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Porosity and permeability evolution of vesicular basalt reservoirs with increasing depth: constraints from the Big Island of Hawai'i

John Millett (1,2), Eric Haskins (3), Donald Thomas (3), Dougal Jerram (4,5), Sverre Planke (1,5), Dave Healy (2), Jochem Kück (6), Lucas Rossetti (2), Natalie Farrell (2), and Simona Pierdominici (6)

(1) VBPR AS, Banff, United Kingdom (john.millett@vbpr.no), (2) Department of Geology & Petroleum Geology, University of Aberdeen, U.K. , (3) University of Hawaii, Hawaii Institute of Geophysics, Hawaii, USA, (4) DougalEARTH Ltd., Solihull, UK, (5) CEED, University of Oslo, Norway, (6) OSG at Helmholtz Center Potsdam - GFZ German Research Center for Geosciences, Germany

Volcanic reservoirs are becoming increasingly important in the targeting of petroleum, geothermal and water resources globally. However, key areas of uncertainty in relation to volcanic reservoir properties during burial in different settings remain. In this contribution, we present results from borehole logging and sampling operations within two fully cored c. 1.5 km deep boreholes, PTA2 and KMA1, from the Humu[U+02BB]ula saddle region on the Big Island of Hawai'i. The boreholes were drilled as part of the Humu'ula Groundwater Research Project (HGRP) between 2013-2016 and provide unique insights into the evolution of pore structure with increasing burial in a basaltic dominated lava sequence. The boreholes encounter mixed sequences of 'a'ā, pāhoehoe and transitional lava flows along with subsidiary intrusions and sediments from the shield to post-shield phases of Mauna Kea. Borehole wireline data including sonic, spectral gamma and Televiewer imagery were collected along with density, porosity, permeability and ultrasonic velocity laboratory measurements from core samples. A range of intra-facies were sampled for analysis from various depths within the two boreholes. By comparison with core data, the potential for high resolution Televiewer imaging to reveal spectacular intra-facies features including individual vesicles, vesicle segregations, 'a'ā rubble zones, intrusive contacts, and intricate pāhoehoe lava flow lobe morphologies is demonstrated. High quality core data enables the calibration of Televiewer facies enabling improved interpretation of volcanic reservoir features in the more common exploration scenario where core is absent. Laboratory results record the ability of natural vesicular basalt samples to host very high porosity (>50%) and permeability (>10 darcies) within lava flow top facies which we demonstrate are associated with vesicle coalescence and not micro-fractures. These properties may be maintained to depths of c. 1.5 km in regions of limited alteration and secondary mineralization and, therefore, additional to fractures, may comprise important fluid pathways at depth. Alteration and porosity occlusion by secondary minerals is highly vertically compartmentalized and does not increase systematically with depth, implying a strong but heterogeneous lateral component in the migration and effects of hydrothermal fluids in these systems. The distribution and timing of dyke feeder zones coupled with the scale and spatial distribution of lava flows making up the lava pile form first order influences on the preservation potential of volcanic reservoir properties during burial. Our results demonstrate the complex relationship between the primary hydrogeology of lava flow fields and the resulting effects of hydrothermal fluid circulation on reservoir property evolution with burial.