AAPG HEDBERG CONFERENCE
"***Deformation History, Fluid Flow Reconstruction and Reservoir Appraisal in Foreland Fold and Thrust Belts***"
May 14-18, 2002, Palermo – Mondello (Sicily, Italy)

Sedimentology and diagenesis of the Chorgali Formation in the Potwar Plateau and Salt Range, Himalayan foothills (N-Pakistan)

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Abstract

Shallow-marine carbonate strata of the Eocene Chorgali Formation form an important hydrocarbon producing horizon in the northern part of the Potwar Basin (N-Pakistan). Based on limited core samples available and on data gathered from an outcrop analogue north and south of the producing field, the sedimentary, early diagenetic and fracture-related characteristics of this dual porosity reservoir were studied and compared with the fold-and-thrust belt evolution context of the area. Additionally microthermometric analyses on aqueous and petroleum fluid inclusions have been integrated with kinematic and thermal 2D basin modelling to link the diagenetic history in the burial and thermal evolution of the reservoir and finally, to comment its implication on reservoir controlling parameters.

The Eocene succession represents a shallowing upward sequence starting with open marine bioclastic medium-bedded limestones, which grades, into fabric destructive massive sucrosic and subsequently fine-crystalline dolomites. The presence of anhydrite nodules and chickenwire-shaped calcite pseudomorphs after anhydrite as well as the existence of dolomitised algal mats point towards restricted sedimentary conditions. The near surface sedimentation conditions are also reflected by the presence of flat channel conglomerate and breccia beds in the upper part of the dolomites. The breccia display features typical for early diagenetic evaporite collapse breccias. These dolomites, which are 15m thick, are overlain by a 32 m thick shale and marl succession in which few lacustrine limestone beds are intercalated. Subsequently a few meters of pedogenetically overprinted marine limestones develop below the regionally recognised Kulana sealing shales above which Fateh Jang conglomerates occurs. This is followed by shales and fine grained sandstones of the Murree Formation which unconformably overlies the Eocene strata.

$\delta^{18}O$- and $\delta^{13}C$-values of the dolomite host rock vary between -0.5 to -6.3‰ and +1.2 and -4.5‰ respectively. These values are interpreted in terms of marine dolomites which were recrystallised by meteoric water infiltration. The marine limestones were also affected by this recrystallisation and possibly by additional interaction with hot fluids as testified by intensive neomorphism and their $\delta^{18}O$- and $\delta^{13}C$-values varying between –7.3 to –9.4‰ and –7.02 to –12.41‰, respectively. Especially the negative carbon isotope values point towards recrystallisation by soil-derived meteoric fluids.

The late diagenesis is mainly characterised by (hydro)fracturation whereby at least seven distinct fracturation episodes were recognized. They are well-developed in the limestones just below the Kuldana shales. Noteworthy is that the carbonate reservoirs in the Potwar Basin are considered to produce mainly from fractures and from the Fateh Jang conglomerates and that the best reservoir producing level occurs just below the seal. The microtectonic analysis of the different fracture generations reflect the complex deformation history typical of "fold-and-thrust belts" (FFTB). The stable isotope signature and coeval fluid inclusions testify of an evolution from mixed marine and meteoric fluida, to burial rock buffered and overpressured fluids (90-170°C), which were episodically expelled below the Kuldana shales from deeper parts of the basin.

Introduction

Integrated approaches combining field and core description, petrography, stable isotope analysis and microthermometry of fluid inclusions allow to reconstruct fluid flow through time (Muchez et al., 1991; Travé et al., 1998; Van Geet et al. 2002) and help to work out predictive exploration models. In complex areas such as FFTB, a good knowledge of the pre-, syn-, and post-tectonic evolution, deduced from seismic transects and from forward kinematic modelling is also of major importance for comparing the diagenetic evolution with the regional and structural history.

The Eocene carbonates of the Potwar Plateau and Salt Range basin have been studied in detail. Data from the Chorgali Formation, which is an important oil producer, in such fields as Dakhni, Turkwal, Sadkal, Fim Kassar, Bhal Syedan and Missa Kesswal, are presented.

The aim of this paper is to infer, on the one hand, the sedimentary control on reservoir characteristics in the Chorgali succession and, on the other hand, to deduce which are the major diagenetic (early and late) features controlling reservoir performance, whereby the latter will be placed into the burial and tectonic framework of this fold-and-thrust belt. Results drawn from this study, especially the results of the fracture study, can be of more general use in other localities.

Geological setting

The Potwar Plateau and Salt Range are located in the south-western foothills of the Himalayas, in northern Pakistan (Fig. 1). The region extends over 120 km from the Main Boundary Thrust (MBT) in the north to the Jhelum River in the south (Jaswal et al., 1997). Due to its contrasted structural styles, the Salt Range-Potwar Province can be subdivided into four distinct domains. Starting from the south, it comprises:

- An autochthonous foreland which is made up of Neogene to Quaternary series that rest directly on top of the crystalline basement or thin Precambrian to Permian strata. The average elevation of these lowlands never exceeds 100m above sea level;
- The Salt Range which constitutes the frontal part of the allochthonous cover thrust sheet, that is detached from its substratum along Precambrian salt horizons;
- The South Potwar sub-basin, frequently referred to as the Potwar Plateau due to its relatively constant elevation (averaging 500 m above sea level). Neogene molasse is widely exposed in surface outcrops, whereas a long living petroleum exploration has resulted in a huge subsurface data base (including both seismic and wells).
- The North Potwar sub-basin, which is bordered by the Khari Murat Ridge and coeval backthrusts in the south, by the northern flank of the Soan syncline in the southeast, and by the MBT in the north. In addition to Neogene outcrops, it also comprises a number of surface anticlines and thrust fronts along which the Eocene platform carbonates are exposed.

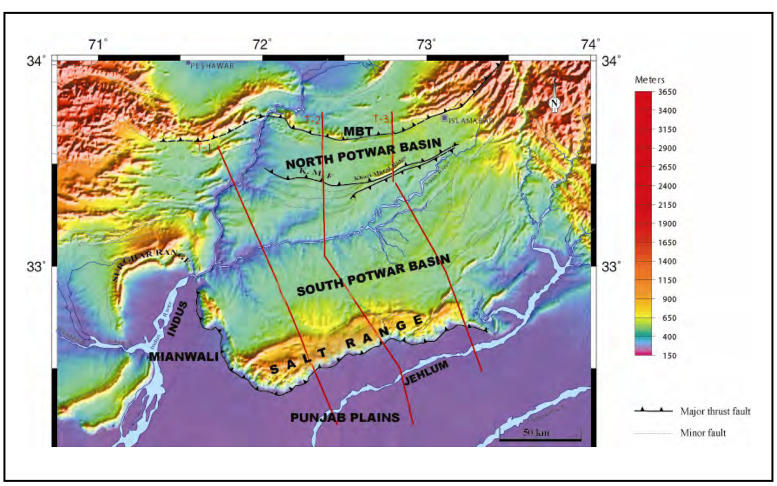

Fig. 1 : Numerical topographic map of the Salt Range-Potwar Basin with the location of the three SUBTRAP transects along which kinematic modelling has been carried out.

Integration of outcrop analogue and core observations

The Chorgali Pass outcrop analogue is located in the eastern part of the Khari Murat Range, next to the Khari Murat Fault. This fault is one of the major thrust faults occurring in the Potwar Plateau. The outcrop area displays an anticlinal structure. Thus, a 3-dimensional overview of the carbonate reservoir (Eocene Chorgali Formation), underlying bioclastic carbonates (Eocene Margala Hill Formation) and the siliciclastic seal (Eocene Kuldana and Miocene Murree formations) were studied. The lithostratigraphical log of the Chorgali Formation, measured in the Chorgali Pass reference site, allowed to reconstruct the sedimentary setting.

Diagenetic evolution

With regard to the fracturation history, more than 7 vein (V-) generations have been recognised (Fig. 2). An attempt is made to characterise individual vein generation as recognised from petrography by its stable isotopic signature, but this was not always possible due to the small size of the veins. In general, there is a major overlap in stable isotopic composition, both in $\delta^{13}C$ and $\delta^{18}O_{PDB}$ between the vein generations V1 to V5. Their $\delta^{13}C$-values vary between –0.92 and –14.10‰ and are commonly similar to the host rock signature in which they developed. Their $\delta^{18}O_{PDB}$-values, however, display a larger spread, varying between –1 and -13.2 ‰. A clear covariant behaviour between both parameters is present. Based on luminescence characteristics and stable isotopes, late stage cements reflect TSR. The diagenetic evolution is replaced at basin-scale according to the burial and thermal history of the Chorgali Formation and microthermometric values of fluid inclusions (Fig. 3).

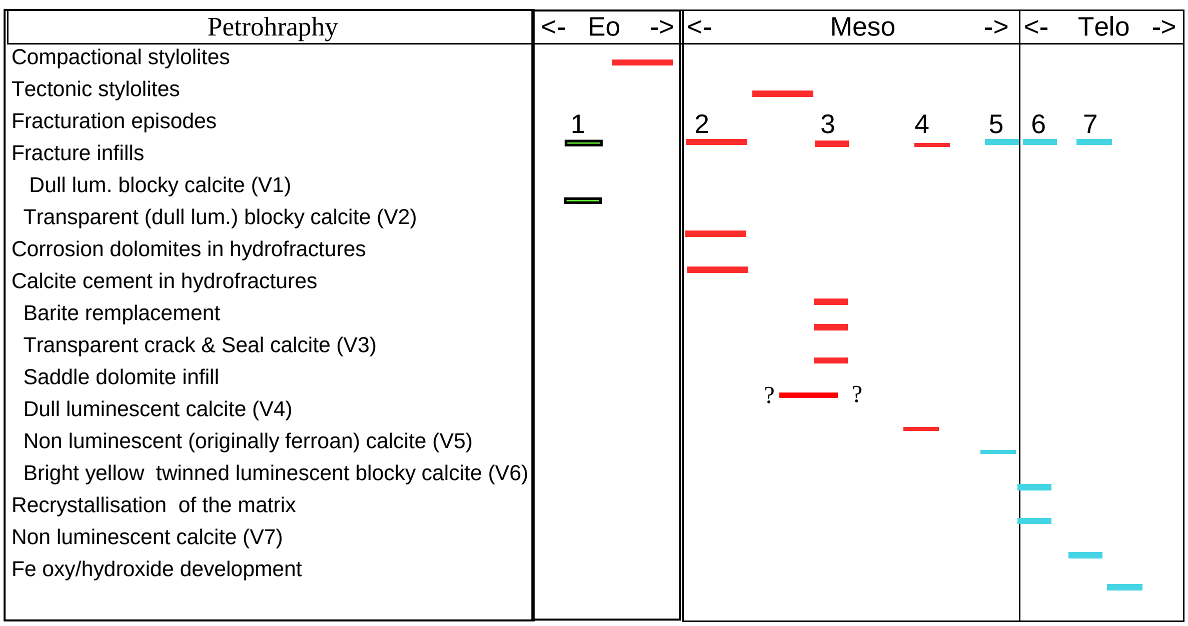

Fig. 2: Fracturing succession of the Chorgali Formation in the Chorgali Pass section.

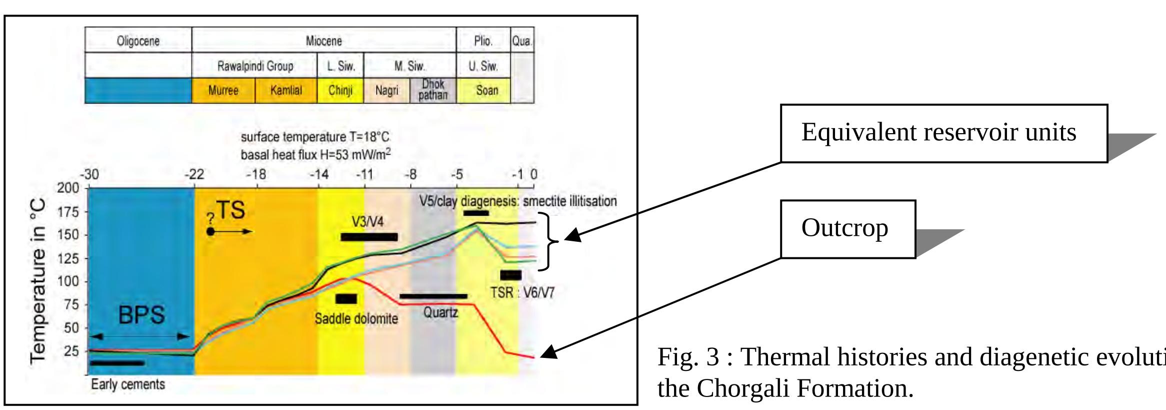

Fig. 3 : Thermal histories and diagenetic evolution of the Chorgali Formation.

Reservoir controls

Porosity in limestones and dolomites is generally low. Only in the coarser sucrosic dolomites some intracrystalline porosity is of potential interest. However, if evaporite dissolution collapse breccias occur, with dissolved fragments, matrix porosity can be locally enhanced. Porosity in the lacustrine limestones and the Fateh Jang conglomerates is also negligible. One should also be aware that if semi-continuous evaporite beds or shale intercalations occur, like it is the case in the Dakhni field, both lithologies will compartmentalise the reservoir. The development of a paleosol/paleokarst system at the top of the Chorgali Formation, as exposed in the Chorgali Pass outcrop, does not improve porosity. Because coeval vug porosity became rapidly calcite cemented, and because also the neomorphism of the underlying marine limestones most likely also obliterated matrix porosity. The Eocene reservoirs are generally considered as fractured reservoirs, whereby the best producing levels are situated at the top of the Chorgali Formation. Indeed, the highest fracture density was observed just below the Kuldana seal in the Chorgali outcrop. Here, most fractures are cemented, however, if reactivated they could form, together with the tectonic stylolites, ideal fluid flow pathways. In fact the question arises whether a relation exists between the intense degree of fracturation and the poor core recovery recognised in different fields. Indeed the few preserved cores in the Dakhni boreholes all were intensively fractured, except in Dakhni 6 where the fragments seem to have been glued together by stratiform anhydrite layers of sedimentary origin, and by vein filling anhydrite. The latter type of vein fill, which also occurs in stylolites, clearly exerts a major negative influence upon reservoir permeability. But anyhow, the contact between the karstified Chorgali carbonates and overlying Kuldana seal and the Fateh Jang conglomerates form an important lihological boundary along which fractures easily developed.

Noteworthy is also the development of secondary porosity along stylolites. In the Turkwal borehole, it was linked, to leaching by acidic fluids derived from the maturation of hydrocarbons. It is also likely that such dissolution process enlarged fracture porosity at this stage.

Acknowledgment

This research was supported by the SUBTRAP-II consortium, the ANRT (Association Nationale de la Recherche Technique) and the Oil and Gas Development Company. We gratefully acknowledge Tariq Majid Jaswal, Shahzad Ahmed Khan and Javed Malik for generously sharing their knowledge. Asghar Ali is acknowledged for facilitating study of core material and well cuttings in the core house. We want also thank William Sassi, Institut Français de Pétrole, for helpful comments on the structural interpretation.

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