Brackish springs in coastal aquifers and the role of calcite dissolution by mixing waters

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CHAPTER 1: THESIS OUTLINE

PhD Thesis
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Chapter 1

Introduction: Thesis outline

This thesis consists of six chapters in addition to this introduction. All chapters are based on published papers or manuscripts in preparation or under review by peer-reviewed journals. The thesis has been structured in two parts. Each part corresponds to one major objective of the thesis:

- Study of (1) the processes that govern brackish springs and (2) the ability to use hydraulic and reactive transport models to simulate the spring response (example of S'Almadrava spring, Mallorca, Spain), and
- quantification of the geochemical processes driven by mixing fresh and sea water in carbonate coastal aquifers.

Part I (chapters 2, 3 and 4) addresses the first objective. Brackish springs are frequent phenomenona in coastal aquifers, essentially consisting of inland or submarine karst outlets discharging waters with flow-dependent salinity. The phenomenon is particularly surprising at inland springs, where high flow rates may discharge with significant salinities (presumably coming from the sea) at elevations of several meters above sea level. The equations governing turbulent flow for density-dependent fluids are derived in Chapter 2 and describe salinization of inland brackish springs connected to the sea through an open conduit or a diffusive seawater intrusion from the porous/fissured matrix. The equations are solved using an iterative algorithm and the main parameters controlling the spring response are obtained. Results are interpreted in terms of energy balance at the conduit branching, mixing ratio of fresh and seawater, and relationship of spring discharge and concentration. Results are compared with field observations from several brackish springs.

Subsequently, we study a particular brackish spring, S'Almadrava spring (Mallorca, Spain). We propose a simple hydraulic conceptual model based on a conduit network that is consistent with the particular hydrogeological features of the spring (Chapter 3). This conceptual model is tested through numerical modelling simulations that reproduced concentration observations during the year 1996. A more complex conceptual model is proposed to explain minor features of the spring response. This model involves the existence of flow through a dual permeability system, with a fast flow component in open karst conduits and low flow component in the fissured matrix.

The validation of complex models for brackish springs based exclusively on salinity measurements is not easy owing to the uncertainties of geology, porosity distribution and water-rock interactions occurring at depth. In Chapter 4 we propose the use of geochemical data to validate the complex hydraulic conceptual model proposed for S'Almadrava spring in Chapter 3. A high frequency sampling campaign is performed at S'Almadrava, and the chemical data obtained are analyzed by means of reactive transport modelling. Field data reveal the complexity of the system at depth and allow us to gain insight into its functioning in order to further validate the proposed model.

Part II (chapters 5 and 6) of the thesis is devoted to the second major objective. Calcite dissolution by mixing has long been assumed to be one of the key factors controlling porosity development in coastal aquifers affected by seawater intrusion. However, neither field observations nor laboratory experiments are unequivocal. In this regard, we perform laboratory flow-through CO_2-cotrolled atmosphere experiments to test the dependence on the mixing ratio under different conditions.and the role that small variations of CO_2 may play in enhancing dissolution rates (Chapter 5). The agreement of calcite saturation and potential calcite dissolution of the mixtures is also studied. The impact on calcite dissolution on large scale porosity generation and groundwater circulation can only be understood over a geological time scale.

Patterns of porosity development in the mixing zone are simulated over geological time scales in chapter 6. We analyse the effect of the two-step method simplifications on dissolution predictions, and compare results with fully coupled reactive transport simulations in 1D and 2D. They shed some light on the processes controlling dissolution and highlight the importance of dispersion on the extent and location of dissolution.

Chapter 7 summarizes the main contributions of this thesis.