, glaciers, burrows and transgressions: The Lower Palaeozoic of Jabel az-Zalmah, Al Kufrah Basin, Libya. Sedimentary Geology. Vol 245-246. Pp. 63-73.

Luces, J. Reano, J. M. Salguero, J. and Morales, J. (2012). Hydraulic Fracture Geometry Evolution and Pressure During Pumping: Chicontepec Experiences Indicate that Natural Fractures of Fissures Are not Activated. Society of Petroleum Engineers. 152396. [Abstract only].

Major, R. P. and Holtz, M. H. (1997). Identifying Fracture Orientation in a Mature Carbonate Platform Reservoir. Geological Note. AAPG Bulletin. Vol 81. No. 7. Pp. 1063-1069.

Martirosyan, V. Popova, L. and Vepreva, M. (1998). The petroleum systems of the Pechora Platform Foreland, Russia. Petroleum Geoscience. Vol 4. Pp. 339-348.

Meng-jun, Z. Zhoa-ming, W. Wen-qing, P. Shao-bo, L. Sheng-fei, Q. and Jian-fa, H. (2008). Lower Palaeozoic source rocks in Manjiaer Sag, Tarim Basin. Petroleum Exploration and Development. Vol 35. (4). Pp. 417-423.

Mironcheva, E. Safronova, P. Golynchik, P. Ogarkova, M. Stoupakova, A. Henriksen, E. and Rafaelsen, B. (2007). Barents-Kara Region Palaeozoic-Mesozoic Hydrocarbon Complexes. EAGE 69th Conference and Exhibition. London, UK. P134.

Montgomery, S. L. (1996). Val Verde Basin: Thrusted Strawn (Pennsylvanian) Carbonate Reservoirs, Pakenham Field Area. E and P Notes. AAPG Bulletin, Vol 80. No. 7. Pp. 987-998.

Nearing, T. R. and Startzman, R. A. (1988). Effects of Stimulation/Completion Practices on Eastern Devonian Shale Well Productivity. Society of Petroleum Engineers. SPE 18553.

Oil and Gas Directory, Middle East. 2011. Research Profile. 7.07. Algeria.

Pedersen, j. H. Karlsen, D. A. Lie, J. E. Brunstad, H. and Di Primio, R. (2006). Maturity and source-rock potential of Palaeozoic sediments in the NW European Northern Permian Basin. Petroleum Geoscience. Vol 12. Pp. 13-28.

Pollastro, R. M. Hill, R. J. Jarvie, D. M. and Henry, M. E. (2003). Assessing Undiscovered Resources of the Barnett-Paleozoic Total Petroleum System, Bend Arch-Fort Worth Basin Province, Texas. Search and Discovery Article #10034. Accessed 26/07/2012 http://www.searchanddiscovery.com/documents/pollastro/images/article.pdf

Robinson, S. Hazzard, V. Leary, M. and Carmack, C. (2000). Redeveloping of the Rhourde el Baguel Field with Underbalanced Drilling Operations. Society of Petroleum Engineers. [Abstract only].

Sabaou, N. Ait-Salem, H. and Zazoun, R. S. (2009). Chemostratigraphy, tectonic setting and provenance of the Cambro-Ordovician clastic deposits of the subsurface Algerian Sahara. Journal of African Earth Sciences. Vol 55. Pp. 158-174.

Saller, A. H. (2004). Palaeozoic dolomite reservoirs in the Permian Basin, SW USA: Stratigraphic distribution, porosity, permeability and production. Geological Society, London, Special Publications. Vol 235. Pp. 309-323.

Sanders, C. Bonora, M. Richards, D. Kozlowski, E. Sylwan, C. and Cohen, M. (2004). Kinematic structural restorations and discrete fracture modelling of a thrust trap: a case study from the Tarija Basin, Argentina. Marine and Petroleum Geology. Vol 21. Pp. 845-855.

Schmieder, M. Buchner, E. and Le Heron, D. P. (2009). The Jebel Hadid structure (Al Kufrah Basin, SE Libya) – A possible impact structure and potential hydrocarbon trap?. Marine and Petroleum Geology. Vol 26. Pp. 310-318.

Sheehan, J. (2011). West of Shetland Development Gathers Momentum. Shetland Islands Development. JTP. Pp. 44-47.

Smith, P. F. L. and Stokes, R. B. (1997). Geology and Petroleum Potential of the Khorat Plateau Basin in the Veintiane Area of Lao P.D.R. journal of Petroleum Geology. Vol 20. (1). Pp. 27-50.

Suchy, V. Dobes, P. Sykorova, I. Machovic, V. Stejskal, M. Kroufek, J. Chodoba, J. Matejovsky, L. Havelcova, M and Matysova, P. (2010). Oil-bearing inclusions in vein quartz and calcite and bitumens in veins: Testament to multiple phases of hydrocarbon migration in the Barrandian basin (lower Palaeozoic), Czech Republic. Marine and Petroleum Geology. Vol 27. Pp. 285-297.

Traut, M. W. Boote, D. R. D. and Clarke-Lowes, D. D. (1998). Exploration history of the Palaeozoic petroleum systems of North Africa. Geological Society, London, Special Publications. Vol 132. Pp. 69-78.

Tubb, S. R. Soulsby, A. and Lawrence, S. R. (1986). Palaeozoic Prospects on the Northern Flanks of the London-Brabant Massif. Geological Society, Special Publication. No. 23. Pp. 55-72.

Wilkins, S. J. and Belfield, W. C. (1998). The influence of fractures and stress on production of the Rhourde el Baguel field, Algeria. Reservoir Geology ARCO Exploration and Production Technology. TM 98-0019.

Veire, H. H. WEnnberg, O. P. Basquet, R. and Ingsoy, P. (2007). Intergration of Wide Asimuth Seismic with Static and Dynamic Well Data for Fractured Reservoir Characterisation. GO29. EAGE 69th Conference and Exhibition – London, UK.

Xiao, X. M. Zhao, B. Q. Thu, Z. L. Song, Z. G. and Wilkins, R. W. T. (2005). Upper Palaeozoic petroleum system, Ordos Basin, China. Marine and Petroleum Geology. Vol 22. Pp. 945-963.

Zhu, H. Chen, K. Liu, K. and He, S. (2008). A sequence stratigraphic model for reservoir sand-body distribution in the Lower Permian Shanxi Formation in the Ordos Basin, northern China. Marine and Petroleum Geology. Vol 25. Pp. 731-743.

3rd North African/Mediterranean Petroleum and Geosciences Conferences and Exhibition. Tripoli, Libya, 26-28th February, 2007. [accessed 25/07/2012] - http://www.iongeo.com/content/released/Simon_Tripoli_2007_Abstract.pdf

Company Websites

Amerada Hess [accessed 31/07/2012] - http://phx.corporate-ir.net/phoenix.zhtml?c=101801&p=irol-newsArticle&ID=490759&highlight=

Aurelian Oil [accessed 12/07/2012] - http://www.aurelianoil.com/english/our-operations/core-area-1/the-area.aspx

BP (2011). BP Confirms Extension of Giant Clair Field West of Shetland in the UK [accessed 03/09/2012]. http://www.bp.com/genericarticle.do?categoryId=2012968&contentId=7071784

BP, Upstream Major Projects, Middle East, Khazzan, Oman [accessed 03/08/2012] - http://www.bp.com/sectiongenericarticle.do?categoryId=9028355&contentId=7051586

BP NSU, Clair. (2008). [accessed 28/08/2012] - http://www.bpnsi.com/index.asp?id=7369643D312669643D313738

Gazprom [accessed 12/07/2012] - http://www.gazprom.com/about/production/projects/deposits/pnm/

GulfPort Energy [accessed 03/08/2012] - http://gulfportenergy.com/thailand

JKX [accessed 13/08/2012] - http://www.jkx.co.uk/files/4913/3656/9602/2010-well-test-results.pdf
Maersk Oil [accessed 12/07/2012] - http://www.maerskoil.com/GlobalOperations/Algeria/Pages/Algeria.aspx
Marathon Oil [accessed 12/07/2012] - http://www.marathonoil.com/Global_Operations/
Oxy Oil and Gas [accessed 13/07/2012] - http://www.oxy.com/OurBusinesses/OilAndGas/UnitedStates/Pages/overview.aspx
PetroChina [accessed 13/07/2012] - http://www.petrochina.com.cn/Ptr/About_PetroChina/Core_Business/Exploration_and_production/
PTTEP [accessed 03/08/2012] - http://www.pttep.com/en/newsDetail.aspx?ContentID=19

Other Websites Used

naturalgaseurope.com [accessed 29/10/2013]
theoildrum.com [accessed 29/10/2013]
gulfportenergy.com/Thailand [accessed 29/10/2013]

References used but not cited:

Galeazz, S. point, O. Haddadi, N. Mather, J. and Drusne, D. (2012). 19-The Illizi and Berkine Basins in Southern Algeria [ABSTRACT]. Regional Geology and Tectonics: Phanerozoic Passive Pargins, Cratonic Basins and Global Tectonic Maps. Pp. 662-729.