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CONTRIBUTION TO HYDROCARBON OCCURRENCE IN BASEMENT ROCKS

Generally considered as non-productive, the basement hydrocarbons reservoirs were for long time neglected by the exploration activity, however as a matter of fact in various areas of the world basement rocks represent important oil and gas reservoir. Hydrocarbons may be accumulated in any igneous, metamorphic or cataclastic rocks with secondary porosity (tectonic porosity and /or dissolution porosity). Basement cataclasites – fault related rocks, produced by brittle deformation at elevated strain rates - can develop an important secondary porosity. Cataclasis can overprint various igneous rocks and metamorphite and may play an important role in the final (total) porosity of the basement. Following the acceptance of igneous and metamorphic rocks as hydrocarbons reservoirs in various petroliferous regions throughout the world, the cataclasites can be considered aptly too to draw the attention of the exploration activity.

Key words: *hydrocarbons, reservoirs, basement reservoirs, igneous rocks, metamorphic rocks, cataclasites, fault related rocks, brittle deformation, secondary porosity, exploration activity.*

Introduction

This paper focuses on the hydrocarbons accumulations found in basement rocks-weathered and/or fractured igneous rocks and metamorphite. Basement rocks considered as any metamorphic or igneous rocks (regardless of age) are unconformably overlaid by a sedimentary sequence [Landes et al., 1960][1]. Almost all basement reservoirs occur below a regional unconformity [P`an, 1982]. Generally neglected as target for exploration the basement reservoir plays have been reported from more than 25 countries till the mid nineties.

Hydrocarbon bearing reservoirs (igneous and metamorphic rocks) have been discovered in several countries like USA (California, Kansas, Texas, Nevada), Columbia, Ecuador, Mexico, Venezuela (first discovered basement reservoir in 1948), Brazil, Chile, China, India, Thailand, Kazakhstan, Russia - Western Siberia, North Africa - Egypt, Libya, Algeria, Morocco, Serbia, Hungary, Romania, Indonesia, Japan, Australia, New Zeeland, etc.

This kind of basement reservoir plays have been exploited for decades; increasing interest and exploitation failed to become reality until the mid nineties. Generally regarded as non-productive, gradually the fractured basement reservoir has begun to capture the attention of exploration activity. Hydrocarbons belonging to the basement were usually discovered “by chance”.

[1] *Landes K.K. et al. (1960) stated „The only major difference between basement rock and overlying sedimentary rock oil deposits is that in the former case the original oil-yielding formation (source rock) can not underlie the reservoir”.*

Basement reservoirs – general presentation

Basement reservoirs are characterized by thick reservoir section, measuring from at least few meters to commonly several hundreds meters and a maximum over a thousand meters [P`an, 1982]. Generally basement rocks are tight and locally brittle, characterized by very low and random distributed primarily porosity and permeability.

Petford N. and McCaffrey K. (2003) discussing the distribution of hydrocarbons in igneous rocks reported the highest occurrences in basalts followed by andesite and rhyolithe tuffs and lavas. Although volcanic rocks in this survey represent about 75% of all hydrocarbons bearing lithotypes, the majority of production and global reserves appears to be confined to fractured basement reservoirs and weathered granitic rocks.

Most basement reservoirs occur either on platforms, or on forland (buried hills, upthrow sides of faulted blocks or horsts). In foredeep basins the basement reservoirs are quite rare.

Basement weathering, erosion, solution and leaching increase porosity and permeability and consequently facilitate hydrocarbon accumulation within basement reservoir [P`an, 1982]. Like in sedimentary section the regional unconformity can be a migration-tortuous pathway for hydrocarbon migration. The contacts between igneous rocks and the host rocks can be often a migration pathway. Hydrocarbon occurrence in fractured basements has been known for many years; evaluation of fractured reservoirs is unfortunately much more difficult and expensive than evaluation of fractured conventional reservoir.

Hydrocarbons can be found within and around igneous and metamorphic rocks. The oil which is generated from the overlaying sediments is accumulated in the older igneous or metamorphic rocks (buried hill). Oil may occurs in any metamorphic or igneous rock with secondary fissures, caverns and/or dissolved interstices; fractured basement reservoir may occur in any kind of rock (such as igneous rock or metamorphite) in which the fractures and solution are abundant [P`an, 1982].

Aguilera R. (1980) characterized fractured reservoirs based on porosity distribution between the matrix and the fracture system; matrix porosity is effectively close to zero and the storage porosity is practically due exclusively to fractures. Studies of intensity of fracture spacing suggest a favourable condition already for a spacing of 0.4-1.1 mm. The aperture width of fractures measured ranges from about 0.3 to about 8 mm. Reservoir of this type can be characterized by initially high production rates that decline to uneconomic limits in a short period of time.

Basement secondary porosity

The secondary porosity may have different origins:

a. fracture porosity (faults producing random - microfracturing and/or macrofracturing fabric),

b. dissolution porosity,

c. cataclastic deformation.

Fractured basement reservoir may occur in any kind of rock in which the fractures and solution cavities are abundant, such as granite, gneiss, or some others igneous rocks or metamorphite (Fig. 1, 2). Several basement hydrocarbon reservoirs have been stored in rocks with secondary porosity formed by solution and leaching by water [Smith, 1956].

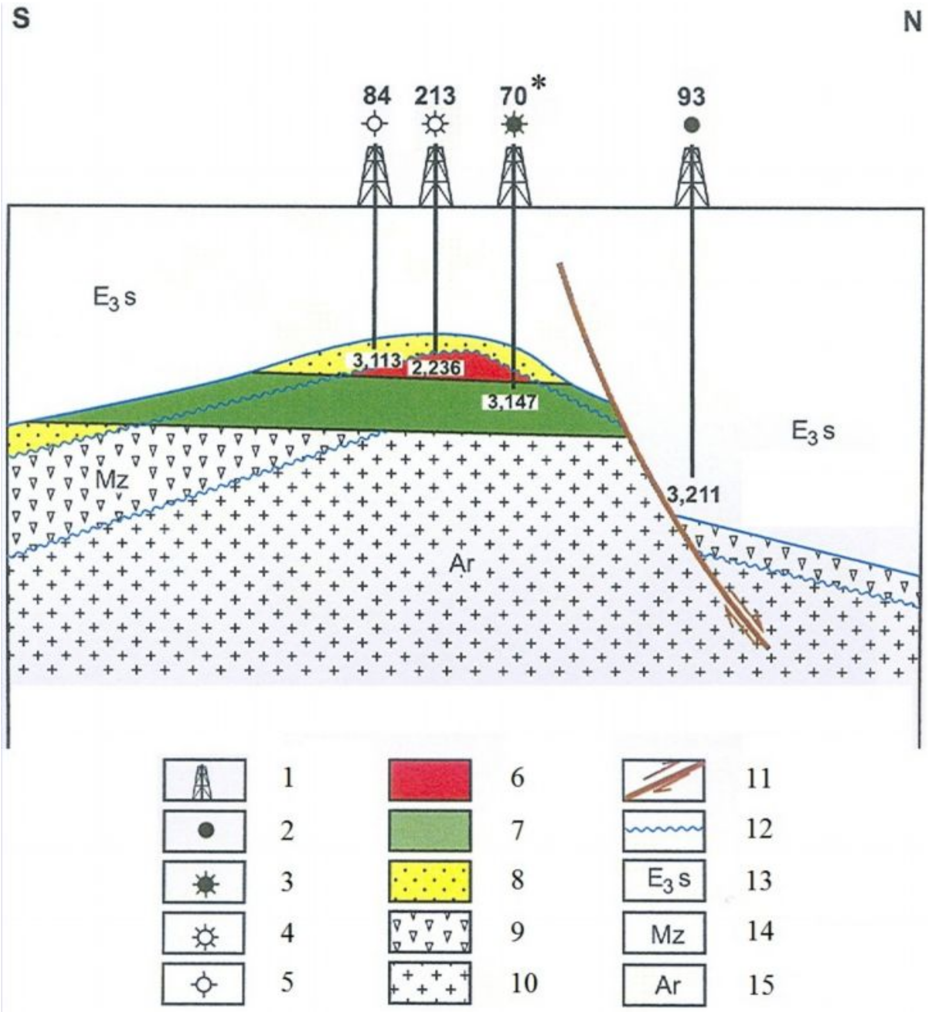

Figure 1. S-N cross section through Xinglongtai basement oil and gas field, China
[Modified after: P`an, 1982]
1 – exploratory well; 2 – oil well; 3 – oil & gas well; 4 – gas well; 5 – dry & abandoned well; 6 – gas pool; 7 – oil pool; 8 – sandstone; 9 – breccia; 10 - granite (slightly metamorphosed); 11 – fault; 12 – unconformity; 13 – Shahejie 3 Fm; 14 – Mesozoic; 15 – Archaean.
**Oil production from granite and metagranitic breccia was about 210 BOPD to 420 BOPD by the end of 1976).*

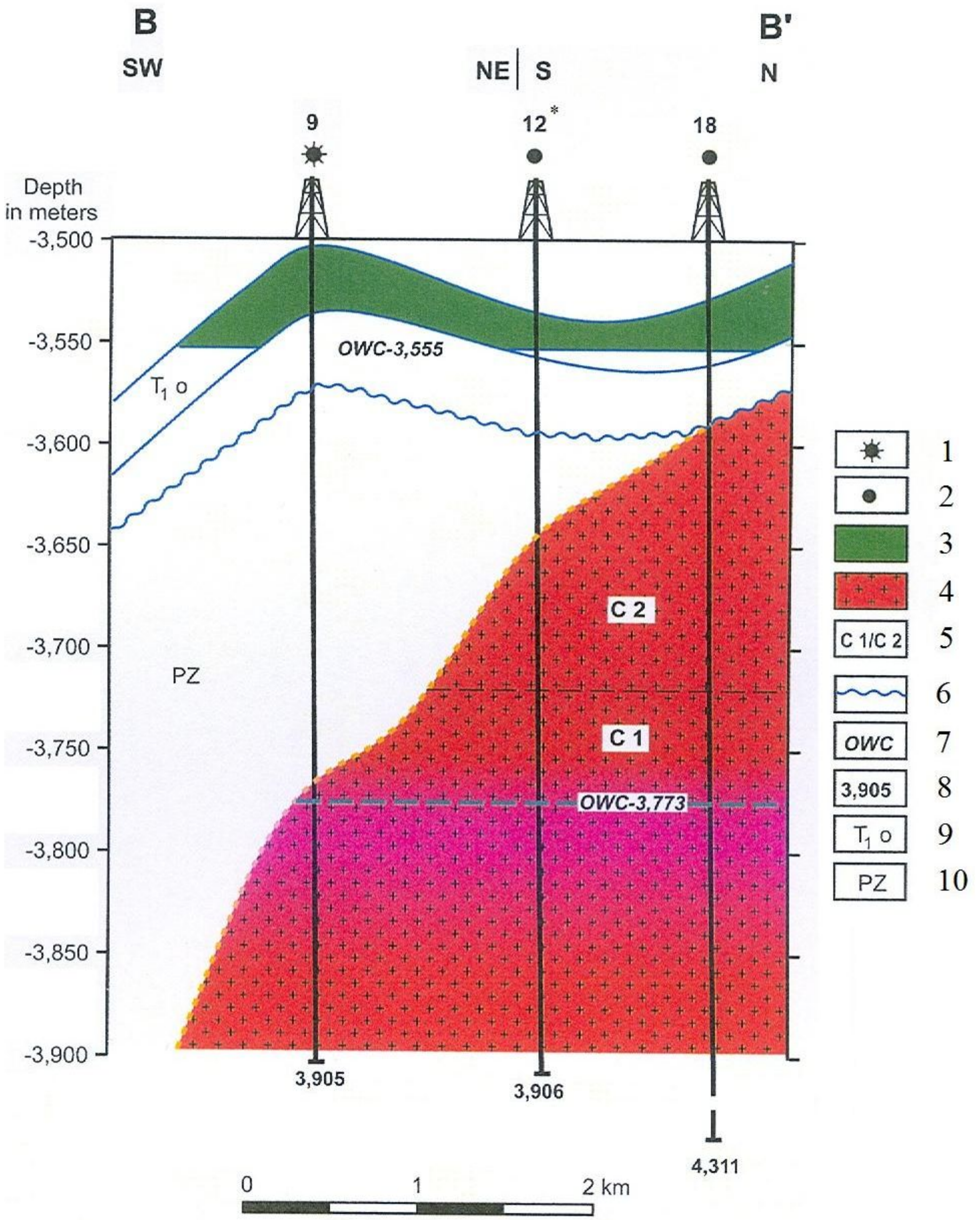

Figure 2. Field section B-B' cross section, Oymasha oil field, Mangyshlak Basin, Kazakhstan
1 – oil & gas well; 2 – oil well; 3– oil pool; 4 – granitoid; 5 – category reserve limit; 6 – unconformity; 7 – oil/water contact; 8 – TD in drilled meters; 9 – Lower Triassic (Olenek Fm); 10 – Paleozoic metamorphite.
**Well 12 tested about 1,380 BOPD from the fractured and/or weathered granite*

Igneous rocks may have primary porosity due to the cooling and sometimes from unloading (associated with extrusive rocks) [Levin, 1995]. Secondary porosity is related with late-stage retrograde metamorphism or hydrothermal alteration with fracturing resulting from cooling or weathering [Schutter, 2003].

Several conjugate faulting systems, commonly shear sets, produce secondary porosity, further fracturing takes place during exhumation of the rocks to the surface; weathering and erosion contribute together with solution and leaching to the porosity and permeability increasing [Sanders et al., 2003]. An important aspect of porosity in extrusive rocks is the fact that, except in tuffs the porosity is lost only slowly through compaction period; porous lava flowing in deeper part of the basin may be more likely to have porosity than the surrounding sediments [Schutter, 2003].

Secondary porosity is due often to the alteration by the latest stages of igneous activity, which may alter the earlier formed minerals and result in intracrystalline or vuggy porosity.

Weathering of granite, especially under tropical conditions, can result in relatively high secondary porosity developing 100-200 meters into the granite; these weathered granites can appear like coarse sandstone (granite wash sandstones) in hand specimens or core [Koning, 2007]. Weathering, erosion, solution, and leaching of basement section play an important role in secondary porosity and permeability increasing.

Basement fractured reservoirs

Nelson R.A. (2001) listed some 370 fields where natural fractures are important for hydrocarbon production; a significant proportion being in basement settings and also reported that in BP Amoco alone, current and future fields in various types of fractured reservoirs are estimated to account for some 21 billion barrels of oil equivalent (BBOE).

Fractured granitoide (Fig. 3, 4), sometime cut by two or more fracture systems, can produce a secondary porosity penetrating 100-200 meters in granitoide [Koning, 2007]. Bulk fracture porosity values of between 0.1 and 1 mm are typical for fractured reservoirs including basement rocks; because the matrix porosity and permeability are generally very small (often < 0.5%) exempts some weathered zones with porosity 5-10%, the open fracture network is essential [Narr et al., 2006]. Fracture porosity can be amplified if in the rock the solution cavities are abundant. Norton D. & Knapp R. (1977) are envisaged two principal modes of fluid transport taking place in igneous rocks, irrespective of composition: flow along macrofractures and interfractures diffusion. Basement reservoir quality depends greatly on the development of secondary porosity-tectonic porosity (most important) and dissolution porosity.

The Bach Ho field located in fractured granitoide in Vietnam, an unusual "buried hill" reservoir (up to 1000 column of liquids) is cut by transpresional wrench faulting and by reverse fault systems. The associated fracture pattern greatly enhances reservoir quality. Faulted intervals with associated damage zones create an enhanced secondary porosity system in the brittle weathered granitoide, effective porosities range from 3 to 5% and occasionally up to 20% [Trinh & Warren, 2009].

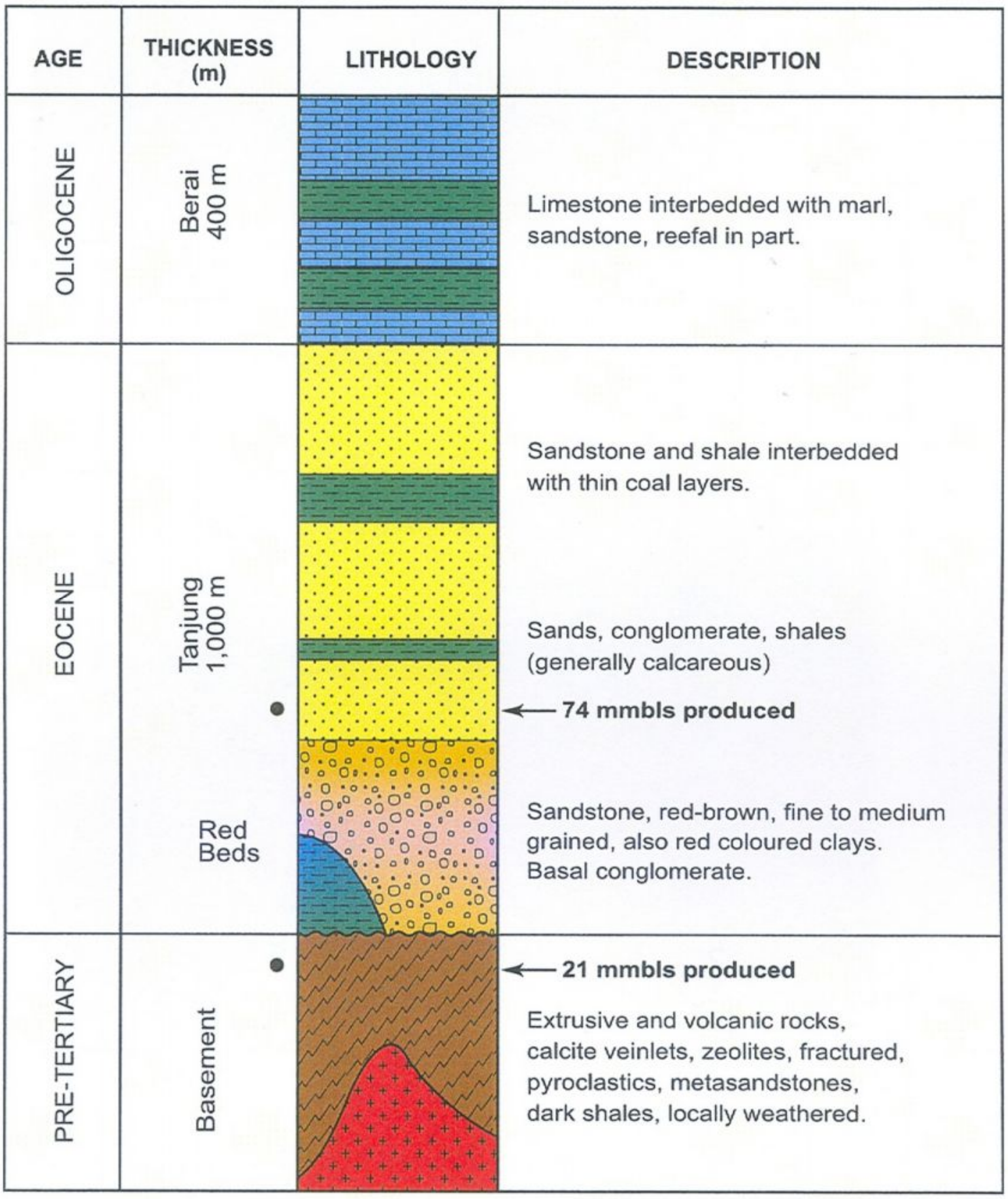

Figure 3. General stratigraphy of the Tanjung field, Barito Basin, Kalimantan, Indonesia
[Modified after: Koning (2000), fide Koning, 2007]

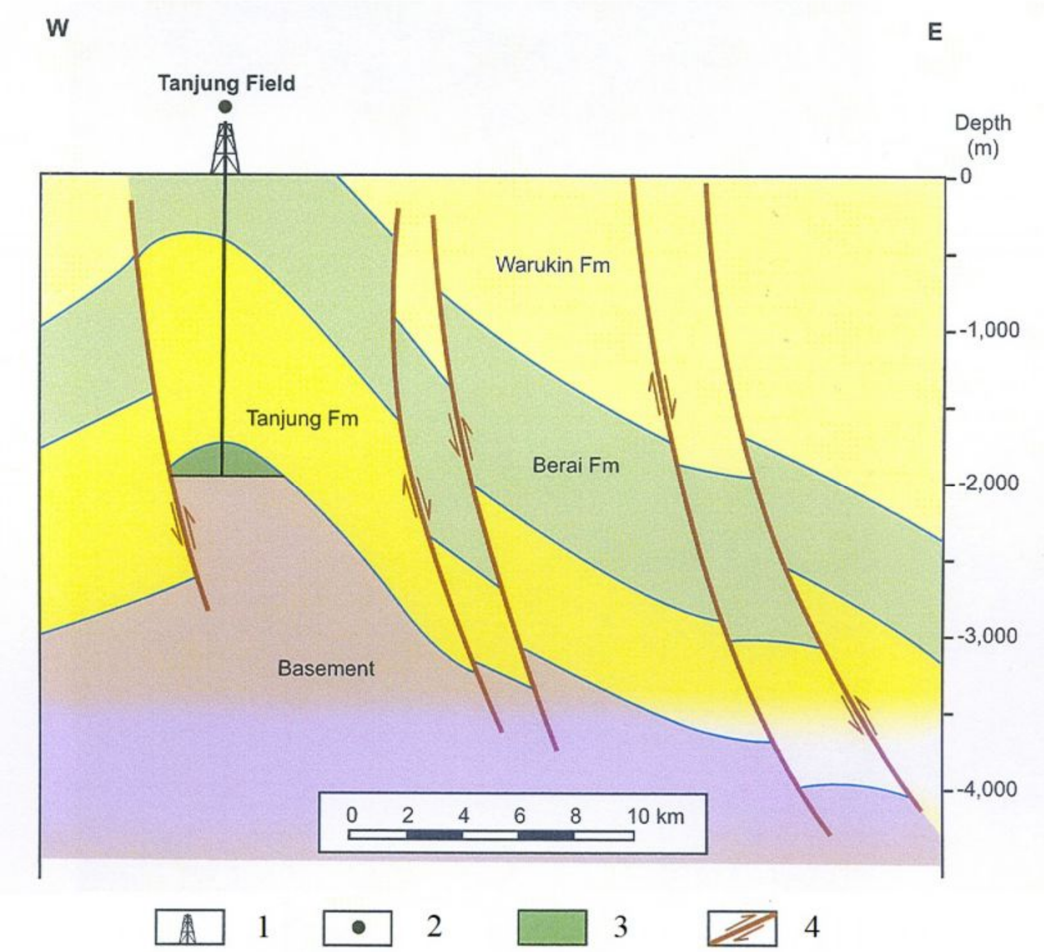

Figure 4. Structural cross section through Barito Basin (Tanjung area), Kalimantan, Indonesia
[Modified after: Koning (2000), fide Koning, 2007]
1 – exploratory well; 2 – oil well; 3 – oil pool; 4 – fault.

Fracturing may also be present on the flank of intrusions; gas-filled fractures were reported along the edges of dolerite in the Karro Basin of South Africa [Petroleum Agency SA, 2000]. Fractured sills or laccolith themselves are also common igneous traps. Cooling may produce fracturing; more fracturing may appear by later brittle deformation. A good example is Dineh-Bi-Keyah oil and gas field in northern Arizona, located in fractured syenite sill [Schutter, 2003].

Many of hydrocarbon fields of Japan are located in altered volcanics in the “Green Tuff Belt” of western Japan [Schutter, 2003]. The volcanic rock porosities range up to 40% in some Japanese oil and gas fields belonging to the “Green Tuff Belt” [Uchida, 1992]. Katahira T. and Ukai M. (1976) compared volcanic reservoirs to those located in carbonates, characterized by vugs connected by fractures and sometimes with similar shapes and log responses as well.

In the Samgori oil field (Republic of Georgia) the zeolitic and andesitic tuff reservoir belonging to the Eocene volcanoclastic section may have porosities up to 26% and permeabilities higher than 400 mD [Grynberg et al., 1993]. The reservoir facies, laumontite tuff is included in unaltered andesitic tuffs and subordinate tuffitic sequences and connected by fractures; fracturing sets, development of vugs and laumontit zeolitisation control the petrophysical properties of the host rock and the development of reservoir heterogeneity [Grynberg et al., 1993]. The secondary porosity within the volcanoclastic section was developed as a result zeolitisation facilitating fracturing. The Samgori field has produced about 165 MMbbl till 1991 [Patton, 1993]. Volcanics and extrusive rocks locally fractured and weathered are considered good basement reservoir like the basement reservoir from the Beruk Northeast and Tanjug fields from Kalimatan (Indonesia). Basement reservoirs can be very promising if the basement is brittle deformed (faulted and fractured) like in case of the fractured quartzitic reservoir – the best reservoir oil reservoir in Beruk Northeast field [Koning & Darmono, 1984].

Igneous fractured rocks can have good reservoir qualities and they can produce their own trapping structures as well as being part of a larger feature (Fig. 5). The hydrocarbons in and around igneous rocks are sufficiently common and orderly that exploration can be done systematically and included in a regional exploration plan [Schutter, 2003].

Basement cataclastic reservoirs

The fractured basement reservoirs have been known by the hydrocarbon exploration for many years (Fig. 6, 7). Generally belonging to the fractured basement reservoir as fault-related rocks the cataclasites represent a peculiar class of brittle deformed rocks occurring in brittle tectonic environment. There are relatively few specific data about generally extent of cataclasites as basement reservoir; the cataclastic rocks are still neglected as exploration targets.

Cataclasites are fault related rocks produced by brittle deformation at elevated strain rates (microbreccia, breccia, fault breccia and fault gauge). Unfortunately there are still insufficient data about the hydrocarbons distribution within the large shear displacement area, detachment faulting zone and along the strike-slip faults and thrust structures.

The cataclastic rocks are strongly dependent on geological and rheological conditions (related to tectonic stress intensity), protolith petrographic composition and fabric. They are located in areas related to pull-apart basins, strike-slip faults, shear zones and subhorizontal thrusting by thrust sheets overridden foreland. Cataclasites are characterized by lack of foliation and by the developing of brittle faulting at high rates of strain producing microfracturing and/or macrofracturing areas and generating breccia, microbreccia and gauge [Wise et al., 1984]. The developing of a secondary porosity is generally more likely within ortocataclasite (typical protholith–granitoid, gneiss and pegmatite). Related to deformation intensity cataclasites were separated in protocataclasite (matrix less than 50% of the rock volume), mesocataclasite (matrix 50-90%) and ultracataclasite (matrix

>90%) [Brodie et al., 2007]. The brecciated and protoclastic zones are often preferred pathway for fluid movement.

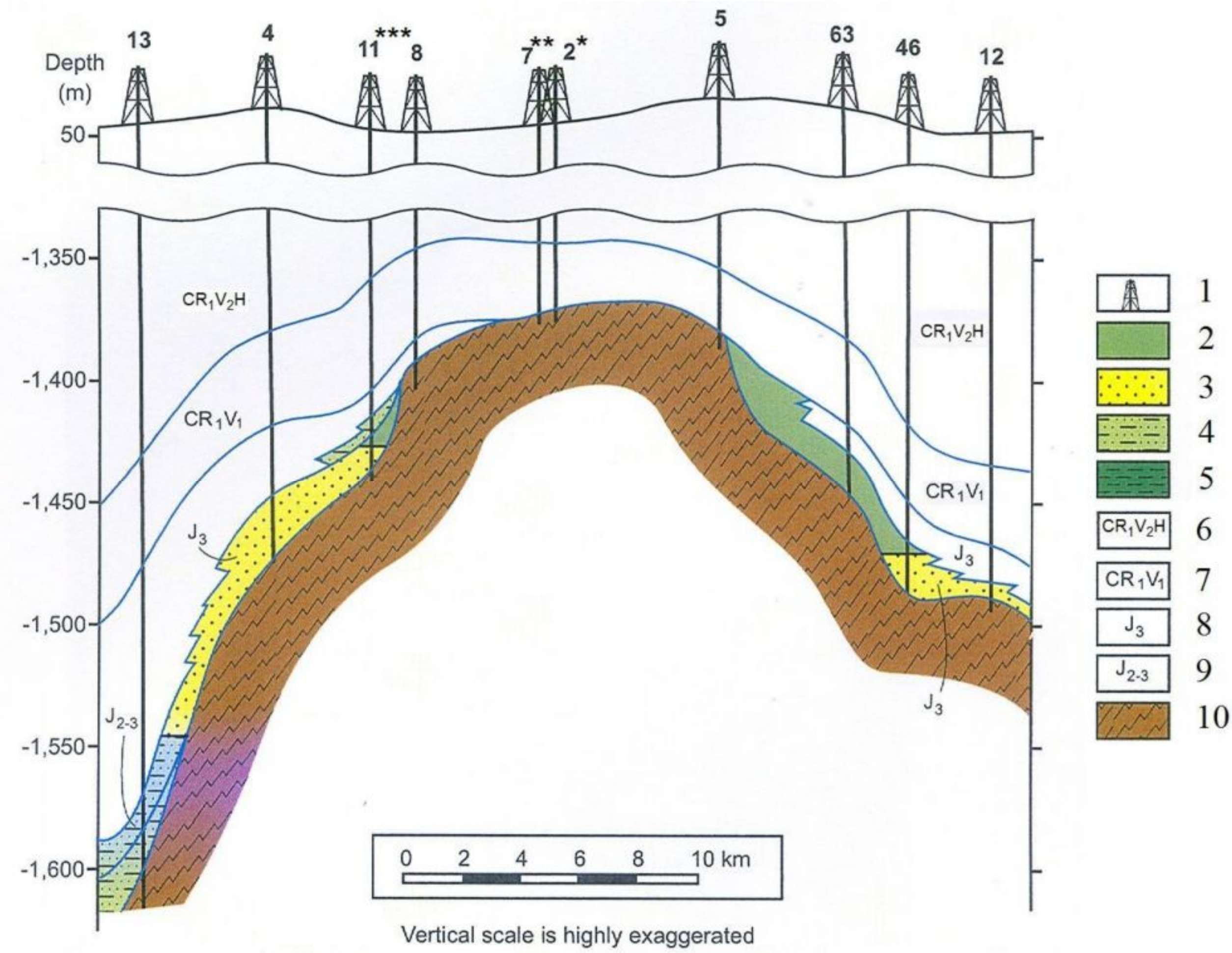

Figure 5. Novomostovskoye Zapadnoye Oil field. Cross section of Shaim uplift Ural-Frolov Province West-Siberian Basin, Russia [Modified after: Rudkevich and Shishigin (1965), fide P`an, 1982]
1 - exploratory well; 2 – oil-bearing sandstone; 3 – sandstone (in the main); 4 – clay and silt; 5 – mudstone; 6 – mudstone; 7 – sandstone; 8 - clay and silt; 9 - mudstone; 10 – folded basement - Paleozoic metamorphite and igneous rocks.
**discovery well.*
***well 7 produced 25 BOPD in April 1960 from the fractured basement.*
****well 11 produced 28 BOPD in 1960 from the fractured basin.*

Higgins M.W. (1971) described cataclastic rocks found along the Moine thrust zone (Northwest Highlands, Scotland). All off the major rock groups in the thrust zone Lewisian, Moinian, Torridonian and Cambrian were cataclastically deformed. Some of this zones east of the Moine thrust are locally more than half a mile wide deformed in polycataclastic rocks.

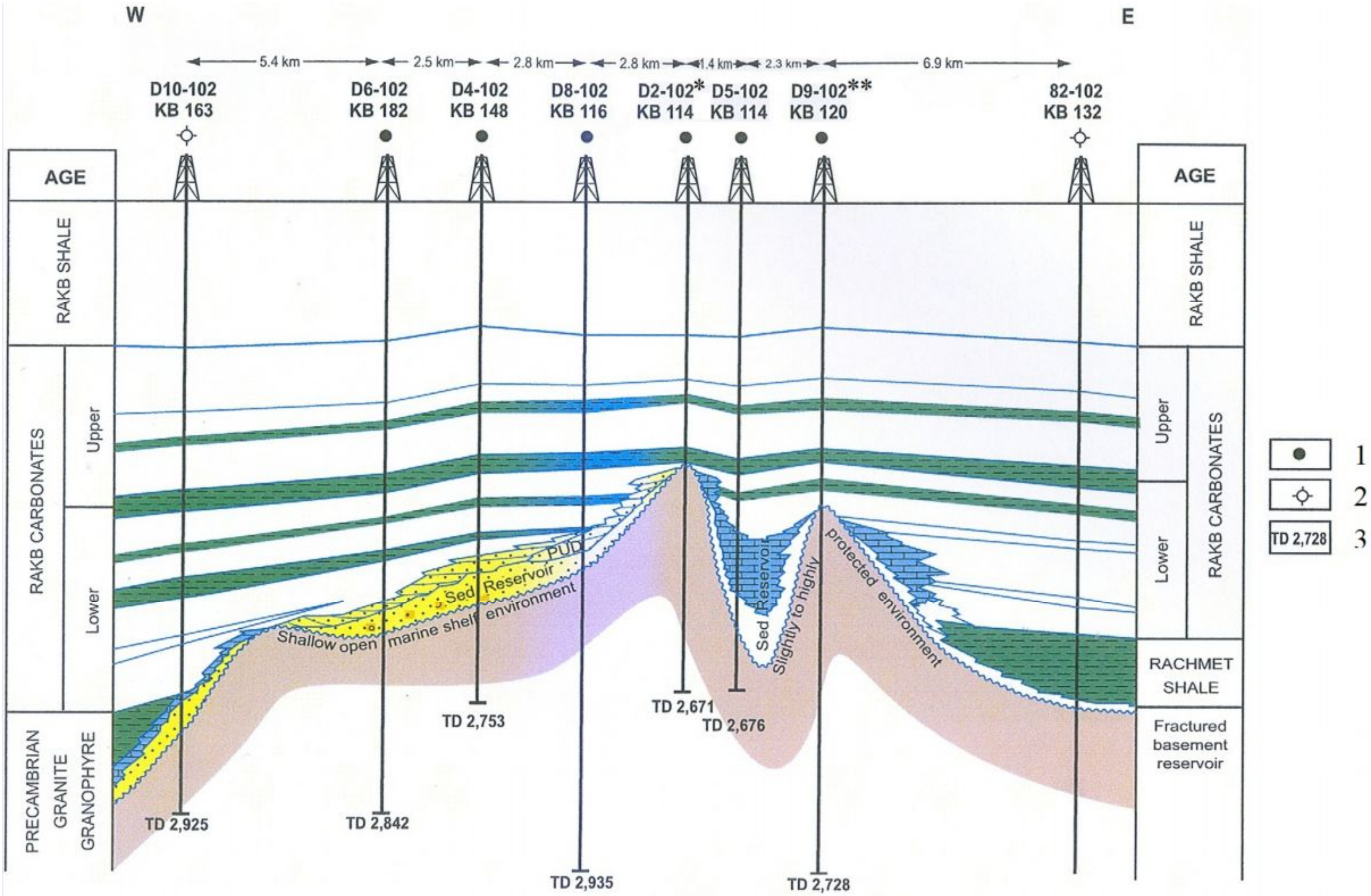

Figure 6. Stratigraphic cross section of Augila oil field, Rakab High Sirte Basin, Libya

[Modified after: Williams (1972), fide P`an, 1982]

1 – oil well; 2 – dry & abandoned well; 3 – TD in drilled metres.

**produced 7,627 BOPD.*

***from rhyolite and also from basement fractured granophyre- initial production was 1500 BOPD.*

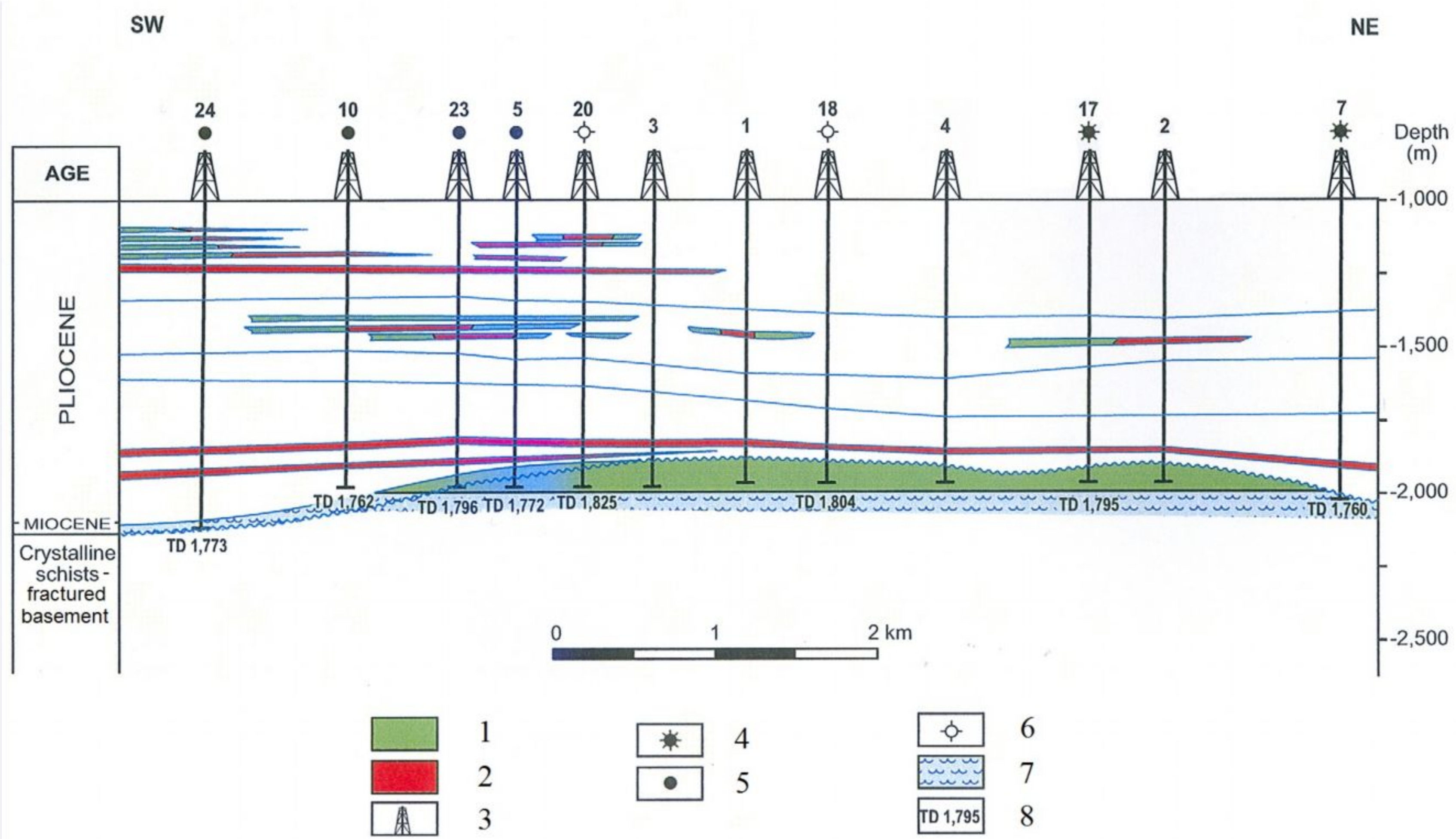

Figure 7. SW-NE cross section of Kikinda oil and gas field Pannonin Basin, Serbia [Modified after: Nikolic in Filjak et al. (1969), fide P`an, 1982]
1 – oil pool; 2 – gas pool; 3 – exploratory well; 4 – oil & gas well; 5 – oil well; 6 – dry & abandoned well; 7 – water; 8 – TD in drilled metres.

Sibson R.H. (1977) described in the Outer Hebrides Thrust (Scotland) in a major thrust zone cutting crystalline quartz-feldspathic crust an important zone ranging up to 30 meters in thickness, intensly microfractured and largely composed of cataclasite and ultracatataclasite. Eastern of the thrust base a crush mélange zone was found - crush breccias, microbreccias, protocataclasite and locally protomilonyte (protolith-acid gneiss with varying metabasite content).

Milnes G.A. and Corfu F. (2011) reported in Jotun Complex in the regional thrust zone (Norway) a large section of cataclasite (protolith represented by migmatic gneisses); cataclasites extent was estimated up to 200 m thickness.

Wang Yu-Hual et al. (2007) reported in Budate Group - Hailes Basin (China) an oil bearing reservoir composed of cataclastic andesitic rocks with daily production of more than 30 tons oil per day obtained from several wells.

Amid the basement belonging rocks, cataclasites represent sometime very important volumes; cataclasis can overprint various protoliths like diverse igneous rocks or metamorphite (Fig. 8).

Summary

On a certain peculiar structure and petrogenetic conditions the basement section can be an excellent hydrocarbon reservoir.

Landes et al. (1960) stated the following: “commercial oil deposits in basement rocks are not geological “accidents” but are oil accumulation which obey all the rules oil sourcing, migration, and entrapment; therefore in areas of not to deep basement oil deposits should be explored with the same professional skill and zeal as accumulation in overlying sediments”.

Most basement reservoirs occur on highs or uplifts on platforms or intramontane/ intermontane basins. The cataclasite bearing reservoirs are located frequently in areas related to pull-apart basins, strike-slip faults, shear zones and subhorizontal thrusting by thrust sheets overridden foreland.

Oil may occur in any basement igneous or metamorphic rocks with secondary porosity, cavernous or dissolved volumes. Developing of secondary porosity (brittle deformation in shear zones at high rates of strain) following by genesis of the dissolution porosity can greatly increase the total porosity and permeability and facilitates hydrocarbon accumulation within cataclasites.

In areas favourable of the developing of basement reservoirs the exploration should be conducted more carefully in conformity with a comprehensive petrophysical evaluation (Aguilera, 1980). Several authors – Aguilera (1980), P`an (1982), Koning (2007) and Sircar (2004) suggest that once the basement section had been reached during drilling , the drilling activity should be continued to allow adequate penetration of basement; the top of basement may be tight but porosity may appear below the overlying tight zone.

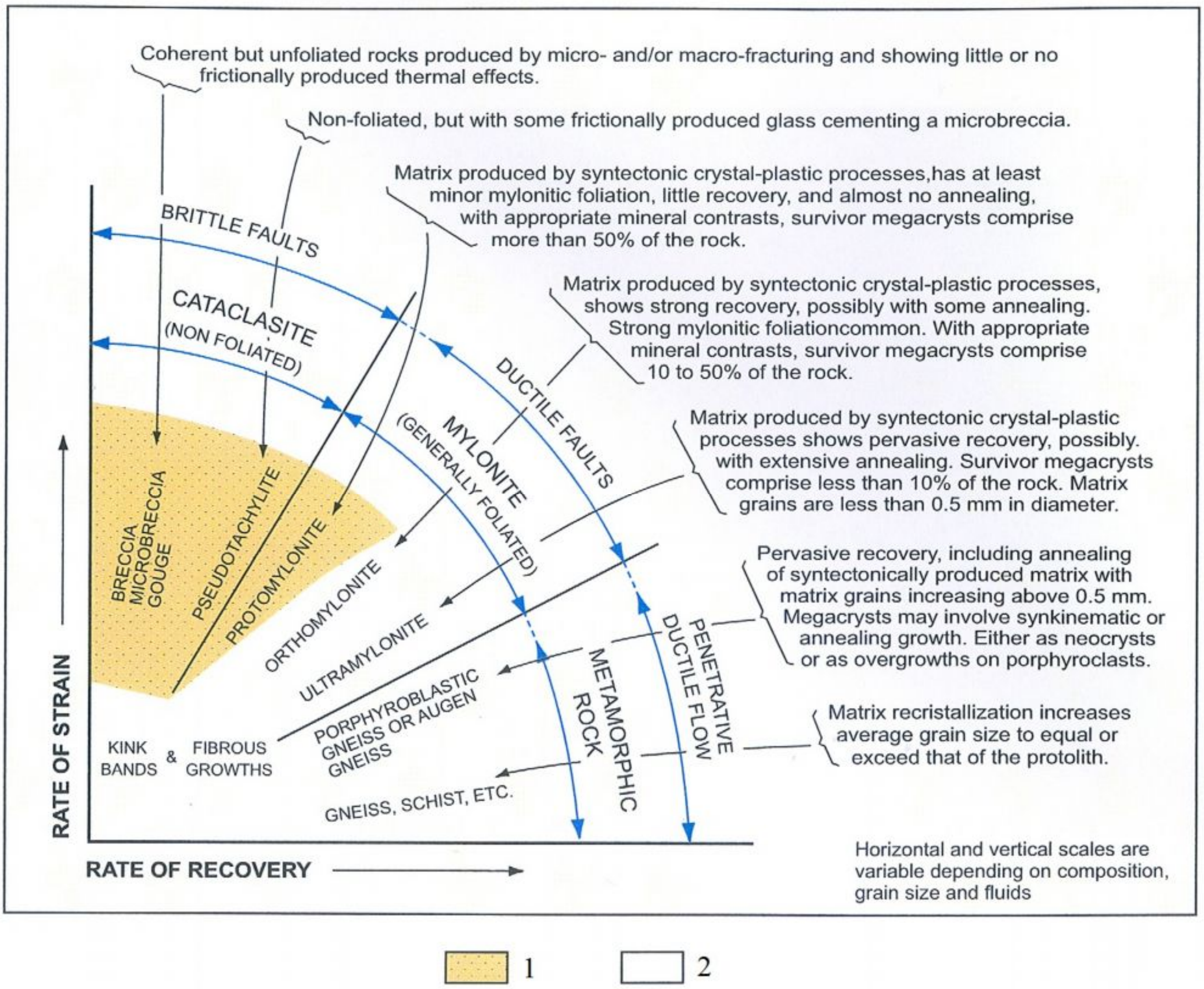

Figure 8. Terminology of fault-related rocks [Modified after: Wise et al., 1984]

Produced by brittle faulting of high rates of strain the cataclasis generates protolith microfracturing or macrofracturing, developing of breccia, gauge and crush mélange random fabric.

Often cataclasites areas form large structures, generally with constant striking; this fact facilitates exploration of an eventual prospective area within the cataclastic zone.

Overprinting basement igneous or metamorphic rocks the cataclasis can greatly increase protolith secondary porosity and permeability permeating a better hydrocarbon accumulation within the basement.

In the hydrocarbon prone areas where basement is not to deep, the basement could and should be regarded as a conclusive exploration objective (target or collateral target – igneous, metamorphic and cataclastic rocks).

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ИССЛЕДОВАНИЕ СКОПЛЕНИЙ УГЛЕВОДОРОДОВ В ПОРОДАХ ФУНДАМЕНТА

Долгое время при постановке геологоразведочных работ пренебрегали коллекторами углеводородов в породах фундамента. Однако в различных регионах мира скопления нефти и газа в породах фундамента открыты и промышленно разрабатываются. Углеводороды могут аккумулироваться в интрузивных, эффузивных, метаморфических и катакластических породах фундамента с вторичной пористостью (тектонической и\или растворения). Катаклазиты (связанные с разломами породы, которые образуются при хрупких деформациях при высоких значениях давления) могут обладать высокой вторичной пористостью. Процесс образования катаклазитов играет важную роль в тотальной вторичной пористости деформированных пород фундамента. Наличие коллекторов нефти и газа в метаморфических и магматических породах является общепризнанным фактом; очевидно, наступило время принять и катакластические породы в качестве возможных коллекторов при постановке геологоразведочных работ.

Ключевые слова: *коллекторы, углеводороды, коллекторы в фундаменте, изверженные породы, метаморфические породы, катаклазиты, приразломные породы, вторичная пористость, хрупкие деформации, геологоразведочные работы.*

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