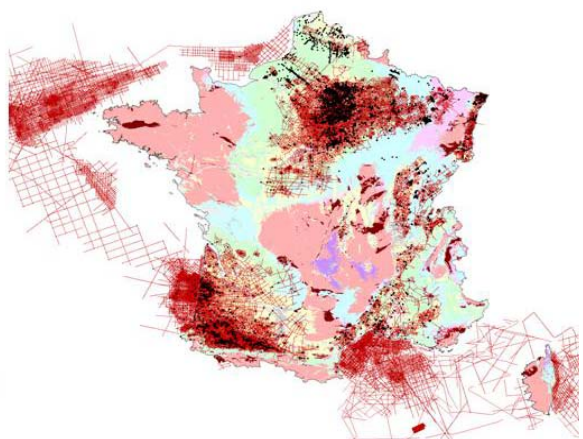
GEOLOGICAL AND PETROPHYSICAL 3D MODELLING OF SEDIMENTARY BASINS FOR GROUNDWATER APPLICATIONS, BRGM

Sunseаré Gabalda Christophe Rigollet, Olivier Serrano, Pascal Audigane, Christophe Chiaberge, Gabriel Courrioux, and Catherine Truffert,
BRGM, France, s.gabalda@brgm.fr,

1. INTRODUCTION

During the past 50 years the Bureau de Recherche Géologiques et Minières, (BRGM) has collected a large amount of diverse data during projects for water and hydrocarbons exploration and underground storage investigations (methane, nuclear-waste, etc.). Societal and environmental issues have had a significant influence on research applied to groundwater exploration and characterization. During this period, methodological improvements have allowed the investigation of new targets, such as deep reservoirs and aquifers that have delineated new geothermal targets, alternative water resources and potential CO_2 storage sites. Most of this data comes from sedimentary basins (Figures 1 & 2) and provides an excellent opportunity for developing new methodologies in deep geology 3D reconstruction.



Figures 1 & 2: Fig 1 (left): Geographic location of France's three main sedimentary basins, i.e. the Paris Basin, Aquitaine Basin and Southeast Basin. Fig 2 (right): Location of seismic lines (red segments) and deep wells (black points) available for study of France's sedimentary basins.

2. GEOLOGICAL DATA MANAGEMENT AND ENHANCEMENT

BRGM is the unique public organisation in France which is in charge of the management of the large amount of geological data acquired in the field, development of geological maps, and archiving of data from major exploration programs (seismics, deep drilling, airborne geophysics, gravity) in sedimentary basins. For the past two decades BRGM has done extensive work on database management, which is essential for producing integrated geological models.

Since 2006 BRGM has managed 350,000 line km of petroleum industry seismic data and the 6 000 boreholes collected in sedimentary basins (Figs. 1 & 2). Raw data are accessible to the public via a public "front office" (guichet.H@brgm.fr) and dedicated re-processing is possible on request. Aside from data management and delivery, BRGM has launched a vast data enhancement program. The seismic lines are gradually being reprocessed and interpreted and then assembled to provide regional reference transects. The borehole data set consists of a suite of downhole geophysical logs (e.g. gamma ray, density, and resistivity) and petrophysical logs (e.g. porosity, permeability) that are being systematically digitized, thus enabling stratigraphical and petrophysical calibration of the geological models (Figures 3 & 4). The methodologies are also being implemented internationally for geological syntheses and basin modelling.

Taking advantage of easy access to data and a renewal of activity in the sedimentary basins, BRGM is now in a position to update existing geological syntheses and to produce digital models in support of various applications. Consequently, the geological models must be constructed in a numeric 3D environment compatible with the dynamic software used downstream by hydrogeologists and reservoir engineers. One of the most studied sedimentary basins in France is the Paris basin, which is currently the focus of this data analysis and model construction.

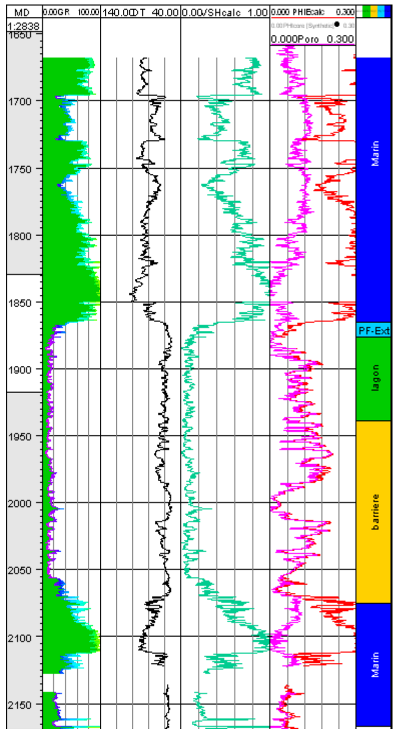


Figure 3: Example of digitized well logs (Dogger aquifer, Paris basin), from the left to the right: Gamma Ray, density, volume of shale in carbonate system (VSH), equivalent porosity (without and with shale effect), facies rocks descriptions

3. UNDERGROUND APPLICATIONS IN PARIS BASIN

Following the 1973 and 1979 oil crises, the development of deep geothermal energy exploded in France between 1980 and 1986. The Dogger carbonate formations of the Paris Basin have been the principal targets for such exploration. Today, in anticipation of a decrease in the thermal potential of the Dogger aquifers, the underlying Triassic aquifers are being studied.

The potable water resources of the shallow aquifers are vulnerable to contamination. It is thus necessary to identify alternative water resources, and thus to explore the deep water reservoirs. Several projects exploring major fracture and/or karst systems in Dogger formations are currently underway in France's three main sedimentary basins. There is also interest in the role of aquifers for underground storage of methane, which has been in constant development since the 1960s, and CO_2. Major French and European research programs have led us to reconsider the principal deep reservoirs of each basin in order to study storage capacities on a regional scale (unlike the storage of methane, localized on anticlinal structures).

4. GEOLOGICAL AND PETROPHYSICAL MODEL PRODUCTION: OUR INTEGRATED METHODOLOGY

The models constructed to date for groundwater applications postulated model layers consisting of homogeneous geological formations. The challenge currently is to model the reservoir heterogeneity so that the 3D models are more geologically realistic. This is an enormous challenge because the characteristics of the geological formations of the reservoir (porosity, permeability) vary greatly from place to place in the sedimentary basin.

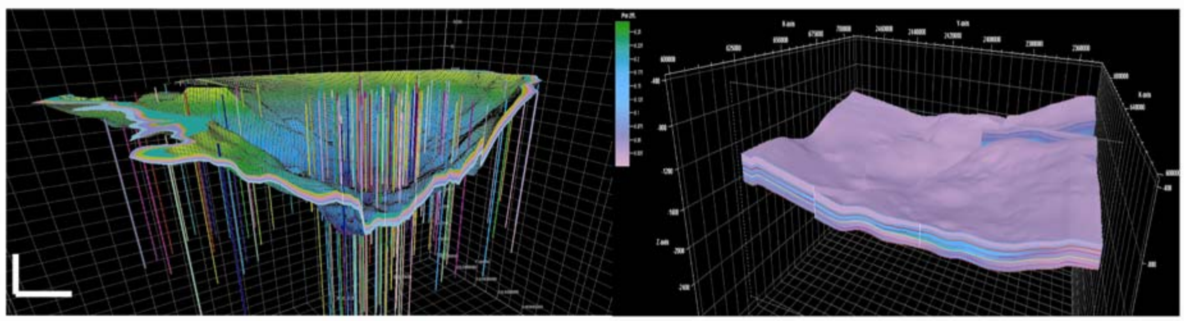


Figure 4: 3D gridded geological and petrophysical models (with Petrel®). On the left: surface and boreholes from geological model of the Paris basin (LogIso project, Author: S.Gabalda). On the right: regional model of the Dogger aquifer (ANR-SHPCO2, Author: S.Gabalda, Geology division, BRGM).)

To build these models, we relied on a methodology developed by petroleum engineers, working at oilfield's scale (a few square kilometers). We have transposed the same approach to a regional and basin system scale (several hundred square kilometers, Figure 4). Models are constructed by integration of deep data (seismic lines and boreholes) and geological map data (limits on geological outcrops) that are then interpreted within a sequence stratigraphic framework (i.e. subdivision of the sedimentary pile into layers bounded by isochronous surfaces) and depositional facies models. Based on this approach we are then able to produce paleogeographic maps and 3D digital models suitable for geodynamic reconstruction of the basins. Prediction of favourable zones for the exploitation of target formations is evaluated by petrophysical modelling. For each type data analysis of boreholes (logs and core data) is completed. These petrophysical data are then interpolated and simulated in the geological model using geostatistical tools.

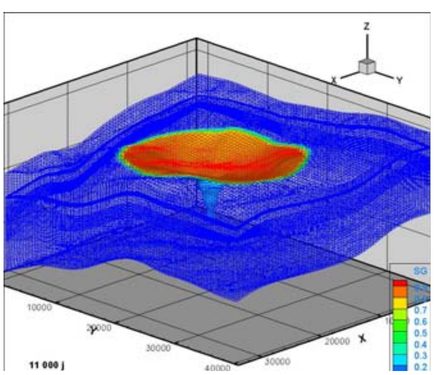


Figure 5: Simulation of CO_2 injection (with Tough 2) into the Dogger aquifer (Paris basin, ANR-SHPCO2, Author: C. Chiaberge, Water division, BRGM).

The large scale models allow delineation of areas within sedimentary basins that are potentially suitable for CO2 storage or e xploitation of geo thermal resources. For zones of interest in the aq uifer more detailed models can be constructed by upscalling of the pr eliminary models. In the example below (Figure 4), we produced a gridded 3D geological model at the bas in scale, that here highlights the petrophysical properties (Figure 4). After potential ar eas for CO_2 storage are identified, a regional model is built (downscaling). Both sca les of mo dels allow dynamic simulations of flow and injection of CO_2, and permit assessment of the impact of the respective fluid on the reservoir with time. Finally, these methodological results are now transferable to other aquifers in the Paris Basin and to others sedimentary basins in France (ie. the Aquitaine basin, South East Basin or, the Upper Rhine Valley, Figure1).

5. ON-GOING CHALLENGES: COMPATIBILITY BETWEEN GEOMODELLING AND SIMULATION SOFTWARES

Due to the diversity of the geology of France and variety of sedimentary basins, we made the choice of using several different software options. This reflects the fact that no software possesses all the required facilities for 3D geological modelling and simulation. Consequently, we take advantage of the complementary software features in commercial software (ISATIS®, Earth Vision®, PETREL®, etc.) and in-house software (GDM Multilayer, Geomodeller 3D, etc.). One or the other is chosen on the basis of the complexity of geology being modelled and the aim of the 3D modelling. For example, Petrel® (©Schlumberger) software is mainly used for 3D gridded models of sedimentary basin and subsequent flow simulations with Eclipse or Tough. More complex geology, such as the margin of basins within the deformation front of of orogenic belts (i.e. non-tabular structures, folds, diapirs, etc) are modelled using Geomodeller 3D (in house software, see an example in Figure 6).

One of our research objectives is to improve compatibility between geomodelling and simulation software (see Figure 7). The workflow integrating multiple software options and facilitating data transfer between one another, and successive projects, needs to be as fluent as possible. Major challenges are faced with model compatibility between software formats and in maintaining the timely delivery of results. Models need to be as complete as possible (geometry, petrophysical information, etc.) and their integrity has to be preserved between software options.

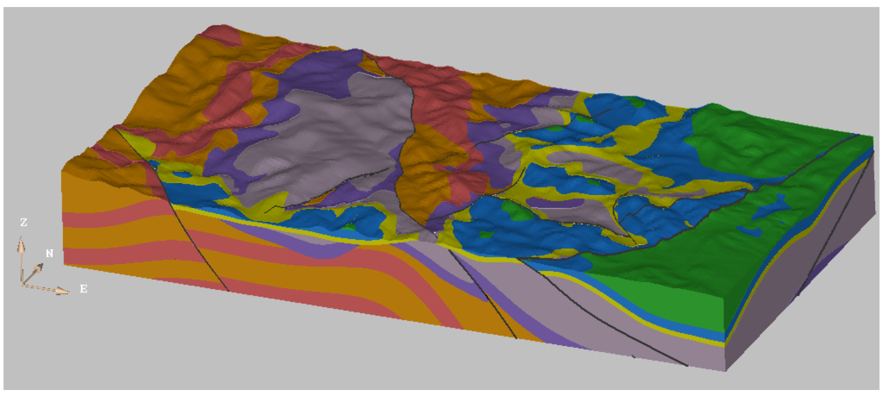


Figure 6: Example of complex geological features in a groundwater study area (with Geomodeller, Author: G. Courrioux, Geology division, BRGM)

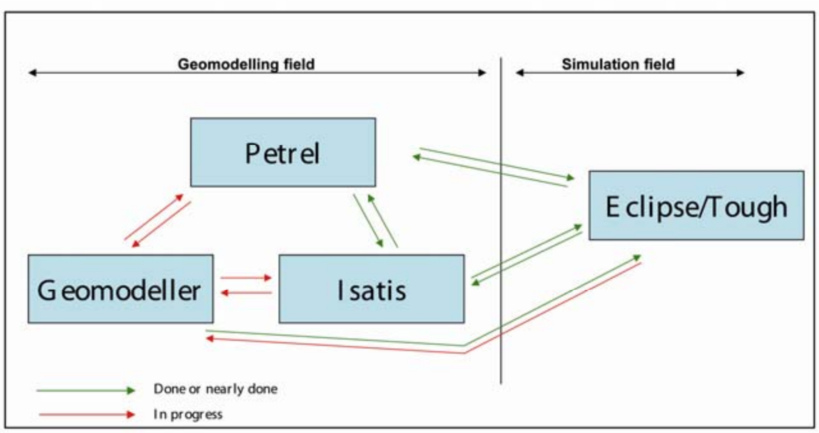


Figure 7: Links between software improvement at BRGM, Geomodeller (©Brgm-Intrepid): models at large scale with few data, Petrel (©Schlumberger): reservoir characterization, Isatis (©Geovariance): complex geostatistics, Eclipse / Tough2 / ToughReact: to compute simulation.