Effect of Igneous Intrusions on the Reservoir Properties of Carbonate Rocks in the Peshawar Basin and its Surroundings, Khyber Pakhtunkhwa, Pakistan: Comparing Conventional and Nouvel Techniques

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Abstract

It was in general consensus that igneous bodies mostly occlude the open spaces when in contact with carbonate rocks. Fluid-rock interaction phenomenon was least studied as hot magmatic fluids (hydrothermal) alter the composition of the host limestone in contact. Such mineralogical modifications result in the enhancement of pore spaces and vice-versa. Present studies focus on the detailed investigations using porosity/permeability plug analyses, scanning electron microscopy (SEM) and computed tomography (CT) of the carbonate rocks affected by igneous intrusions. Surface analogues include excellent exposures in the Khyber Agency (FATA) and near Burawai village in the Kaghan valley. In the Khyber Agency (FATA), these outcrops of Khyber Limestone (Devonian) have NE-SW extension from Kali Shilman to Bara Fort respectively. Second studied section in the Kaghan valley consisted of carbonate successions of Kaghan group, which contained fracture-controlled igneous intrusions.

Field relationship, petrographic studies and geochemical analyses helped in understanding the paragenetic history of the carbonate rocks and their relationship to igneous intrusions. In the two studied locations, field observations revealed 10's of meter thick numerous mafic intrusions in the host limestone. Due to these igneous intrusions (dolerite dykes), host limestone is altered into dolomite and marble in the study area. Due to these igneous intrusions, contact metamorphism resulted in coarse crystalline marble. Cross-cutting relationship showed that dolomitization occurred after the emplacement of igneous intrusion in the host limestone. Petrographic studies revealed alteration of host limestone, which resulted in diagenetic alteration (i.e., dolomite formation) and metamorphism (marble). Cataclastic deformation resulted in brecciation of host limestone as well. Fractures and faults provided pathways to the hydrothermal fluids, which resulted in above mentioned alteration. It is also observed that marble resulted from contact metamorphism acted as barrier for dolomitising fluids to alter host limestone. Stable isotope analyses showed depleted $\delta^{18}O$ values (-15.56 to -09.41‰ V-PDB), which shows high temperature fluids for dolomitisation (i.e., igneous origin).

Carbonate rocks affected by igneous intrusions showed mineralogical alteration which resulted in either enhancement in porosity/permeability (due to dolomite) or reduction in porosity/permeability (due to marble). Air porosity and klinkenberg permeability of dolomite showed considerably higher values (8 to 12% and 4 to 10mD respectively). Besides this, marble showed negligible porosity (1 to 3%) and permeability (< 1mD) values. Fracture porosity mostly contributed in the porosity enhancement of these carbonate successions (8 to 15%). Besides this, cataclastic deformation due to dolerite intrusions resulted in brecciation. This phenomenon also resulted in porosity enhancement (5 to 12%).

Late stage calcite precipitation resulted in occludation of porosity and permeability. SEM studies revealed dolomite and marble crystals development due to interaction of magmatic bodies. Besides this, pore space development mostly resulted from dolomite formation whereas marble resulted in the filling of porosity. Computed Tomography (CT) also confirmed porosity results obtained from previously used techniques. Besides this, zonations of various mineralogical compositions revealed that hot magmatic fluids with diverse chemical composition affected the host limestone and resulted in diverse rock types (i.e., dolostone, marble, anhydrite etc.).

In conclusion, fluid-rock interaction due to igneous intrusions resulted in the mineralogical substitution of the host limestone and resulted in the formation of various rock types and cataclastic deformation. Such alteration due to igneous intrusions showed positive impact on the reservoir behaviour of the carbonate succession by increasing its porosity/permeability. Besides this, lesser negative effect on reservoir properties due to marble formation is also evident.

Keywords: Fluid-rock interaction, Igneous intrusions, Dolomite, SEM, Computed tomography, Reservoir properties.