Zeitschrift: Bulletin der Vereinigung Schweiz. Petroleum-Geologen und -Ingenieure
Herausgeber: Vereinigung Schweizerischer Petroleum-Geologen und -Ingenieure
Band: 58 (1991-1992)
Heft: 132

Artikel: Riff systems can point way to hydrocarbon richness
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DOI: https://doi.org/10.5169/seals-215191

Bull. Swiss Assoc. of Petroleum Geol. and Eng., V. 58, Nr. 132, May 1991 - p. 33-38

Rift systems can point way to hydrocarbon richness*

by H.R. GRUNAU**
1 fig., 1 table

Abstract:

A study of rift systems worldwide shows they display specific geological peculiarities. This makes it imperative to define the common denominators that separate rift systems which are tied to major petroleum provinces from those with marginal or no hydrocarbon accumulation

Introduction

A study of rift systems outside the U.S., Canada, Eastern Europe and the USSR shows they often are linked to a favorable hydrocarbon habitat. Major petroleum provinces, such as the North Sea rift system, the Sirte basin and the Gulf of Suez owe their hydrocarbon richness to an interplay of sedimentary and tectonic factors, which have led to unique hydrocarbon-geological configurations. Some rift systems are known to contain only marginally commercial hydrocarbon accumulations, such as the Upper Rhine graben and, at the present exploration stage, the Red Sea, or in which no hydrocarbons have been found so far. Explorationists are eager to know why a system ticks in terms of hydrocarbon richness or, in a negative sense, why hydrocarbons are absent. Rifts clearly display specific geological peculiarities and, therefore, merit close attention on a global scale. The aim is to define common denominators in rift systems which are of hydrocarbon-geological significance and can be used for evaluating the hydrocarbon potential of inadequately explored, or even unknown, rift provinces. Many prospect appraisal systems are geared to detailed assessment of the individual trap taking all factors of hydrocarbon-geological relevance and probabilities into consideration. This approach cannot, in our opinion, be replaced, but should be supplemented by an assessment of regional geological units such as rift-related provinces. Integration of hydrocarbon-geological parameters, timing of events and E&P statistical figures, especially on reserves and production, provide yardsticks on province level for global comparison. In particular, the following elements are of prime relevance in rift systems:

- Fault tectonics and synchronous sedimentation
- Evolution of heat flow in time, in relation to magmatic history and its effect on source rock maturation
- Migration paths and remigration in active fault systems
- Diagenesis and fluid movement in a dynamic fault system
- Seismotectonic belts, fracture patterns and their impact on retention.

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* Reprinted: from WORLD OIL®, November 1990.

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Rift system classifications

The term «rift» was first used in geology by Gregory (1894) in the form of «rift valley» to describe the East African rifts. The term «rift» alone subsequently has been applied to both the valleys (grabens, troughs, basins) and the fault zones bounding them. In North America, where the Gulf of California and the graben structures related to the San Andreas fault are the most outstanding «rift valleys», the term «rift» is applied commonly to megashears. Narrow median valleys of mid-ocean ridges also have come to be called rifts and are now distinguished as «oceanic rifts» from the classical continental rifts. In terms of plate tectonics, the Atlantic-type passive continental margins have been regarded equally as products of rifting and represent a special category ot rift structures. In continental rifts, the Moho discontinuity is at shallow depth, the crust is thinned and includes in the lower part levels of low seismic velocity. The term «aulacogen» has been used widely in Russian literature to designate old continental rifts that lie buried below the thick, undeformed platform cover sediments of large intracontinental depressions. It has become customary to distinguish three major stages in the evolution of rifts: pre-rift, syn-rift and post-rift. Interrelationship of these stages determines the hydrocarbon habitat of the basin. Its interpretation, however, is faced with major uncertainties. It is most likely that the majority of the world's sedimentary provinces which contain a sequence ranging from the Paleozoic to the Neogene, have, at one time or another, passed through a rift stage. This rift stage often has been given little attention or even has passed unnoticed, especially when no seismic information from deeper layers was available. It seems probable that many post-rift deltaic provinces and carbonate platforms are underlain by rift systems, which contain mature and/or post-mature source rocks and have charged the post-rift reservoirs, at least partially. Klemme's basin classification proved to be convenient for selecting rift-related basins. Most basins shown on the map correspond to type III on Klemme's list.

Typical rift system features

Recent application of modern, multichannel seismic studies to many rift systems (e.g., North Sea, Brazil) points to a common element in extensional rift architecture and dynamics. This common element has been labeled the Tilt Block/Half Graben Unit. Tilt block/half grabens are important, as they exert considerable control on sedimentation and constitute the basis of generation cells and subcells. In overpressured systems, their block bounding faults commonly control fluid movement and gases in migration cells, and from oil and gas kitchens into superincumbent sag basin reservoir systems, from which they may be somewhat remote. The North Sea rift system is a convincing example. The relationship between tectonics and sedimentation can be described best by using the following models:

- *Model A.* Continental basins with interior drainage: Rich source rocks of algal-derived kerogen may often accumulate in rift lake environments. Siliciclastic reservoirs may develop in the fan/cone facies, favorably juxtaposed with lacustrine source rocks.
- *Model B.* Continental basins with through-axial drainage: The characteristic feature involves the reaction of the axial river to tectonic tilting. Source and reservoir rocks basically have the same characteristics as in Model A.
- *Model C.* Coastal/marine basins: The classic rift in this category is the North Sea rift system, which evolved under marine condtions from Rhaetic times onward. Source

rocks frequently are generated in the deeper tilt block/half graben-controlled depocenters and are sometimes very rich. The prolific Middle Jurassic Brent Sands, e.g., were deposited in a transgressive-regressive sequence within the confines of the Viking and East Shetland rift systems.

- *Model D and E.* Coastal/marine basins, with or without carbonate buildups, often characterizing the post-rift stage.

Viewing Atlantic-type miogeoclines as a whole, three principal depositional systems may be differetiated in general terms: delta and fan delta; slope environments; carbonate platform and shelf. In terms of volume of favorable reservoir facies, delta systems perhaps are the most important component of miogeoclines. It should be noted, however, that models D and E are characteristic principally of the post-rift stage and could be regarded independently from rift-related basins. These five models adequately describe the source rock/reservoir/seal characteristics and relationships. Therefore, they are of considerable value to the seismic interpreter. Present and past temperature regime in rift-related basins is a factor of high relevance. Source rock maturation and post-maturation depend on it. Unfortunately, data on heat flow evolution in time are scarce in literature and relevant information only could be traced for the Tertiary of the Upper Rhine graben. Based on vitrinite reflectance, it could be demonstrated that paleo-temperature gradient peaks existed in the Eocene and in the uppermost Pliocene to Recent times in parts of the Upper Rhine graben. Maximum temperature gradients were, and still are, in the order of 8°C/100 m.

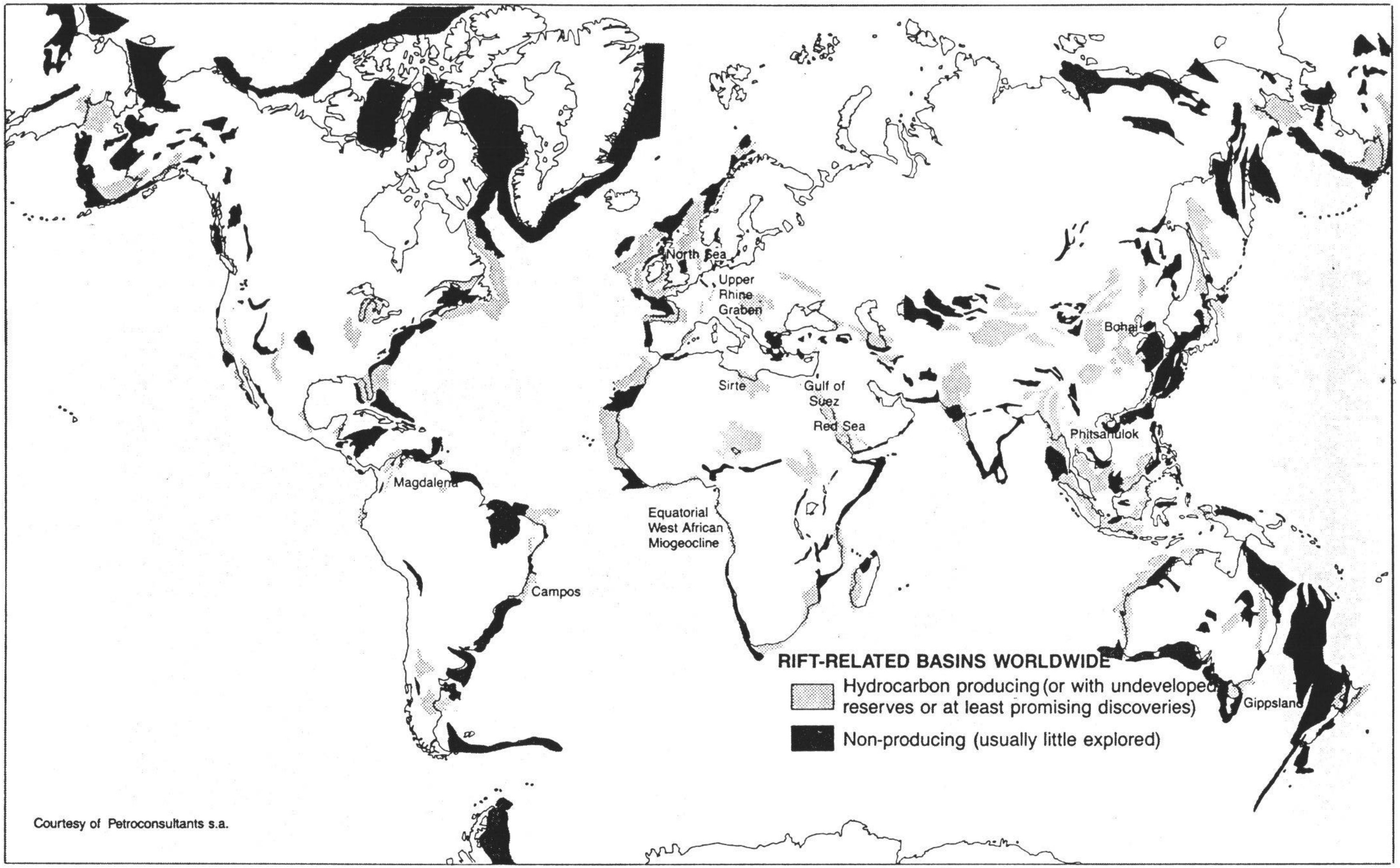
Hydrocarbon richness

One of this investigation's main targets was the relating of hydrocarbon-geological parameters of relevance to basin richness. This was in terms of ultimately recoverable oil, natural gas liquids and gas, as well as total hydrocarbons, expressed as boe (barrels of oil equivalent) per km^2. Ultimately recoverable reserves, however, depend on exploration maturity. Valid statements and comparisons, therefore, only can be made for basins in an elaborate or at least mature stage of exploration, where the degree of geolocical knowledge is high and most hydrocarbon fields have been found. Basins in an initial or advanced stage of exploration maturity are of considerable interest to the explorer but provide less solid ground for meaningful comparisons and calibrations. Statements on the undrilled future potential of a basin have varying probabilities and, therefore, cannot be added to the ultimately recoverable reserves found so far. A ranking of a dozen rift-related basins, considered as representative and studied in some detail, is shown in Table 1.

What makes systems tick

A few remarks on the hydrocarbongeological parameters of relevance are made below for the 12 rift-related basins listed in Table 1.

Source rock. As one would expect, the source rock properties of the four richest basins can be rated from good to excellent. This refers especially to source rock richness, thickness and multiplicity. The source rocks of the two leanest basins are fair to ambiguous, whereas the source rocks of all the other basins range from fair to good. One exception is the Equatorial West African miogeocline, which has good-to-excellent sources but does not rank high in boe/km^2 for other reasons.



The selection of worldwide rift-related basins shown here is adopted mostly from Klemme's Type III rift basins, 1984.

Table 1 - Worldwide rift-related basins

Area	boe/km²
North Sea rift system	275,234
Gulf of Suez	268,821
Campos basin (Brazil)	112,204
Sirte basin (Libya)	100,252
Gippsland basin (Australia)	93,551
Magdalena basin, upper and middle (Colombia)	70,571
Bohai basin (mainland China)	55,541
Equatorial West African miogeocline	43,773
Taranaki basin (New Zealand)	28,549
Phitsanulok basin(Thailand)	7,189
Upper Rhine graben (West Germany, France)	6,971
Red Sea*	—

* No hydrocarbon reserve figures have been reported for the Red Sea.

Source rock maturity and migration. The four richest basins have large drainage areas for oil. The Gulf of Suez graben is lean in gas, as the deeper parts of the pre-rift sequence do not contain large volumes of humic sources in the gas window. Migrational aspects in the Campos basin cannot be considered particularly favorable, as complex migration paths are involved. In the Upper Rhine graben, a comparatively lean province, complex segmentation by faulting and facies changes did not provide large drainage areas for syn-rift soure rocks. As a general rule, very rich provinces can only be expected when the source rock, maturity and migration parameters are good to excellent, apart from other conditions which have to be fulfilled.

Reservoir. Although reservoir conditions in the richest basins do not deserve an overall excellent rating, reservoirs are numerous and have good-to-excellent qualities locally. In less-rich basins, reservoir conditions vary widely, due to frequent syn-rift facies changes, strong segmentation by faulting and diagenetic pore-destructing events.

Seal. The Gulf of Suez graben is a classical case for excellent sealing conditions due to an Upper Miocene anhydrite top seal. This basin, which only has a surface of 27,400 km², is an exceptionally rich oil province because of this impermeable top cover in combination with other favorable conditions. Eight of the representative basins contain evaporite seals, though mostly of subordinate importance. Although shale seals are numerous in all the 12 basins, they are thought to be less effective than anhydrite, especially when they only reach thicknesses of tens of meters.

Trap. The complex trap parameter hardly can be assessed for the type areas, as no detailed 3-D seismic network is, or will ever be, available for entire basins of some extent. Field size distribution curves, though not always complete, provide yardsticks for the trap parameter in type areas. Giant fields having recoverable oil or equivalent natural gas reserves of 500 MMbbl or more are not abundant in the 12 areas. Exceptional in this respect are the North Sea rift system and the Sirte basin.

Retention. Timing of events, especially time of trap formation versus time of migration, is of paramount importance. For all 12 areas, with the partial exception of the Gippsland basin, the relation between time of trap formation and time of migration appears good to excellent, as migration also took place in Neogene times and may partly have lasted up to Recent. In other words, volumes of hydrocarbons which may have been lost by diffusion, escape along faults and other processes, may have been wholly or partly replaced by ongoing migration. In the Gippsland basin, part of the migration took place before trap formation, and large volumes of hydrocarbons are likely to have escaped. Adverse factors for retention are still active faults and seismotectonic belts. The Upper Rhine graben is a classic example in this respect, as large volumes of gas may have migrated to the surface along faults and fractures and been lost in Pleistocene to Recent times.

Uncertainties and research scope

Future research may concentrate on the several aspects detailed below.

Maturation and explusion. Earliest time of expulsion and peak generation from a mature and post-mature source rock depend on the evolution of the paleo-temperature regime in time. As paleo-temperature determinations based on vitrinite reflectance and other methods (e.g., apatite fission track dating) are either lacking completely for most basins or have not been published, maturity considerations are usually based on present-day temperature gradients and/or assumptions. This procedure is unsatisfactory and provides a distorted picture of source rock maturation. Additional complexity originates from multiple source rocks of different types. In particular, the regional and local impact of magmatic events and asthenosphere bulges at depth on the regional and local paleo-temperature regime cannot be satisfactorily judged. Source rock maturation and hydrocarbon expulsion may sometimes be retarded by specific source rock composition. Past and recent seismotectonic events provide microfractures and may, in specific cases, even trigger off hydrocarbon expulsion. This aspect probably has received little attention.

Migration paths and the driving forces in the syn-rift and post-rift phases are not adequately understood. Forecasts and assessments of undrilled future potential may often be wrong, as a firm grip on the migration parameter is lacking.

Retention. The retention parameter, both for the geological past as well as Recent times, cannot be quantified. Escape routes are provided by active fault systems, regional tilt and permeability/porosity channels. The paleo-retention factor often is misjudged or not judged at all. This may have a severe negative impact on prospect evaluation. The role of flushing often is neglected, as meaningful data are lacking.

Acknowledgment

The author wishes to thank Petroconsultants S.A., Geneva, Switzerland, for permission to use their nonexclusive report on Rift Systems, Hydrocarbon Habitat and Potential of Rift-Related Basins, 1989-1990. This article is based entirely on that report, especially Volume I, with contributions by J. STÖCKLIN and Prof. A. WHITEMAN.

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