The injection of CO2 at 'In Salah' (Krechba gas field) in the Algerian Sahara tests the behaviour of the sequestered CO2 in the subsurface. Figures 1 and 2 depict the occurrence of the injected CO2 reservoir in approximately 1350 m depth in 20 m of Carboniferous sandstone. It is overlain by 900 m of Carboniferous mudstone, 700 m of Lower Cretaceous sandstone, an aquifer and 200 m of Middle and Upper Cretaceous mudstone. In a newly drilled observation well water from the aquifer rose to about the middle of the overlying Cretaceous mudstone. When drilling through the Carboniferous mudstone, loss of circulation was frequently encountered in the upper 400 m and lower 200 m of the mudstone, a caprock in oil field terminology, an aquifer in hydrogeological terminology. It is under debate whether the circulation losses were caused by pre-existing fractures or by hydraulic fracturing (Idig & Ringrose, 2009).

The Cretaceous aquifers of the 'Tademait Plateau' belong to the 'Aquifère du Continental Intercalaire' system (Castany, 1982). Traditionally much of the groundwater flow in the Sahara Basin was seen as originating in the Atlas Mountains and shown to underlie the Tademait Plateau partially from northeast to south and partially from northeast to southwest (Ben Dhia, 1991, his Fig.4 and 5). The guiding concept was the conceptual model that groundwater flow would be limited to aquifers themselves and, in this area an aquifer system with an outcrop in the recharge area is a particularity of the Atlas Mountains. In Groundwater Flow Systems theory aquifers at the surface (Figure 3) were shown to be natural recharge areas for deeper aquifers by Freeze & Witherspoon (1967). Tóth (1962) had introduced the concept of Groundwater Flow Systems with recharge and discharge areas whereby the penetration depth can exceed 5 km (Tóth, 2009). In a recharge area the flux of groundwater crosses the groundwater table into surface waters or to the surface for evaporation. In a discharge area the flux of groundwater is directed from the groundwater body into surface waters or to the surface for evaporation.

Unexpectedly the geo-mechanical behaviour and flow direction of the injected CO2 did not follow predictions. Firstly, rises in water level from the aquifer were observed at the surface (Figure 2). Second, the regional extent of these upwelling areas showed that in about 2000 m depth the CO2 migrates down dip and, in a northwestern direction away from the pressure sink of the gas production area which is located up dip of the CO2 injection sites (Fig. 1). Thus, gas reservoir and CO2 injection site are located within the same Carboniferous sandstone of approximately 20 m thickness (Fig. 2).

We thank Alan S. Matheson for making, at the occasion of a 2011 SPE Forum on CO2 sequestration, the primary author and we bring to his attention the following papers:

- "Regional Groundwater Flow in the Tademait Plateau. The Tademait Plateau is a distinctive mountain system in the centre of the Algerian Sahara. It is wedged between the Algeciras basin to the north and west of the Western Sahara and the Liwa, Fijah, and Ubari plateaux to the south and east. The Tademait Plateau is bounded between the main part of the Tademait Plateau and the surrounding lowlands to the SW reach up to 550 metres, with the length of the flow systems exceeding 200 km. The southwestern edge of the Plateau is highlighted by the occurrence of 81 oases (black dots in Figure 4). According to surface topography and thereby the approximate topography of the groundwater table, 53 of these oases are located on the slopes of the Tademait Plateau with additional 36 arranged in the down slope area of the Atlas Mountain system. Oases occur in groundwater discharge areas; hence a rim of discharge areas occurs to the west, southwest, and east of the Tademait Plateau. The geometry of these occurrences and the hydraulic head are suited very well for recharge areas for deeper aquifers by Freeze & Witherspoon (1967). The permeability contrast is 1000.

The encountered flow direction cannot be explained by buoyant flow behaviour as had been expected from the supercritical CO2 fluid with a density of about 0.7 g/m³ in a salt host fluid of a density probably exceeding 1.1 g/m³. The hydrodynamic behaviour of the CO2 can be explained, however, by applying Hubbert's (1940, 1953) force potential model and groundwater flow systems theory (Tóth, 1962, Freeze & Witherspoon, 1967)."

The conceptual model of sustained groundwater recharge in the middle of the Sahara seems to contradict traditional knowledge. For decades the assumption prevailed that, in a desert environment, most of the precipitation would evaporate. In the presence of plants the suction of the root system creates very negative pressures at a depth from 1 to 5 metres (Phillips et al., 2004). This strongly unsaturated zone, permanently maintained by evapotranspiration, prevents significant recharge to the groundwater system, even if large amounts of precipitation infiltrate the soil layers.

Research at the Yucca Mountain (in the Death Valley area of the Western United States) identified soil infiltration rates for soil, plant, and exposure conditions through field studies and mathematical modeling. Depending upon the thickness of soil, plant density, and exposure conditions at the sites, infiltration rates varied from 5 to 10 mm/year to >250 mm/year (Peel et al., 2011). Higher recharge rates occur where soils over fractured bedrock to less than 0.5 m in thickness and in topographic depressions such as ephemeral streams (Phillips et al., 2004). Wilson and Guan (2004) confirm that significant recharge can occur where soils are thin or absent over fractured bedrock.

Characteristically most of the area of Tademait Plateau is without continuous plant cover and much of it seems to have thin soil cover over fractured bedrock leading to the conclusion that much of the precipitation may infiltrate the soil and recharge the groundwater body. In addition, at the Krechba site the water table appears to be less than 100 m below surface while it is up to 500 m below surface at the Yucca Mountains implying active infiltration into the soil and recharge to the groundwater body. The actual infiltration rates in the past maintained the water supply of the oases at the rim of the Tademait Plateau system.

Introduction

Behaviour of sequestered CO2 in the Krechba field

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References

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Tademait Plateau: A regional groundwater recharge area in the centre of the Algerian Sahara

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