PERSPECTIVES ON FUTURE SHALE GAS DEVELOPMENTS IN N.W. EUROPE

Professor Dick Selley
Department of Earth Science & Engineering, Imperial College

Imperial College London

TALK OUTLINE

HISTORY

PARAMETERS

BASIN REVIEW

GEOPOLITICS

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THE PRODUCTION OF UNCONVENTIONAL PETROLEUM HAS A LONG HISTORY IN EUROLAND.

(From Agricola's De Re Metallica 1531)

A—Bituminous spring. B—Bucket. C—Pot. D—Lid.

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MONUMENT TO THE FIRST SHALE GAS WELL DRILLED IN 1821, FREDONIA, NEW YORK STATE.
PHOTO COURTESY OF A. GIEBEL

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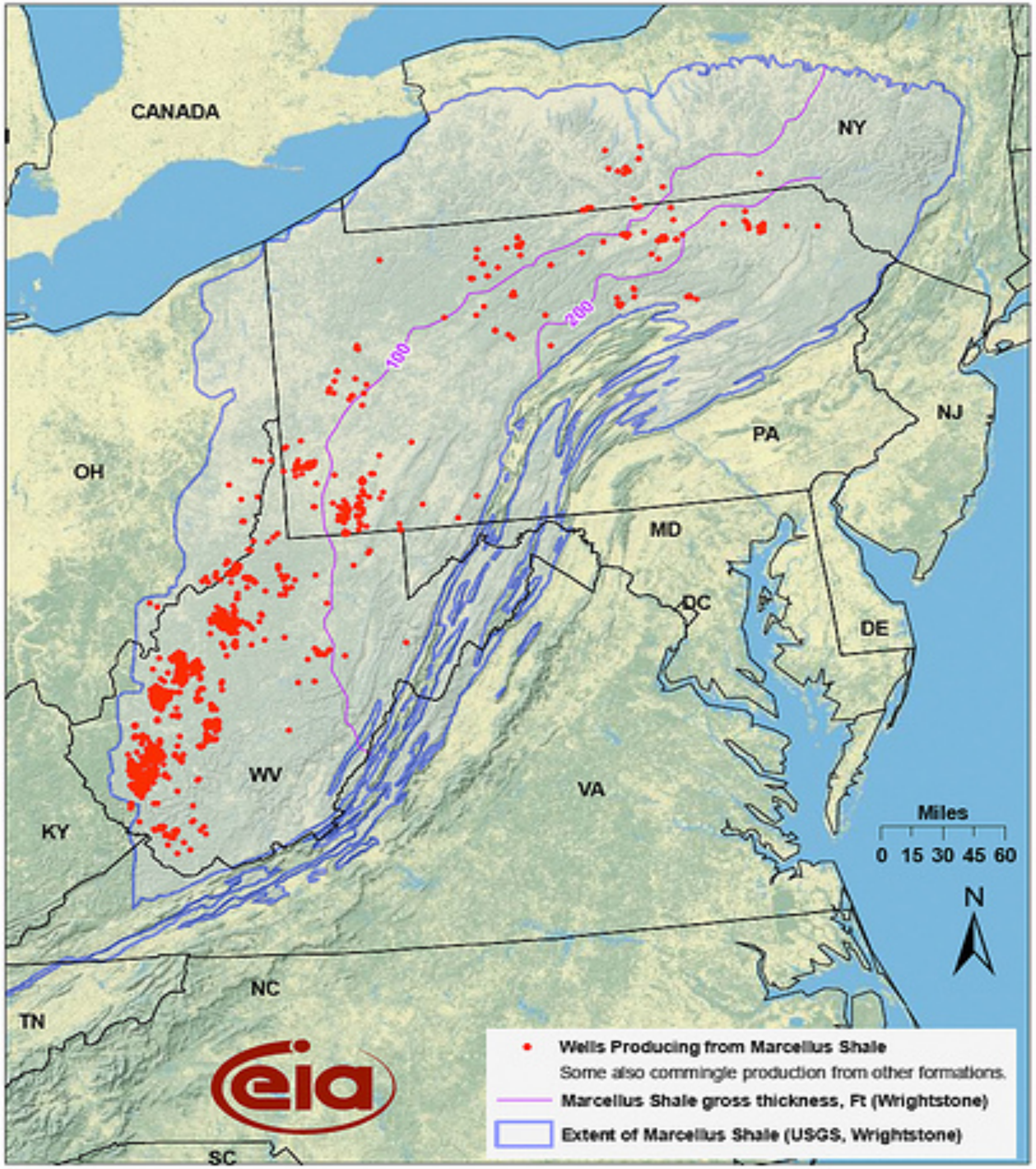
‘COTTAGE INDUSTRY’ APPALACHIAN NATURALLY FRACTURED SHALE GAS PLAY



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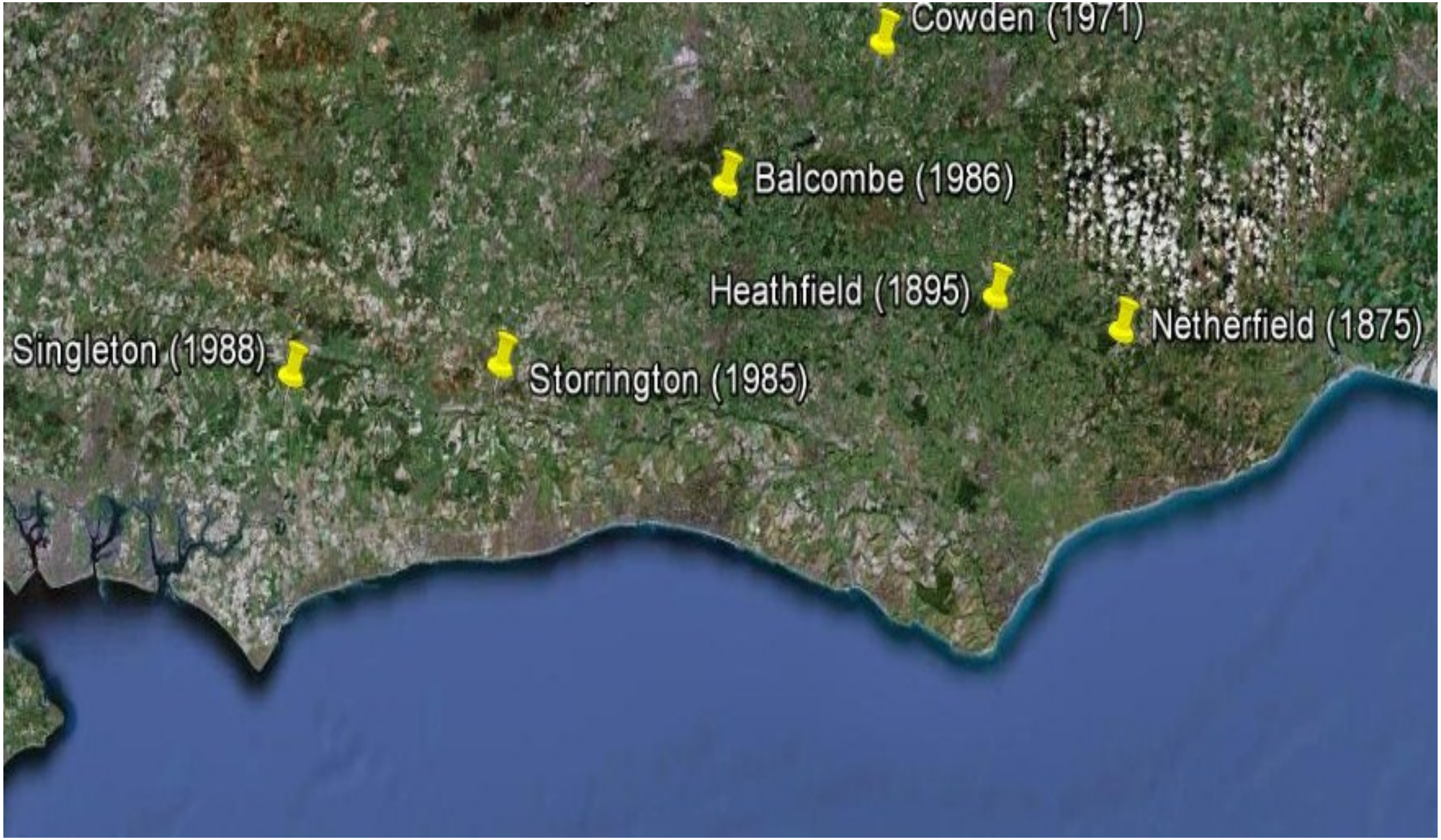

THE LOCATION OF NETHERFIELD No. 1 & LATER WEALDEN WELLS

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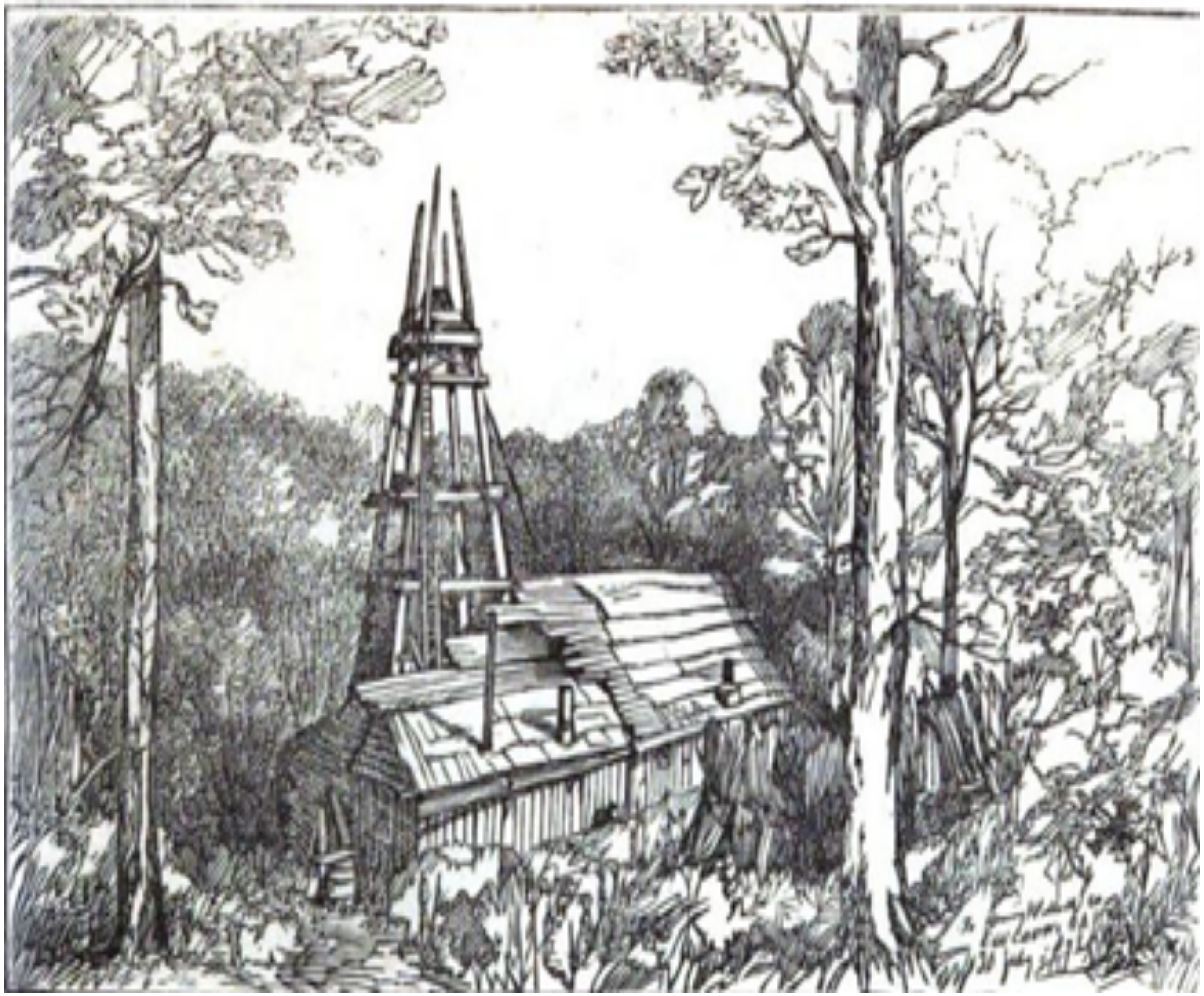
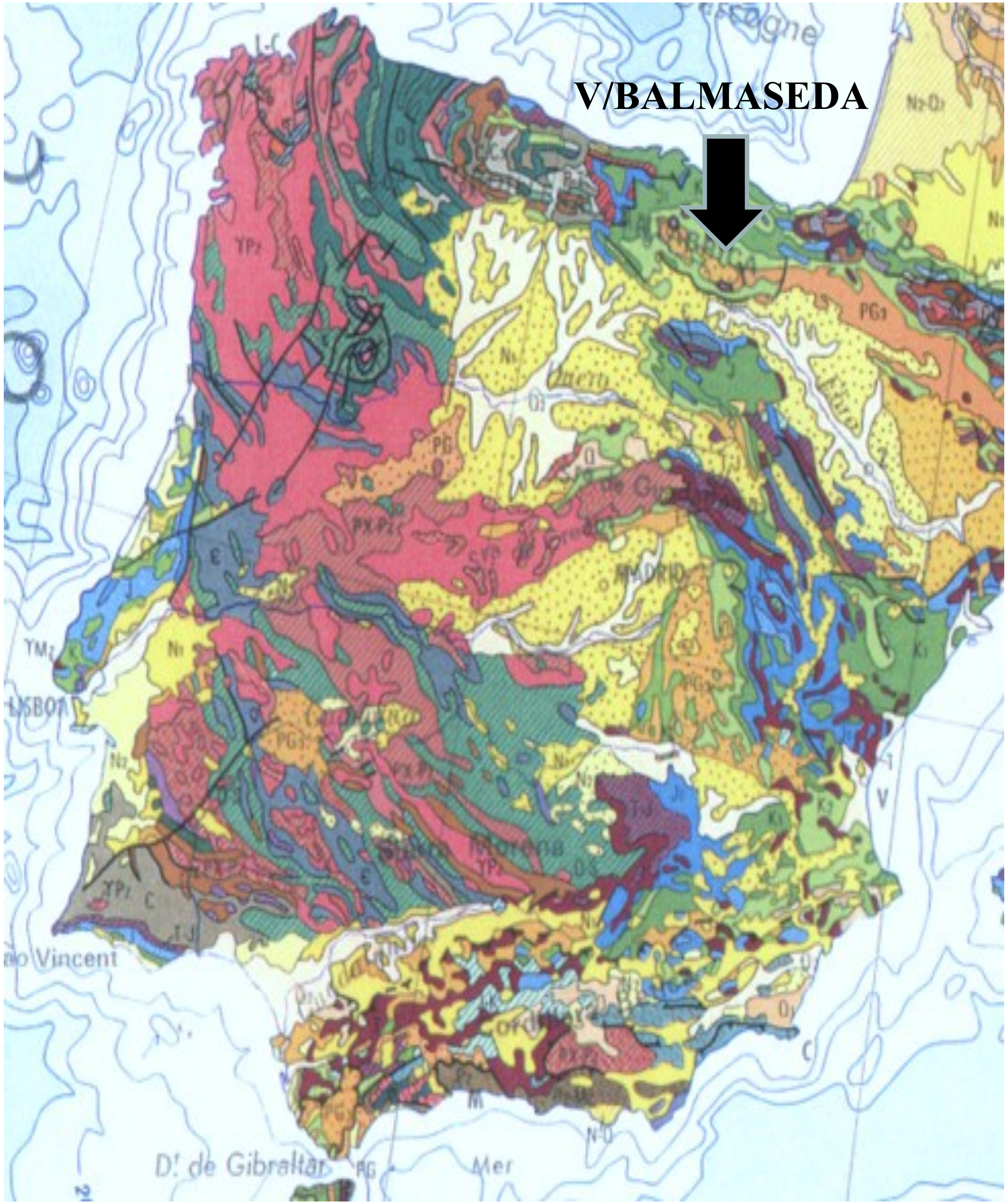


NETHERFIELD NO. 1 WELL, SUSSEX.
THE FIRST UK WELL TO DISCOVER SHALE GAS IN 1875.
DRAWN BY E COOKE, ESQ, RA.

FIRST EUROPEAN SHALE GAS PRODUCED IN SPAIN IN THE 1950's



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IN THE EARLY 1980'S RESEARCH AT IMPERIAL COLLEGE APPLIED THE U.S. APPALACHIAN SHALE GAS PARADIGM TO THE U.K. & EUROLAND

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EXPLORATION

British shale gas potential scrutinized

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Petroleum gas was first produced in the U.S. from fractured shale reservoirs in 1821.

Subsequently, extensive shale gas production was established in the Appalachian basin from Kentucky to New York State (Fig. 1). Gas is produced from organic-rich black shales of Devonian and Mississippian age. Gas is seldom trapped in well defined fields but occurs in siltstone bands and irregular fracture systems. The gas is of high calorific value (c. 1,200 BTU), and commonly wet, with over 10% ethane. After an initial high pressure "blow" wellhead pressures stabilize at 300-500 psi with flow rates of 50-100 Mcfd of gas. Depletion rates, however, are in the order of 10%/annum, with individual wells producing for 40-50 years. Wells are shallow, seldom more than 2,000 ft deep, and thus cheap to drill.

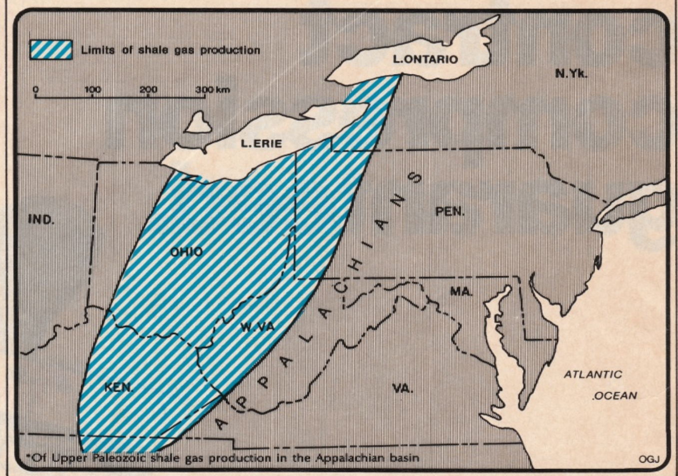
Shale gas exploitation is not profitable for major oil companies. The reserves are too small and the payout time too long. Shale gas is, however, economically viable in the U.S. for two reasons. The "cottage industry" scale of many oil companies permits operations with small profit margins. Unlike many countries landownership includes the mineral rights of a property. Thus, landowners are generally only too pleased to see their natural resources developed. In the late 19th century shale gas was found by random drilling. Shale gas production became widespread across the Appalachian basin.

Today most of the world's petroleum is produced from sandstone and carbonate rocks that possess both porosity and permeability. Petroleum has migrated into these reservoirs from organic-rich shale source beds. Shales are often porous and may be saturated with petroleum. But they generally lack sufficient permeability to permit petroleum production at sufficiently fast rates to be commercially viable reservoirs. Shale gas production became of secondary importance with the establishment of the conventional dogma of drilling for petroleum in sandstone and carbonate reservoirs on structural highs.

Shale gas production, which had continued steadily since 1821, underwent a renaissance during the energy crisis of the late 1970s and early 1980s. Extensive research has been under-

Fig. 1

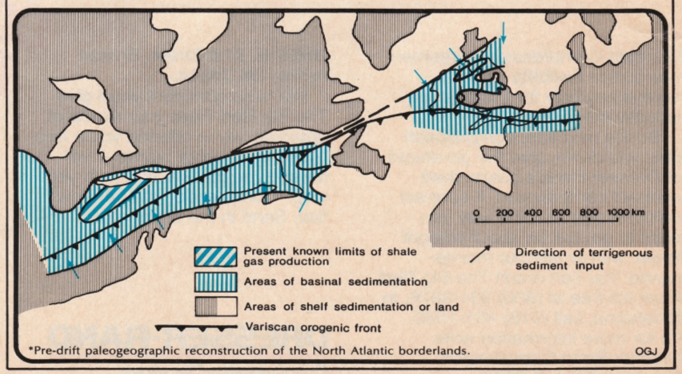
Approximate extent*



*Of Upper Paleozoic shale gas production in the Appalachian basin

Fig. 2

Mississippian*



*Pre-drift paleogeographic reconstruction of the North Atlantic borderlands.

LOWER CARBONIFEROUS BASINS IDENTIFIED AS PRIMARY TARGET FOR SHALE GAS EXPLORATION.

RESEARCH RUBBISHED IN THE UK. FINALLY PUBLISHED IN THE OIL & GAS JOURNAL IN 1987

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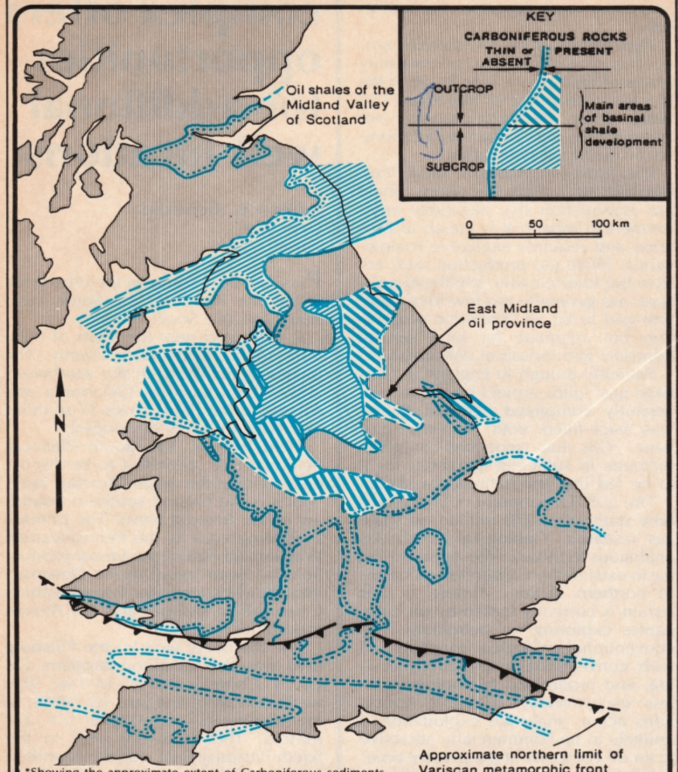
Map of Britain*

Fig. 3



*Showing the approximate extent of Carboniferous sediments and the main areas of Mississippian basinal shale development.

OGJ

taken recently in the exploration for and production of shale gas. It is now known that the regional distribution of shale gas is controlled by the quantity, quality, and level of thermal maturation of organic matter in the shale formations. Local concentrations of shale gas occur in siltstone strata, in fracture systems, or, most productively, where the two are combined.

The siltstones commonly occur as distal turbidite submarine fans thinly interbedded with the organic-rich shale source beds. Thus, the optimum geological parameters for shale gas generation and accumulation normally occur in the syndepositional lows that are carefully avoided in conventional petroleum exploration. Fracture systems may be best developed where strata are stretched over the crests of anticlines, but they also occur along regional fault and basin hinge-line trends.

These can be located by remote sensing and by seismic surveys. Conventional seismic surveys are inappropriate to locate low velocity gas-charged shale zones. Specific methods of shooting and processing seismic data have now been developed. Conventional drilling with a mud-filled hole will seldom locate shale gas. The weight of the mud forces the gas away from the well bore. Such gas as may escape into the drilling mud is recorded as "background gas," with little thought that it may be commercial. Shale gas is found by air drilling. Production is only established after specialized well stimulation techniques have been applied.

Transportation of shale gas far from the wellhead is seldom feasible. Because of the low pressure the gas requires pressurizing for it to flow along a pipeline. This additional cost generally destroys the profitability of the project. On the other hand, shale gas is an eminently suitable energy source when located adjacent to a town, or even individual factories, schools, farms, hospitals, and similar establishments. Shale gas production has a negligible environmental impact. Once the well is drilled, there is no derrick. Unlike an oil field there is no need for wellhead pumps, and there is no flaring. No long distance pipelines have to be built across the countryside. Once established, shale gas production is inconspicuous, undemanding, and silent. Apart from routine maintenance, production is modest but reliable and lengthy.

British shale gas resources. Analogues of the Appalachian shale gas province may exist in Northwest Europe, especially in the U.K.

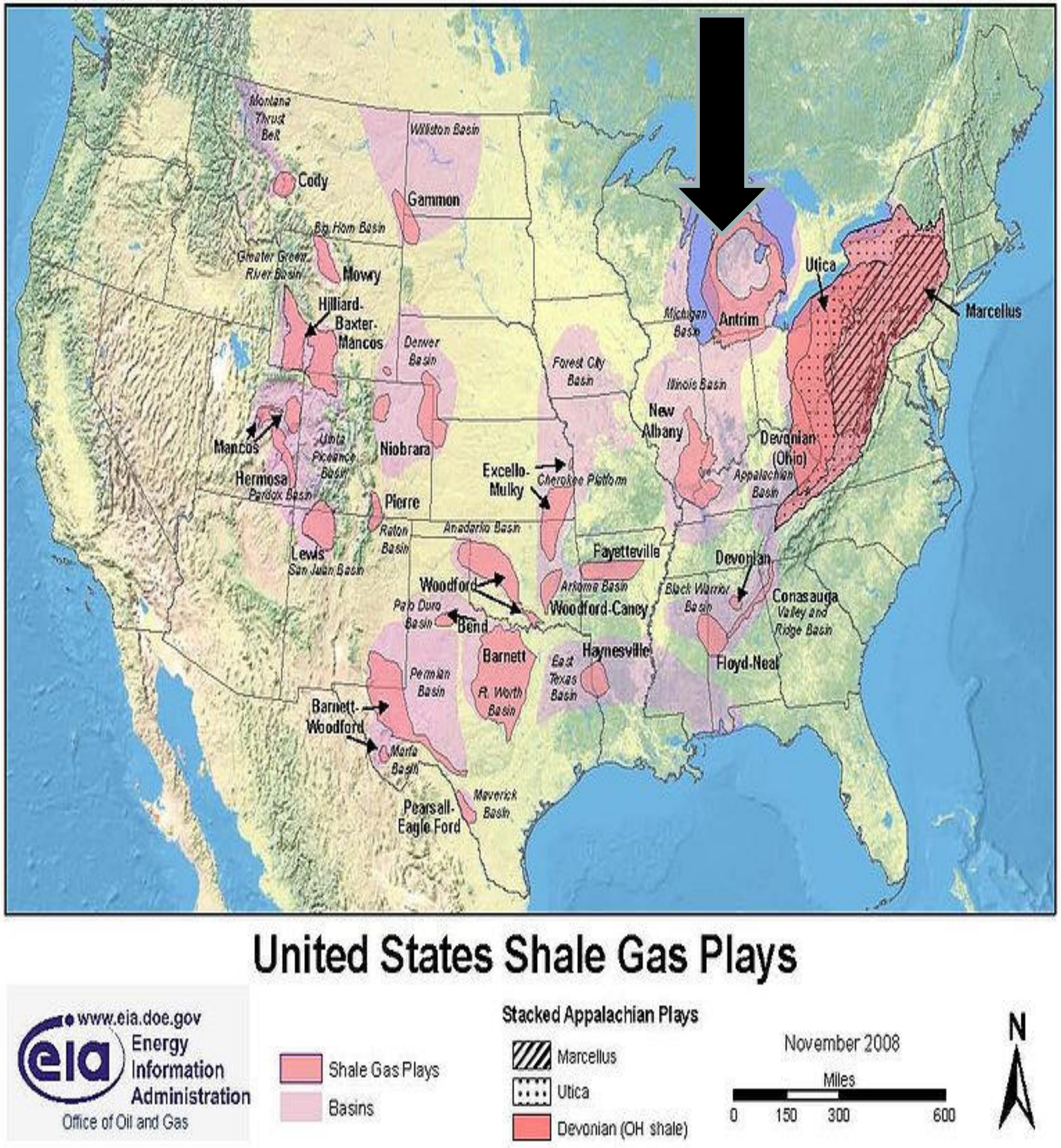
The fine-grained carbonaceous sediments that are potential source beds are widely distributed both geographically and stratigraphically. The Late Precambrian and Lower Paleozoic rocks of Scotland and Wales contain many formations that were once no doubt organic-rich petroleum source beds. Most of these were metamorphosed into graphitic slates by the Caledonide orogeny. Such slates are generally deemed overmature as petroleum source beds. At the other extreme there are organic-rich shales of Jurassic age. These include the Liassic and Kimmeridge slay formations.

The Lias shales are believed to have generated much of the oil in the Wessex basin. The more extensive Kimmeridge clay, the major source of North Sea oil, is largely immature onshore. Neither of these formations appear to have been sufficiently matured to have generated gas, nor to have been sufficiently indurated to develop the extensive fracture systems required for permeability.

Between the Caledonide basement and the Jurassic strata, however, there occur the black shales of the Carboniferous system. These contain considerable organic matter, both oil-prone and gas-prone. In many areas, they have undergone burial sufficient to generate petroleum and to lithify them to permit fracturing. But, except in the Variscan fold belt of southern England, these shales have seldom been overmatured by metamorphism. Fig. 2 shows a plate tectonic reconstruction of the North Atlantic borderlands for the Mississippian.

Fig. 3 shows the main Carboniferous features of Britain. These rocks are extremely well known at outcrop. The subsurface geology of the Pennsylvanian Coal Measures is also well

SHALE GAS RENAISSANCE OF THE USA



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GEOLOGICAL PARAMETERS FOR SUCCESS

- HIGH TOC
- LOW CLAY CONTENT
- KEROGEN TYPE
- MATURITY & BURIAL HISTORY

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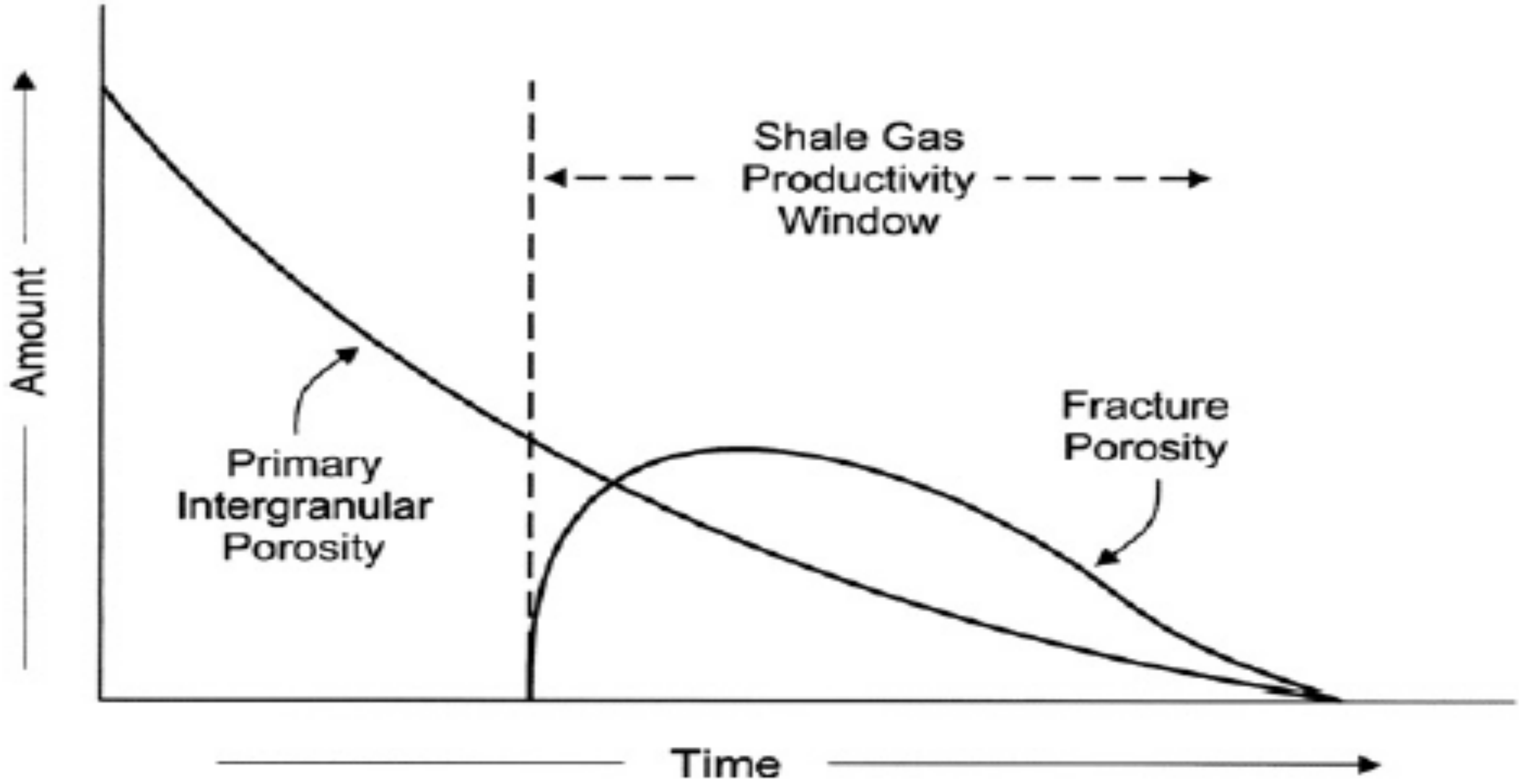
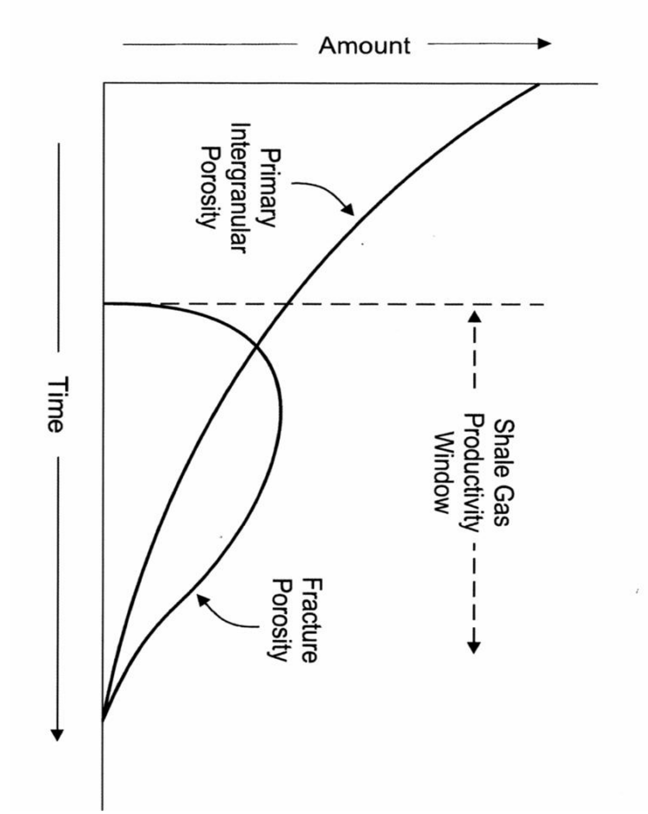
FINDING THE 'GOLDILOCKS' ZONE





U.K. STRATIGRAPHY SHOWING THE 'GOLDYLOCKS' ZONE

GEOLOGICAL PERIOD		ROCK FORMATION	ROCK TYPE	SHALE GAS POTENTIAL
RECENT				
TERTIARY		Clays & sands		
CRETACEOUS		Chalk Upper Greensand Gault Clay Lower Greensand Weald Clay Hastings Sands		THERMAL BIOGENIC
JURASSIC		**Purbeck & Portland L-stns Kimmeridge Clay** M Jurassic L-stns Lias Clays		
TRIASSIC	NEW RED S-SST	Mercia mudstone Sherwood S-stn		
PERMIAN		Sands Dolomites & shales		
CARBONIFEROUS		Coal Measures 'culm' & black shales- limestone		PREECE HALL SHALE GAS WELL
DEVONIAN	OLD RED S-SST	S-stns & Shales		
SILURIAN ORDOVICIAN CAMBRIAN PRECAMBRIAN		Assorted igneous and metamorphic rocks		

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NORTH-WEST EUROPEAN BASINS WITH SHALE GAS POTENTIAL

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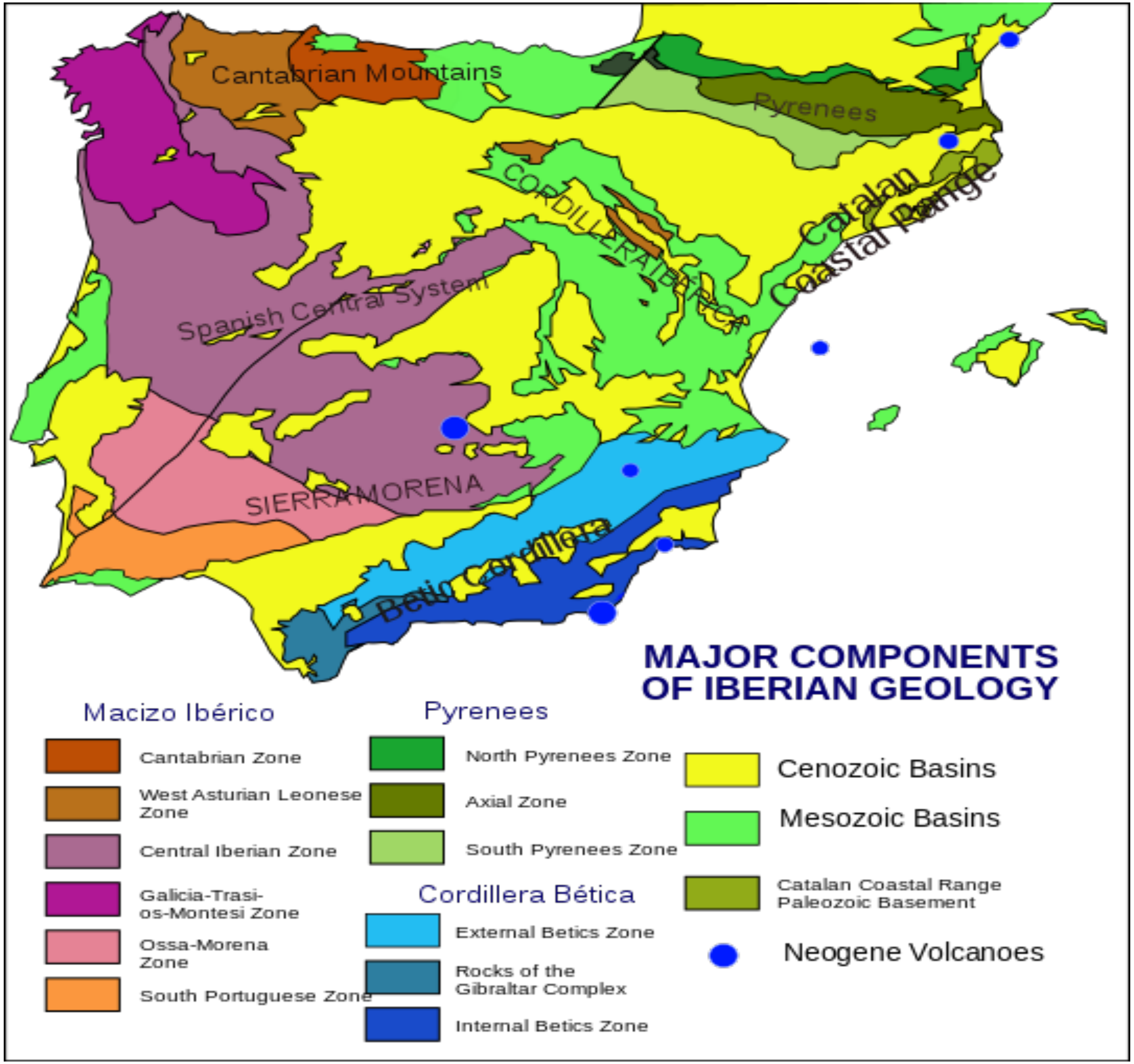

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VALMASEDA FORMATION

- Up to 4000 Meters Thick

- Flowing Gas Tests and Production

HEYCO Energy Group

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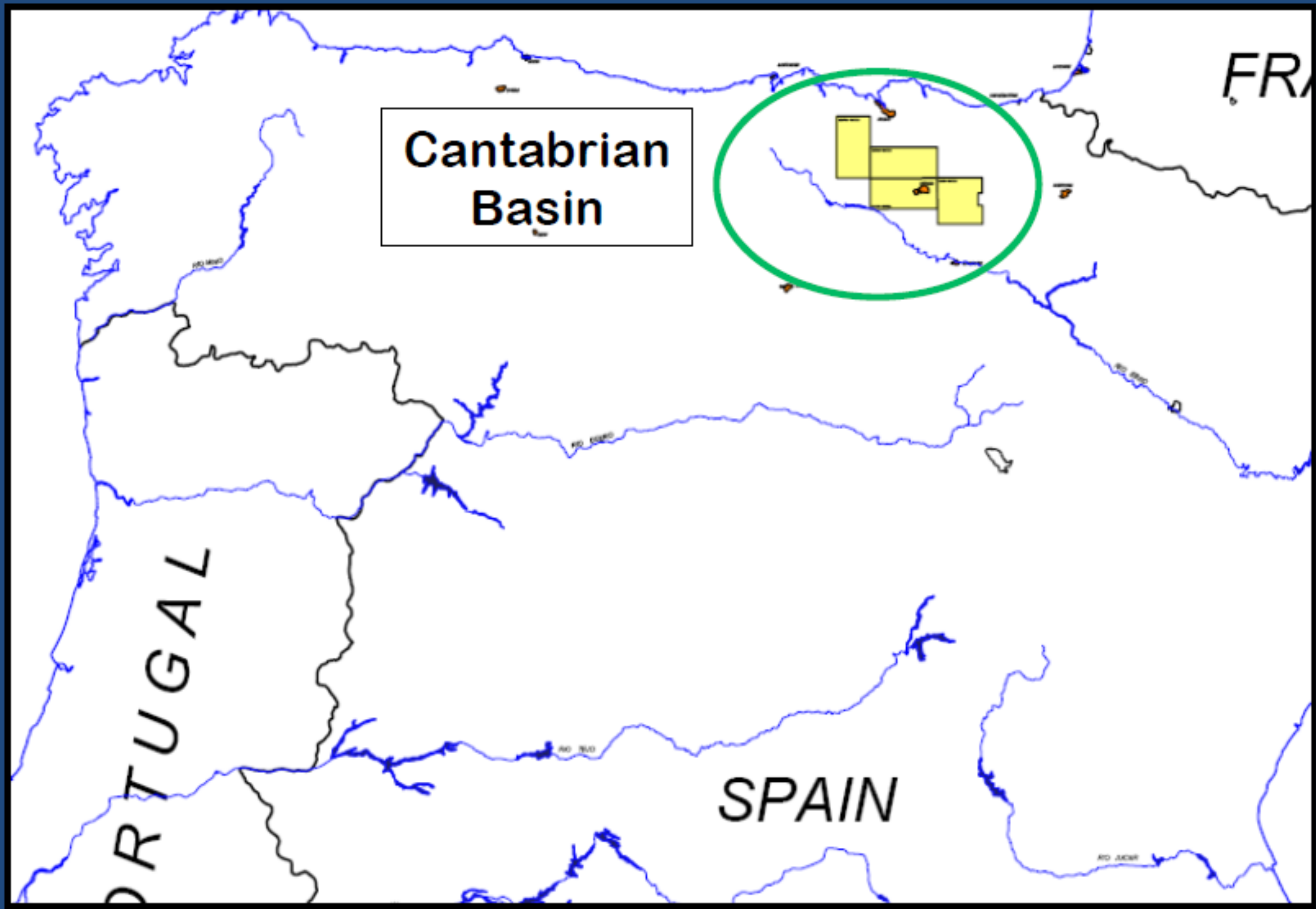
V/BALMASEDA (CRETACOUS) SHALE WITH THIN SAND STRINGERS



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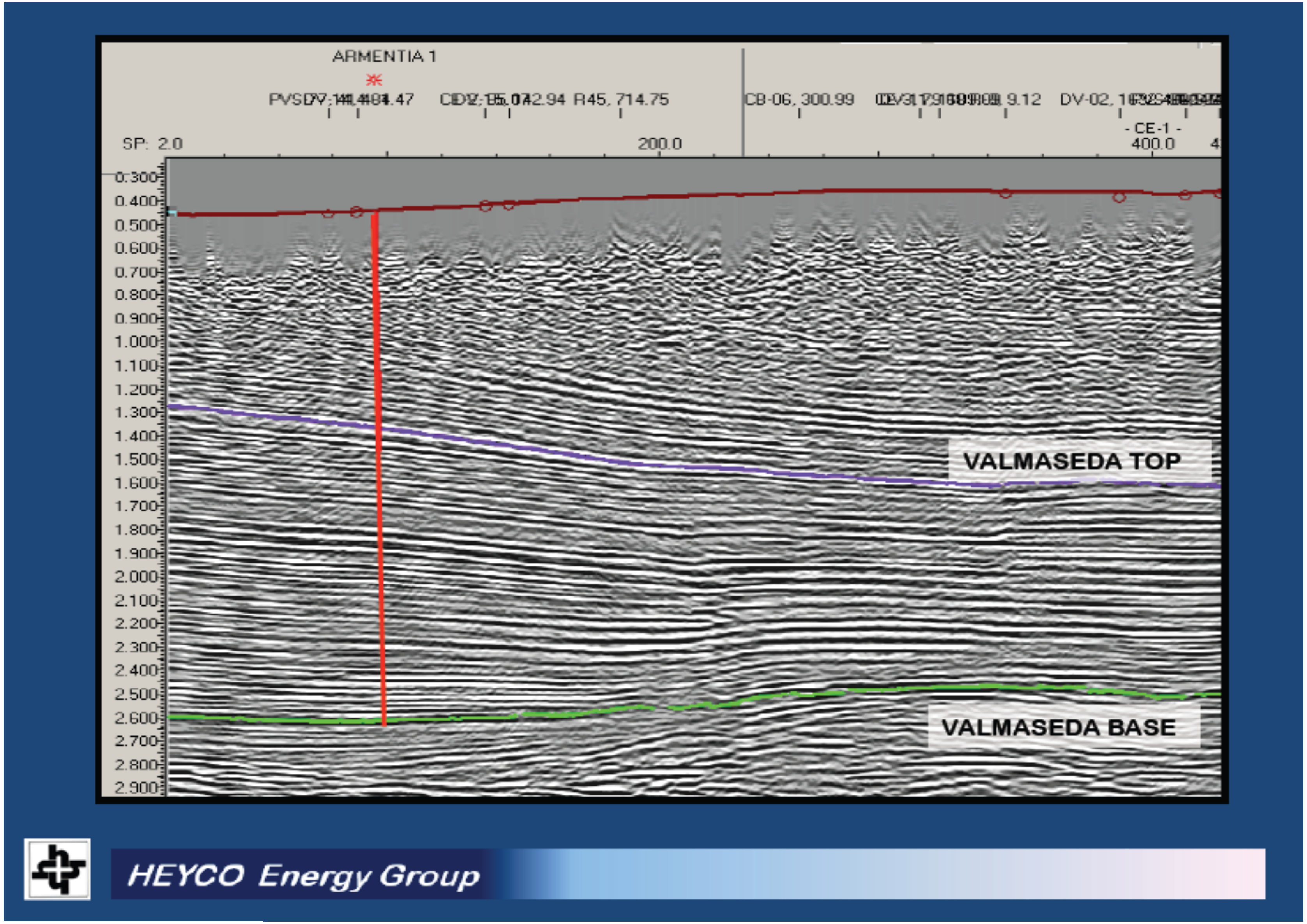
WELL	YEAR	TESTS / PRODUCTION
CASTILLO-1	1959	PRODUCED 1,036 MMCFG
ARMENTIA-1	1997	PRODUCED 560 MMCFG
CASTILLO-2	1961	PRODUCED 120 MMCFG
VITORIA OESTE-1	1963	TEST 9,181 MCF/D
VITORIA OESTE-2	1963	TEST 5,197 MCF/D
CASTILLO-5	1972	TEST 5,192 MCF/D
CASTILLO-4	1966	TEST 4,073 MCF/D
ZUAZO-1	1961	TEST 1,500 MCF/D
SAN ANTONIO-1	1982	TEST 530 MCF/D
ANTEZANA-1	1961	TEST 141 MCF/D
OSMA-1	1967	TEST ~.5 MCF/D



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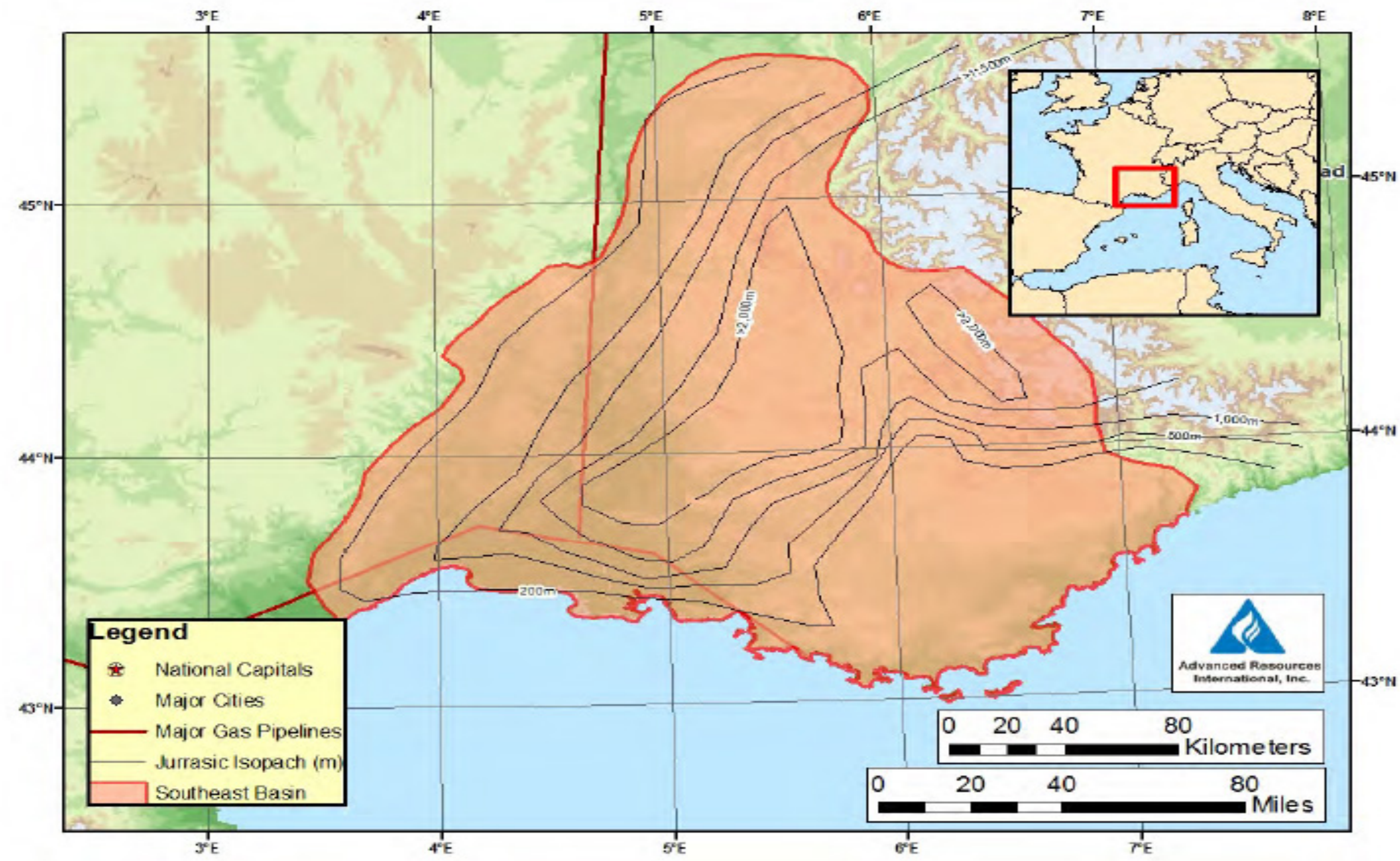
HOW TO PICK A WELL LOCATION:
ARMENTIA – 1 (1997) PRODUCED 120MMCFG

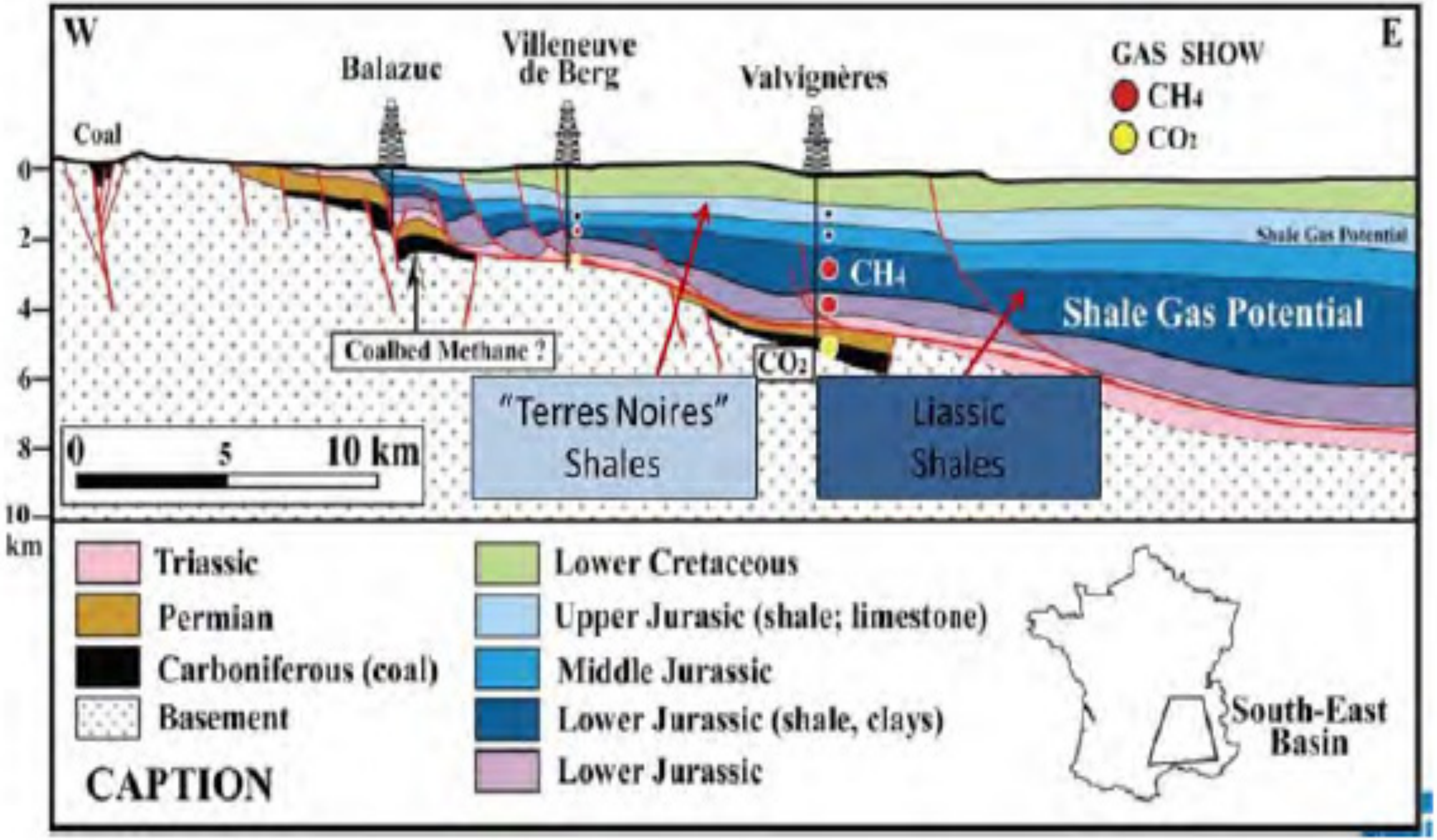
SPANISH GEOPOLITICS

- 42 Tcf GIP. 8.0 Tcf Technically recoverable
- 76% of energy hydrocarbons
- 99% of which is imported
- Fracking permitted by central government.
- Banned by local Cantabrian Government

Figure VII-6. Southeast Basin Prospective Area and Upper Jurassic Shale Isopach



S.E. FRANCE PROSPECTIVE JURASSIC SHALE GAS IN THE
PROVENCE BASIN. FROM EIA/ARI (2013)



WEST – EAST CROSS-SECTION OF THE PROVENCE BASIN
SHOWING LOWER & UPPER JURASSIC SHALE GAS POTENTIAL
(FROM EIA/ARI 2013)

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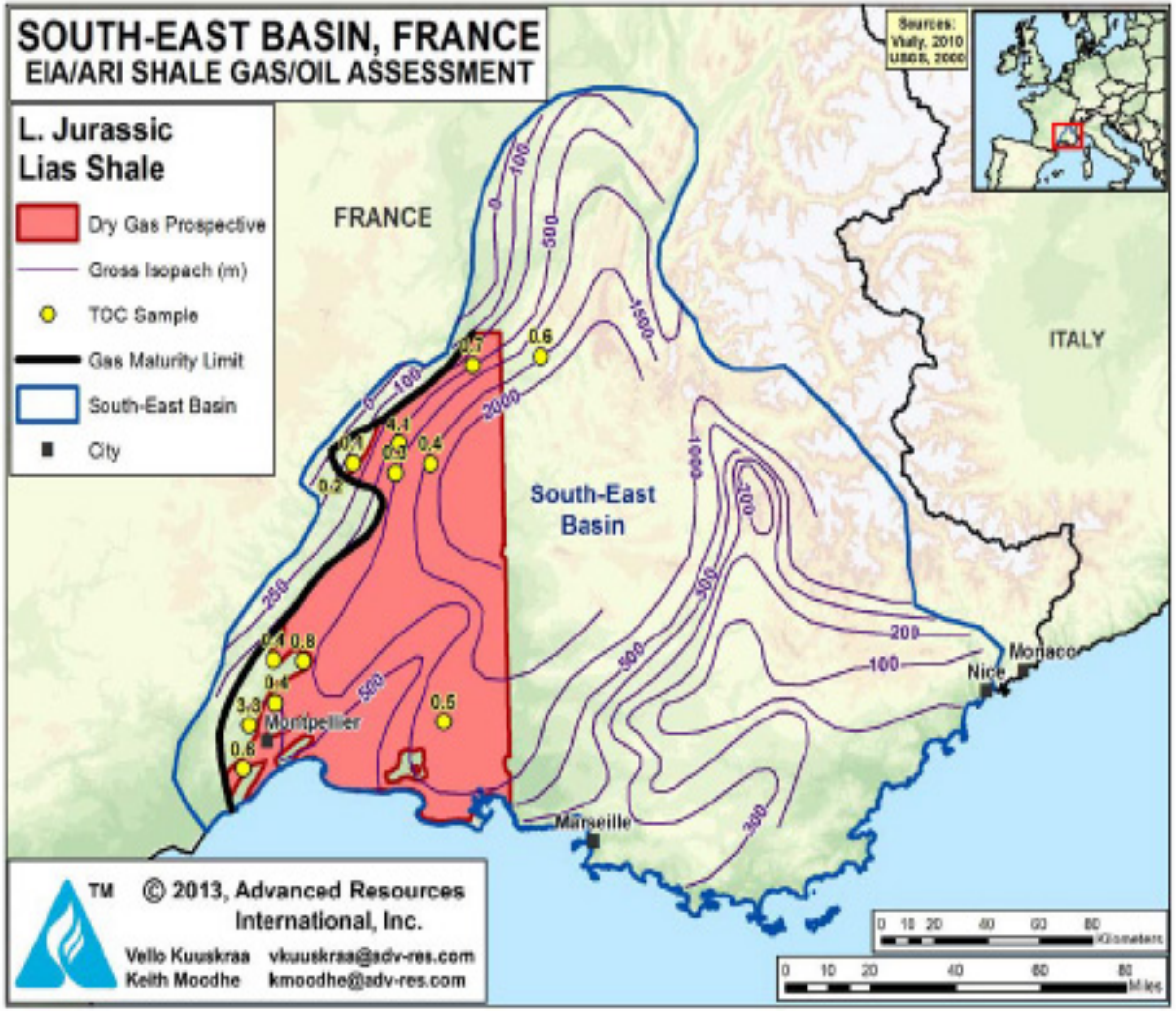
PROVENCE BASIN SHALE GAS MATURITY (EIA/ARI 2013)



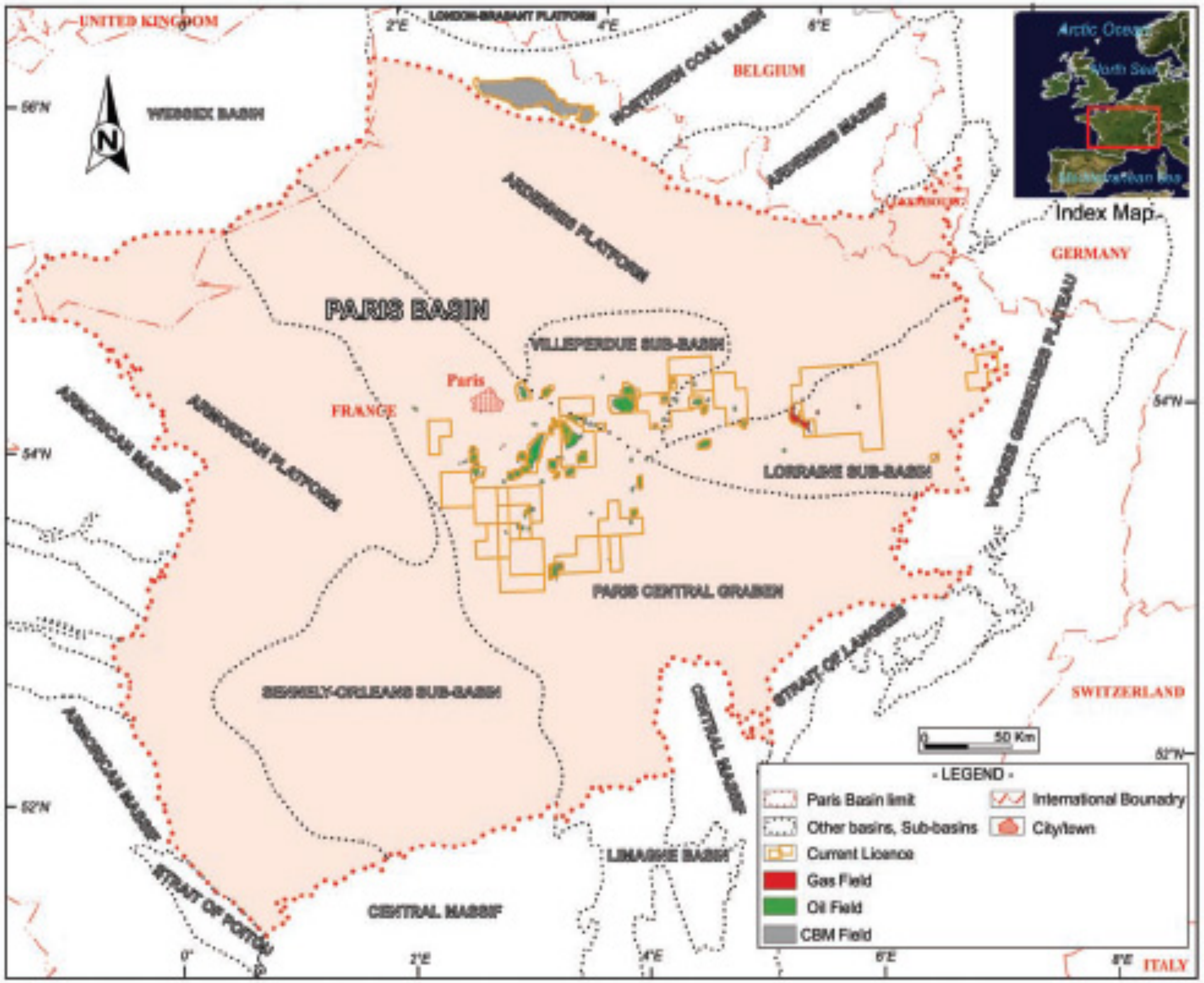


Figure 1 Location and hydrocarbon activity map of the Paris Basin (compiled from IHS data as of July 2008).

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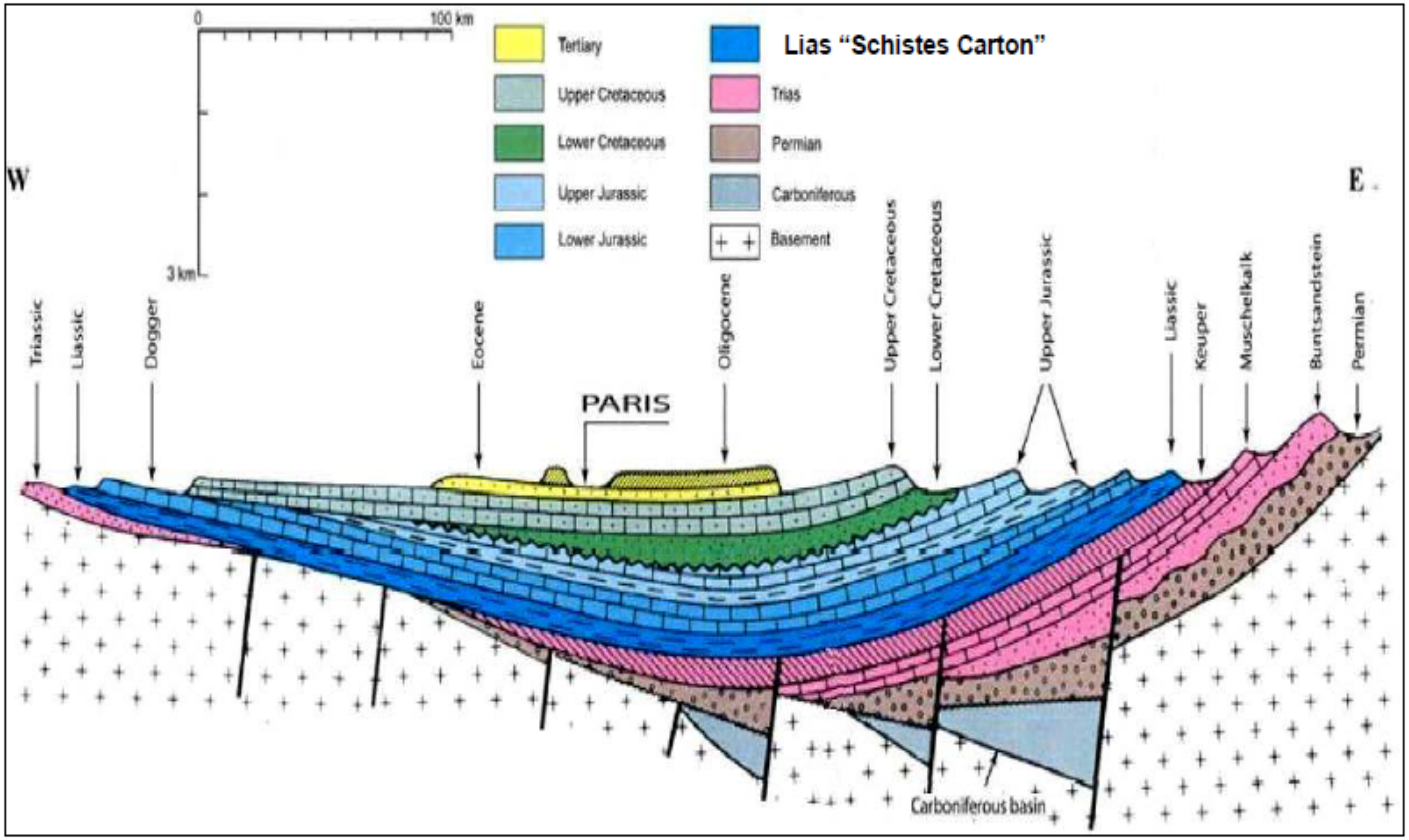
MAP OF THE PARIS BASIN
SHOWING CONVENTIONAL OIL & GAS FIELDS

The Lower Jurassic "Schistes Carton" black shales are the target for Shale-Oil exploration.



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FROM PERRODON & ZABEK (1990) VIA F. SPATHOPOULOS

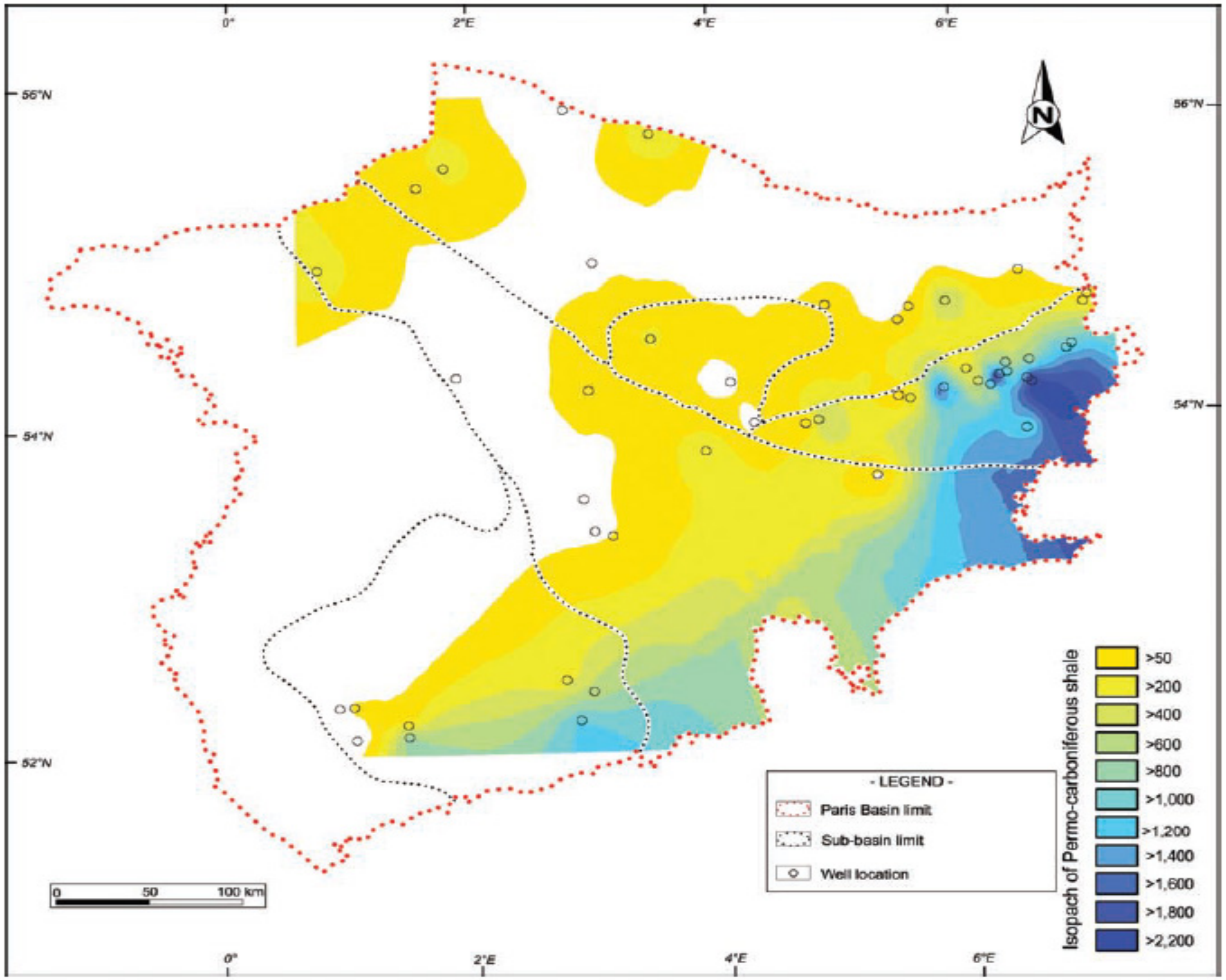

Figure 6 Preliminary Isopach map of the Permo-Carboniferous Shale, Paris Basin. The isopachs are based on penetrated vertical thickness at wells, as most of the wells bottom within this horizon.

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PARIS BASIN PERMO-CARBONIFEROUS SHALE ISOPACH MAP. FROM EIA/ARI (2013)

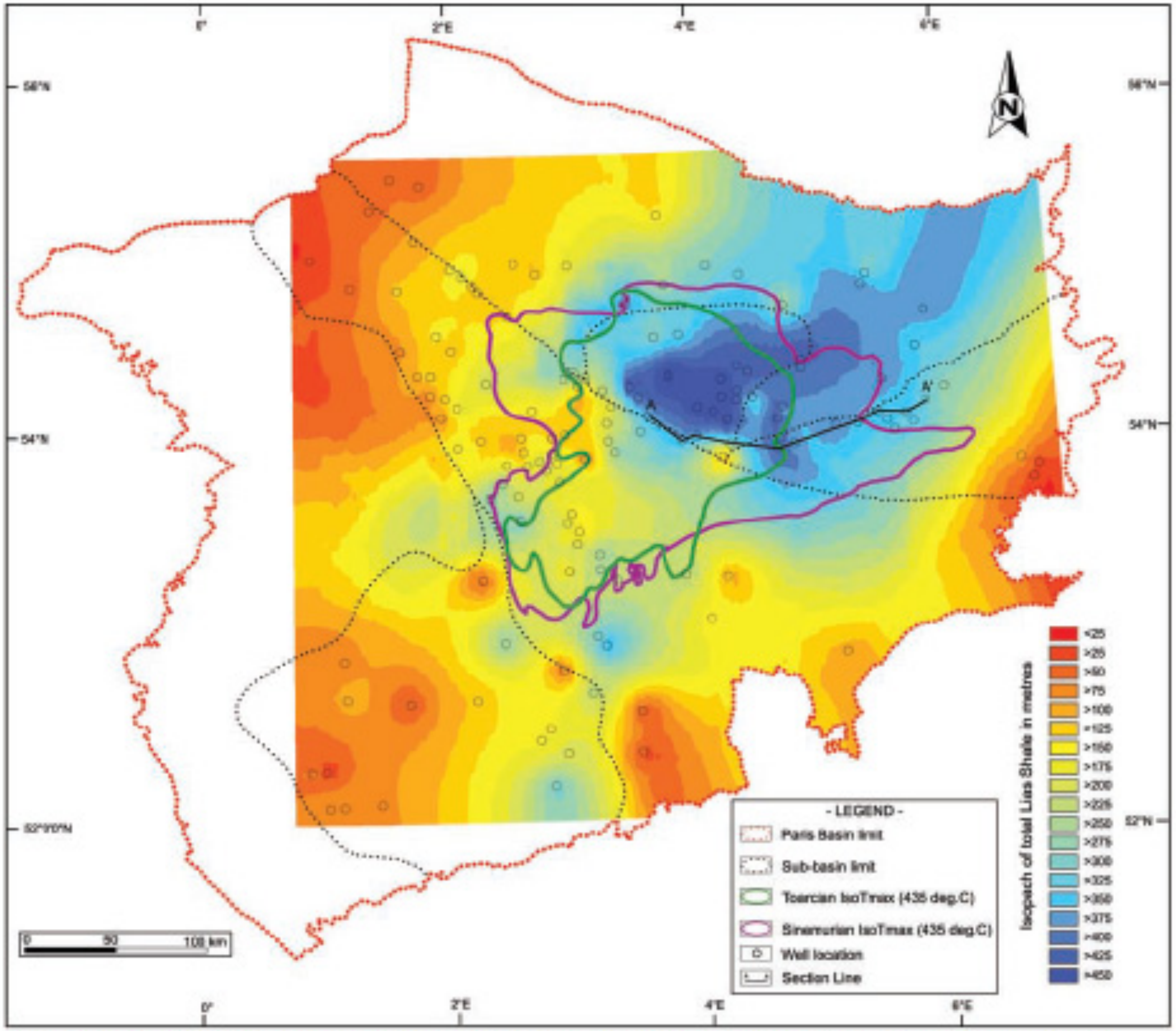

Figure 5 Isopach map of the total Lias Shale and contours of equal maximum temperature of 435°C for two source rock horizons, Paris Basin.

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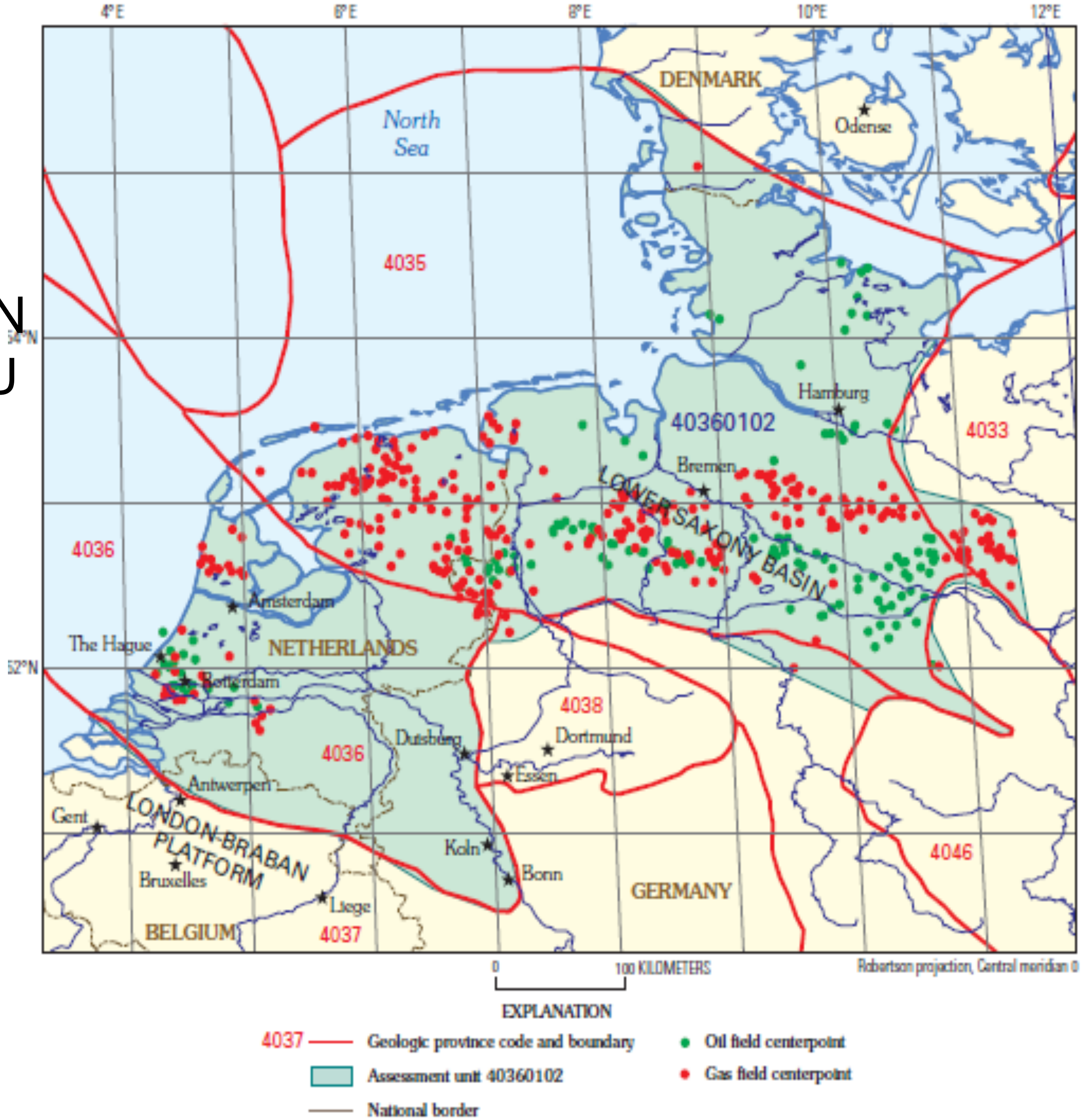
PARIS BASIN LIAS ISOPACH & MATURITY MAP
FROM EIA/ARI (2013)

FRENCH GEOPOLITICS

- 732 Tcf GIP 137 Tcf Recoverable
- 14% of energy gas. Most power nuclear.
- Fraccing banned & licenses revoked in 2010.
- Parliamentary Office for the Evaluation of Science & Technology report concluded fracking is safe.
- Ban still in place

DUTCH-GERMAN CARBONIFEROUS BASIN (U.S.G.S. 2003)



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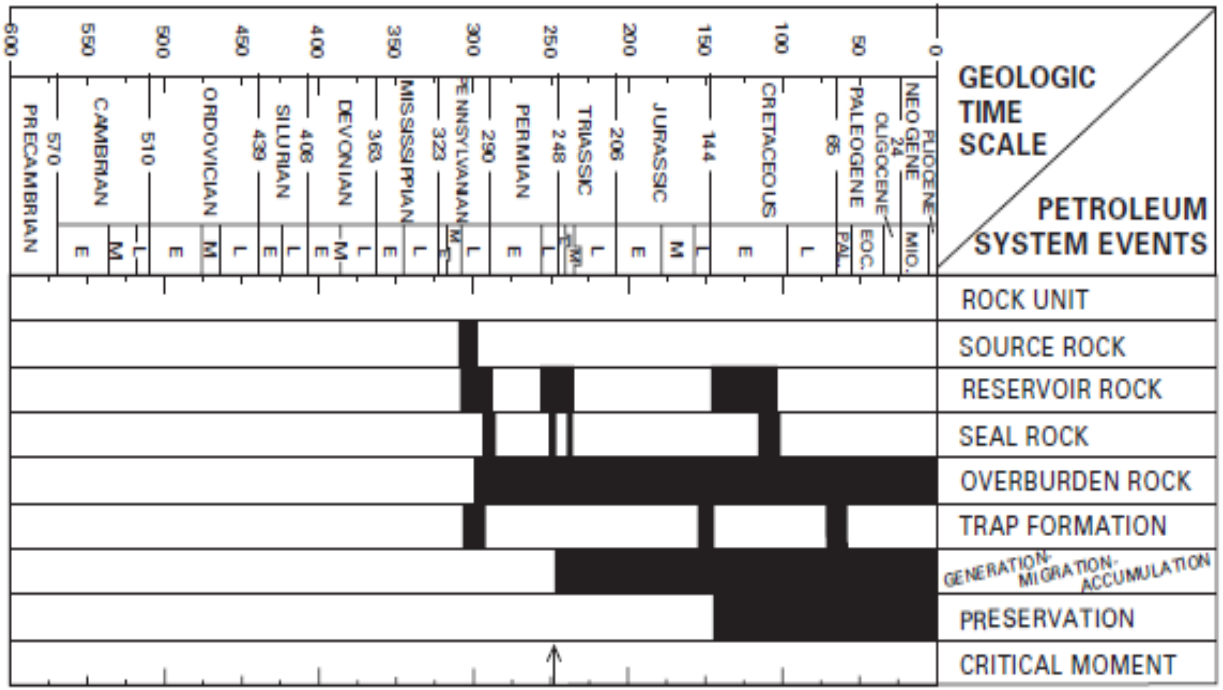
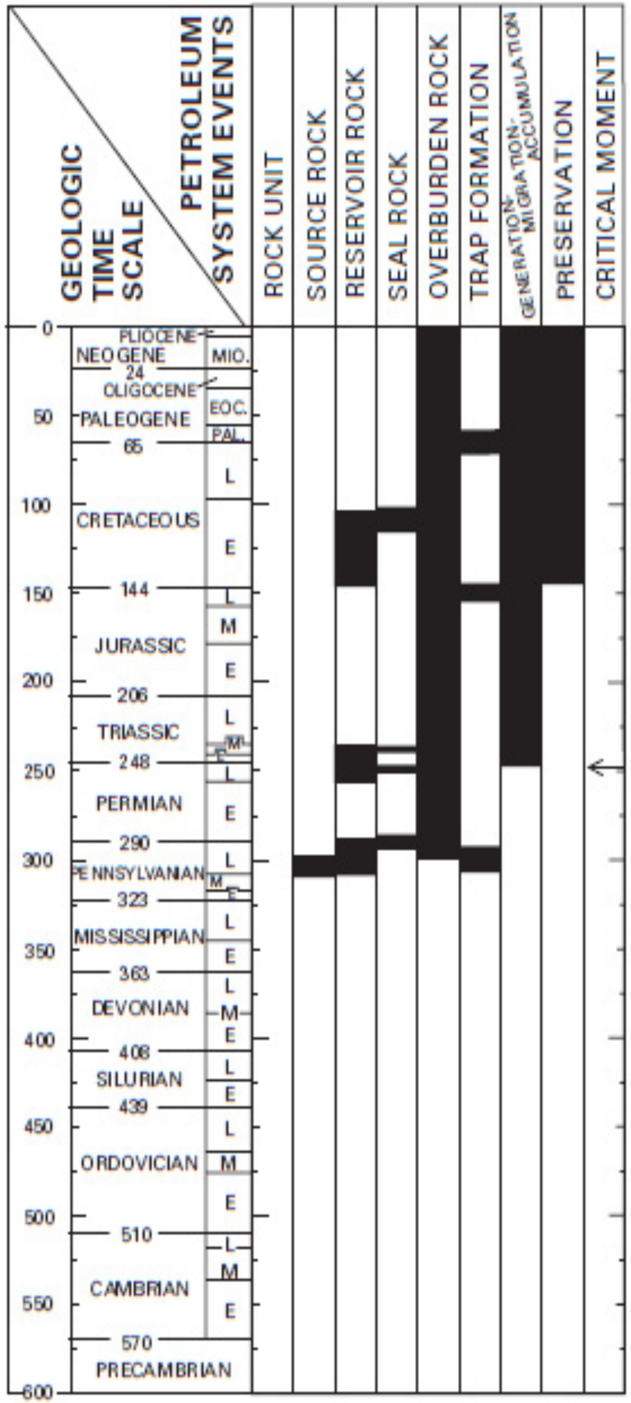


DUTCH – GERMAN CARBONIFEROUS BASIN PETROLEUM SYSTEM PARAMETERS (U.S.G.S. 2003)



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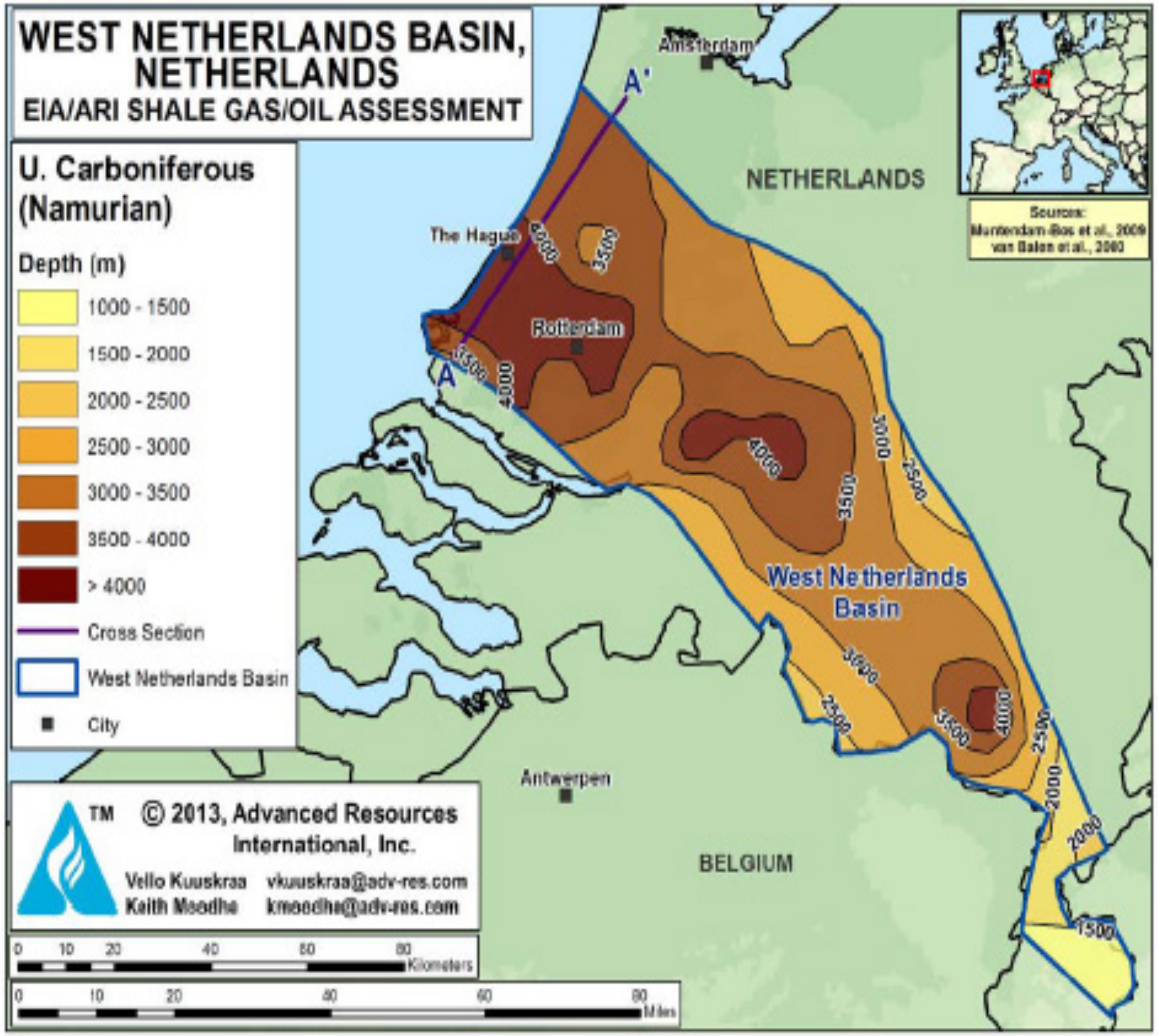
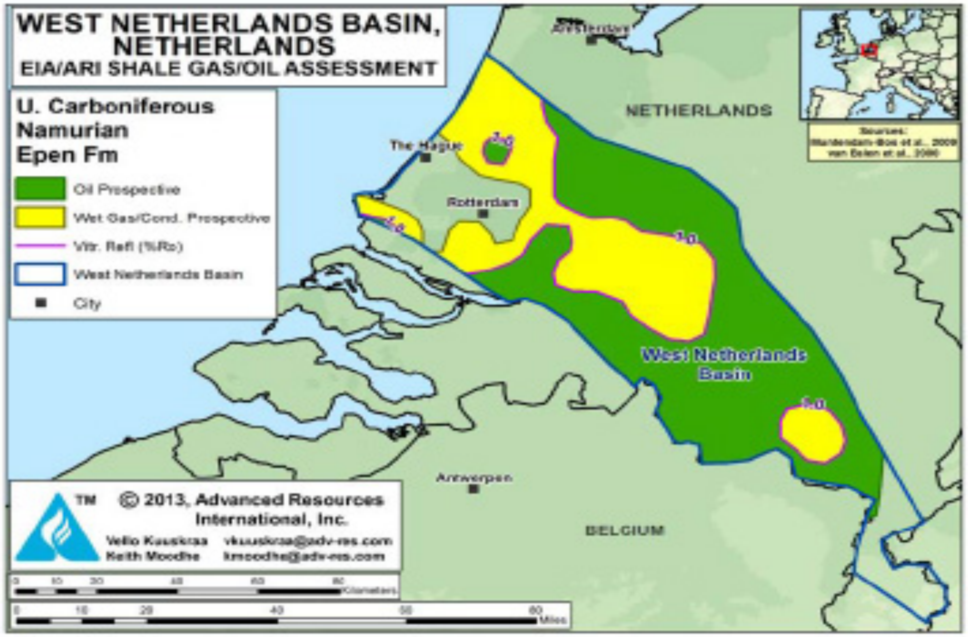
DUTCH BASIN
BURIAL DEPTH OF
BASE NAMURIAN
(FROM EIA/ARI 2013)



DUTCH BASIN SHALE OIL & SHALE GAS POTENTIAL (EIA/ARI 2013)



Source: ARI, 2013

Figure XIII-23. Prospective Areas for Geverik Shale, West Netherland Basin.

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GEOPOLITICS

HOLLAND

- 152 Tcf GIP. 26 Tcf Technically recoverable
- Fraccing >20 years
- Gas dependent economy.
- Government report endorses fraccing
- Strong local opposition.
- Offshore exploration under way

GERMANY

- 80 Tcf GIP. 17 Tcf Technically recoverable (Lower Saxony only)
- Fracking >20 years
- Large gas imports from Russia & Norway
- Premature nuclear power decline
- Draft law before parliament enactment awaits result of general election (22 Sept!)
- Expensive renewables

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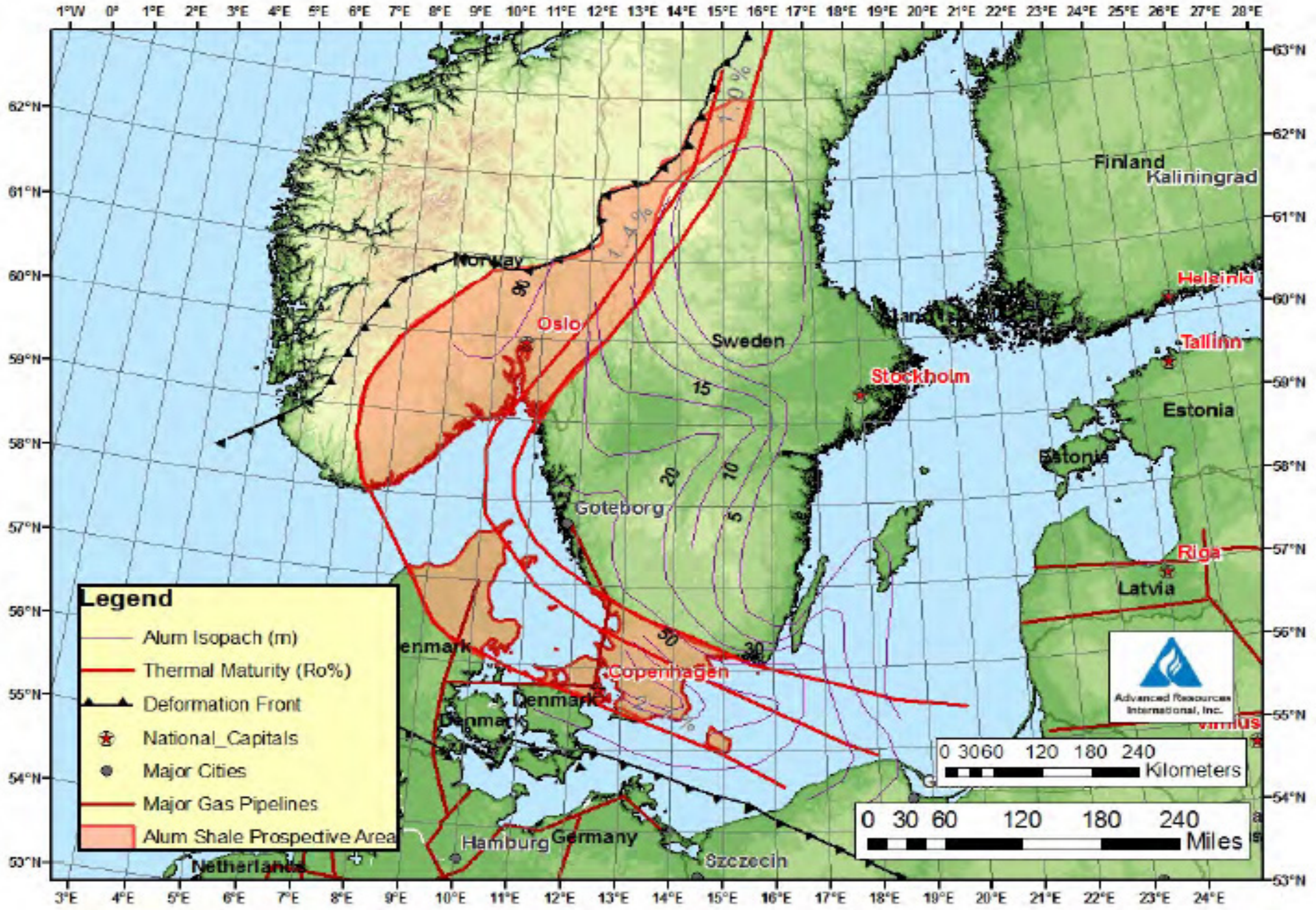
Figure VII-14. Alum Shale Geographic Extent



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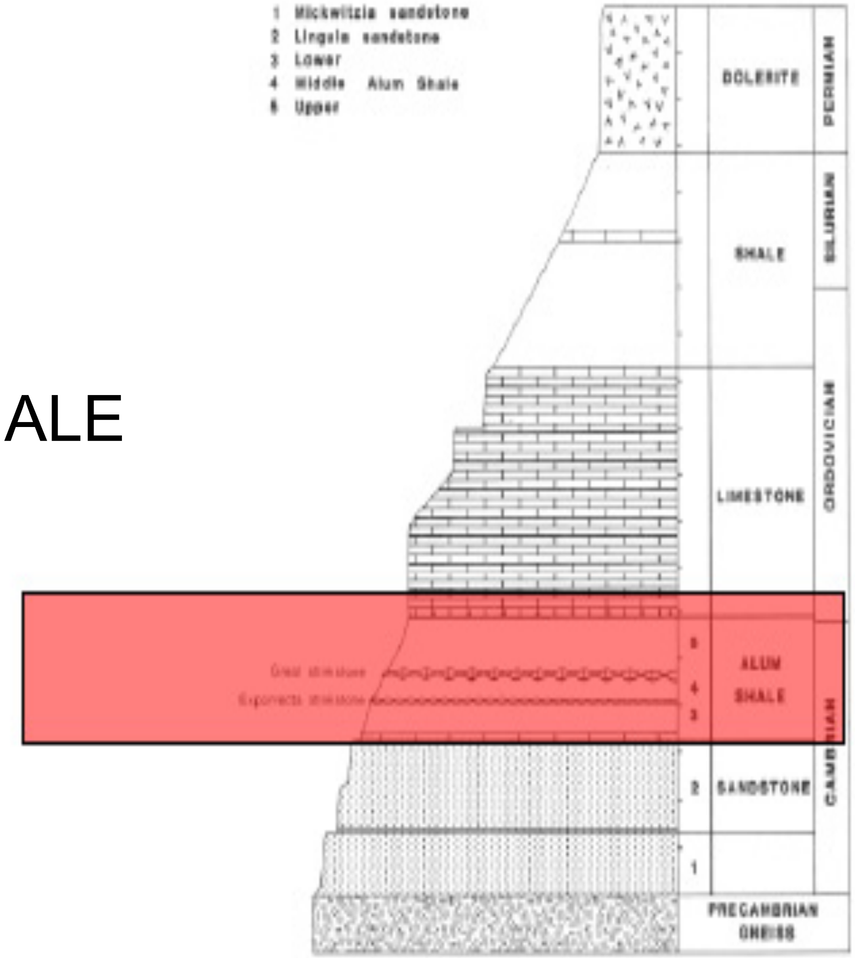
EXTENT OF ALUM SHALE ACROSS THE SCANDINAVIAN SHIELD (FROM EIA/ARI 2013)

OCCURRENCE OF ALUM SHALE IN SCANDINAVIAN SHIELD STRATIGRAPHY (FROM THICKPENNY 1984)



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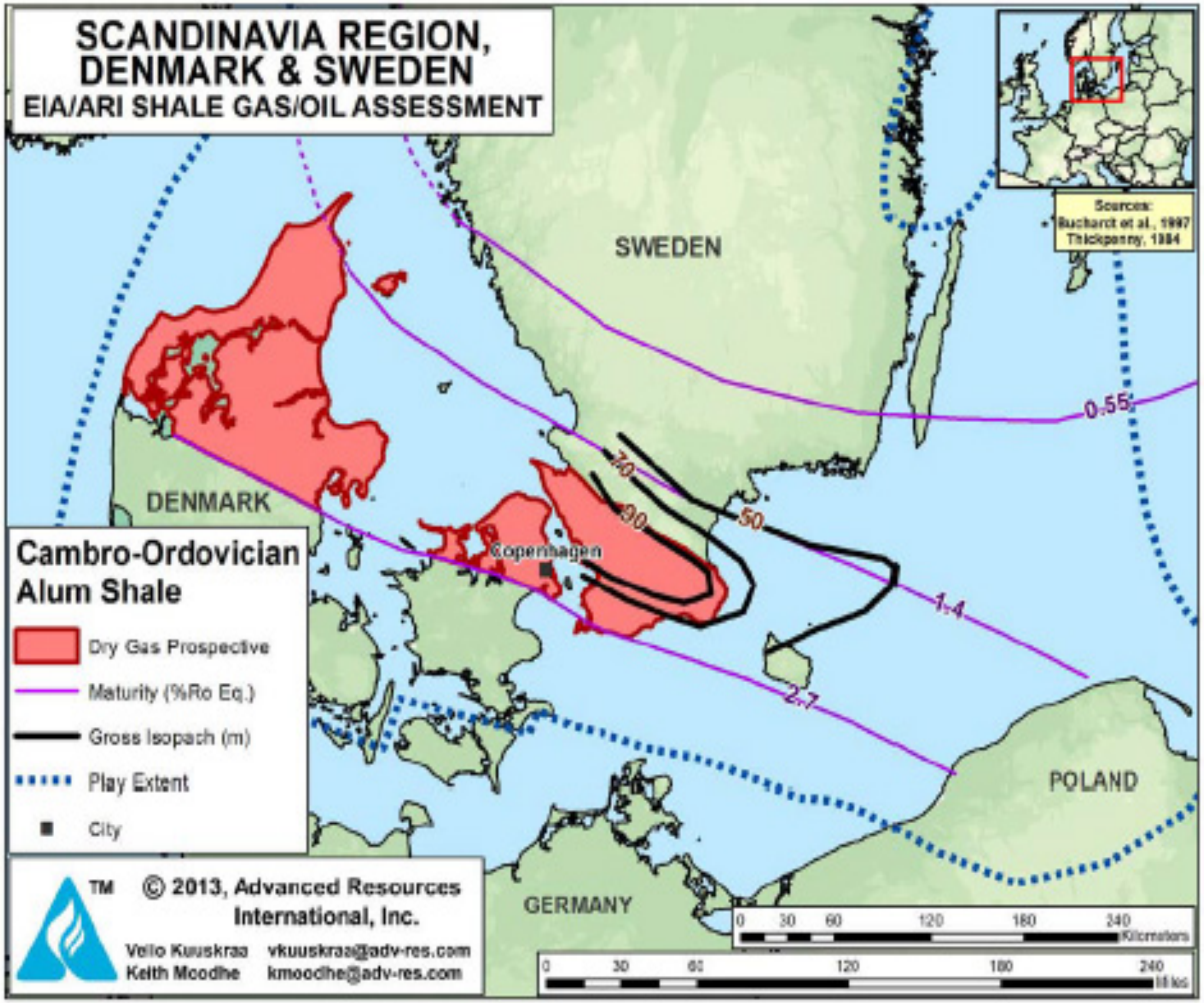

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SCANDINAVIAN ALUM SHALE GAS PLAY (FROM EIA/ARI 2013)

SWEDISH GEOPOLITICS

- Gas is shallow<100m
- Gas is biogenic (Gripen: burn methane to release less toxic CO_2)
- Drill with slimline mining rigs
- Mainly vertical wells
- Rely on natural fractures, or frac with water as in conventional water well work overs.
- Simples

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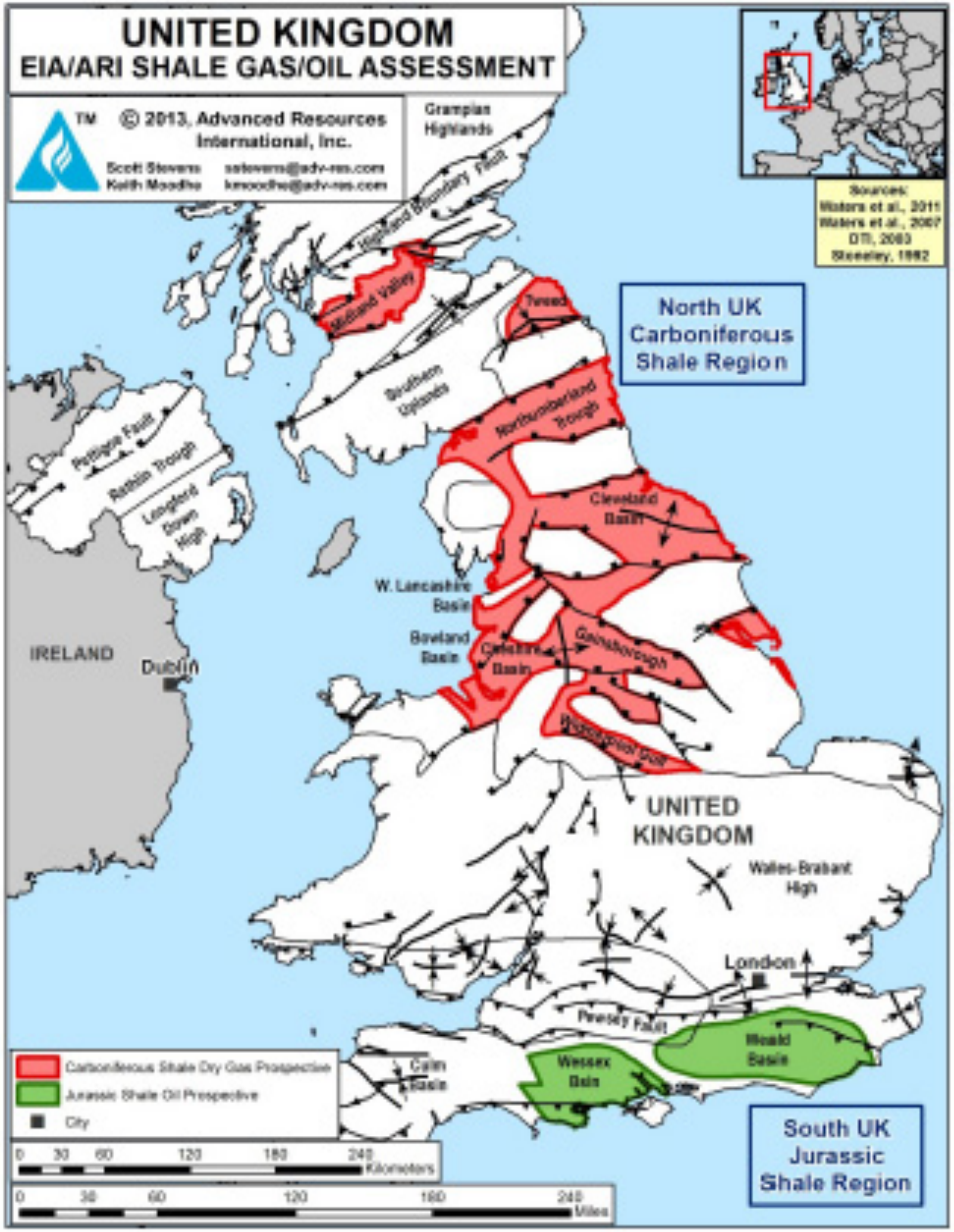
UK SHALE GAS & OIL POTENTIAL (EIA/ARI 2013)



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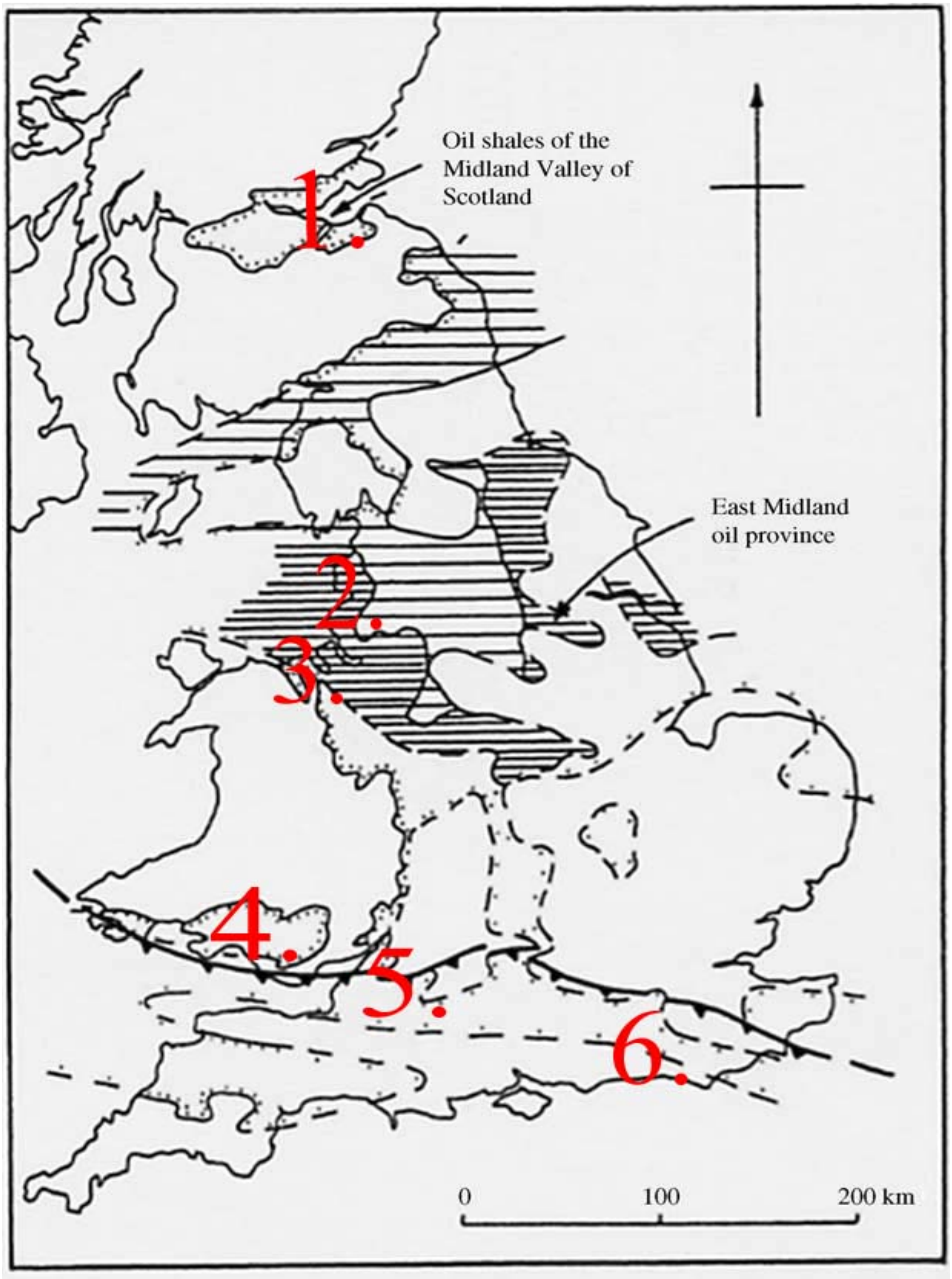
UK SHALE GAS/OIL EXPLORATION IN 2013

1. Composite Energy
2. Cuadrilla Resources
3. IGas
4. Coastal Oil & Gas
5. Eden Energy & UK Methane
6. Cuadrilla Resources



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UK GEOPOLITICS

- 133 Tcf GIP. 26 Tcf Technically recoverable
- 1956 First fracced well. 200 since
- 2008 concessions awarded in 13^{th} Round
- 2011 fraccing banned post Cuadrilla's tremors
- 2012 June. Roy Soc/Roy Acad of Eng. Report
- 2012 December. Ban on fraccing lifted
- Local infestations of Nimbies & Bananas

COUNTRY	BASIN	FORMATION	RISKED GIP (Tcf)	TECHNICALLY RECOVERABLE	RISKED OIP (B bbl)	TECHNICALLY RECOVERABLE (B BBL)
UNITED KINGDOM	N'N Carboniferous	Bowland & equivalents	125 (1329)	25	0	0.0
	Weald & Wessex	Lias shale	8	1	17	0.7
SPAIN	Cantabrian	Jurassic	42	8	3	0.1
FRANCE	Paris	Lias shale	24	2	0	0.0
		Permo-Carboniferous	666	127	79	3.2
	Provence	Lias shale	37	10	0	0.0
GERMANY	Lower Saxony	Posidonia	78	17	11	0.5
		Wealden	2	0	3	0.1
NETHERLANDS	W N'lands basin	Epen	94	15	47	2.4
		Gevenik Member	51	10	6	0.3
		Posidonia	7	1	5	0.3
SWEDEN		Alum shale	49	10	0	0.0
DENMARK		Alum shale	159	32	0	0.0

SOURCE:
U.S. ENERGY INFORMATION ADMINISTRATION ADVANCED RESOURCES INTERNATIONAL JUNE 2013

Figure in red is BGS estimate

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U.S.A. V EUROLAND SHALE GAS EXPERIENCE

USA

- Energy price collapse
- Cheap energy aids economic recovery
- CO_2 emissions drop as coal burning declines
- change from importing to exporting petroleum

EUROLAND

- Fraccing long established
- Companies eager to explore
- Most governments endorse
- Green policies inhibit fraccing & increase CO_2 emissions & fuel poverty

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THE FUTURE?

Sir, You report (Mar 26) that the UK is to import shale gas from the US. Yet it is nearly 30 years since research at Imperial College identified the UK's shale gas resources. How bizarre is that?

RICHARD SELLEY
Professor of Petroleum Geology
Imperial College, London

LETTER TO 'THE TIMES' 27TH MARCH 2013

Imperial College
London

Those whom the Gods wish to destroy they first drive mad.
EURIPEDES 480-406 BC

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ADVANCED RESOURCES INTERNATIONAL INC.

HEYCO ENERGY GROUP

FIVOS SPATHOPOULOS

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THE

END

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