ArchPy : Semi-automated hierarchical modeling of Quaternary aquifers

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Motivation

- Quaternary formations : complex and hierarchical relations
- Need a automated workflow
- Stochastic models for uncertainty
- Inequality data must be taken into account

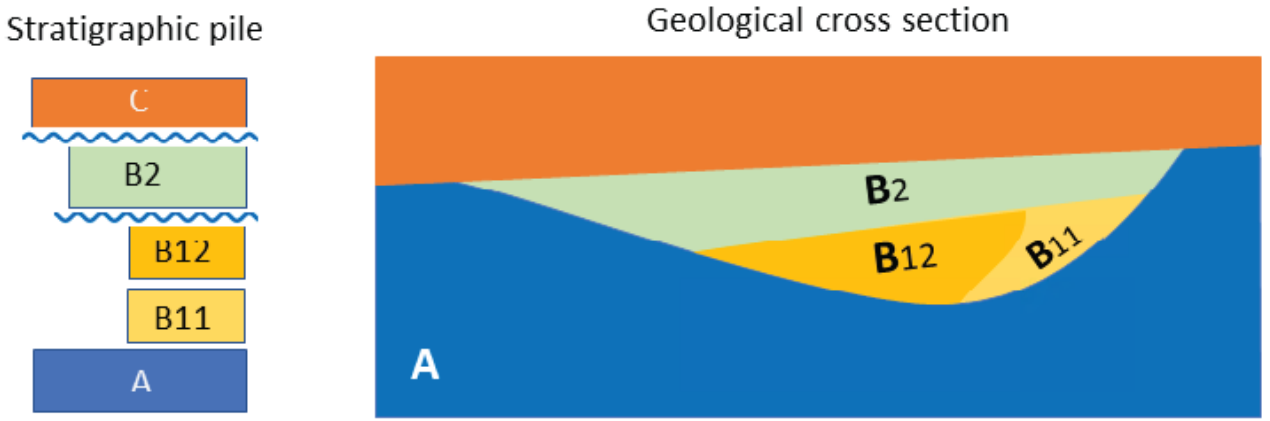
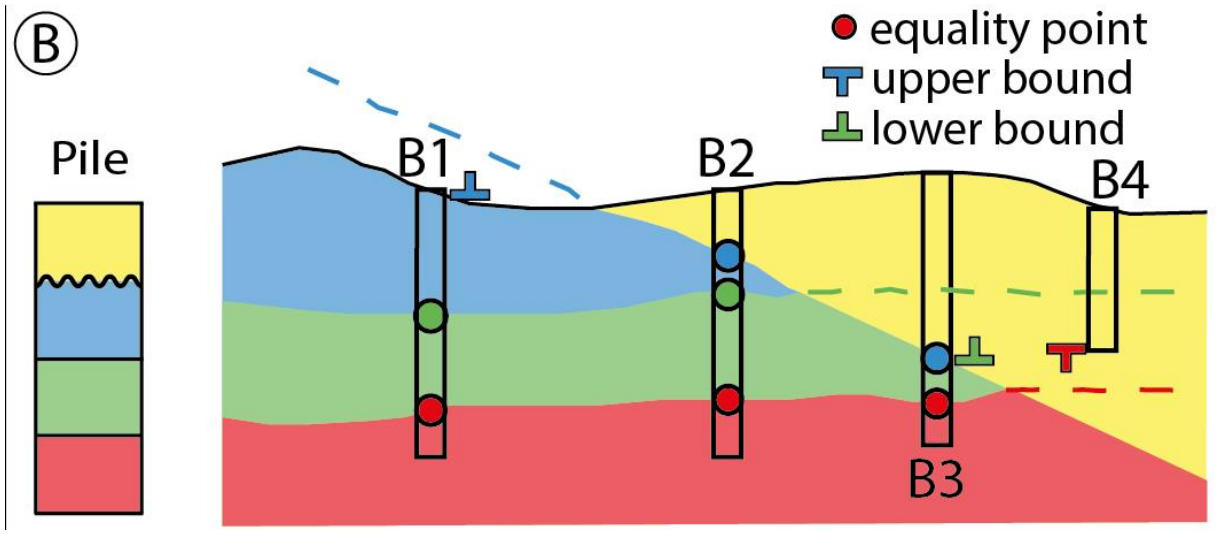
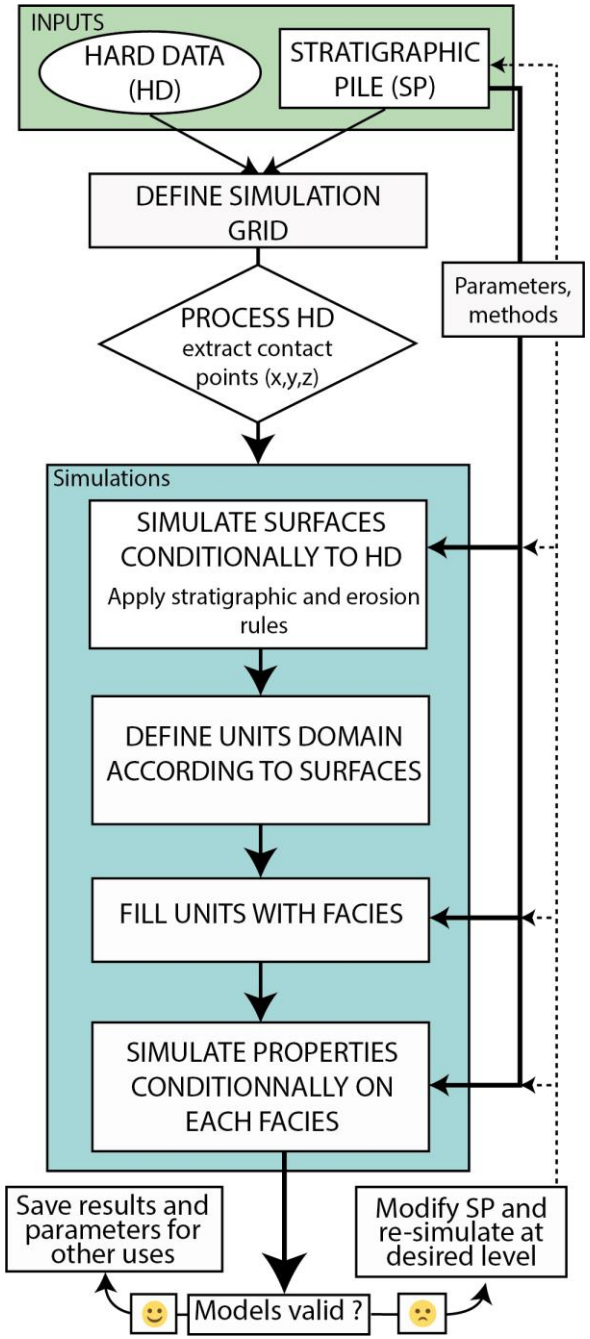


Figure 1 : Schematic representation of hirearchical relations. Erosion horizon are marked by the blue sinusoidal line on the pile.

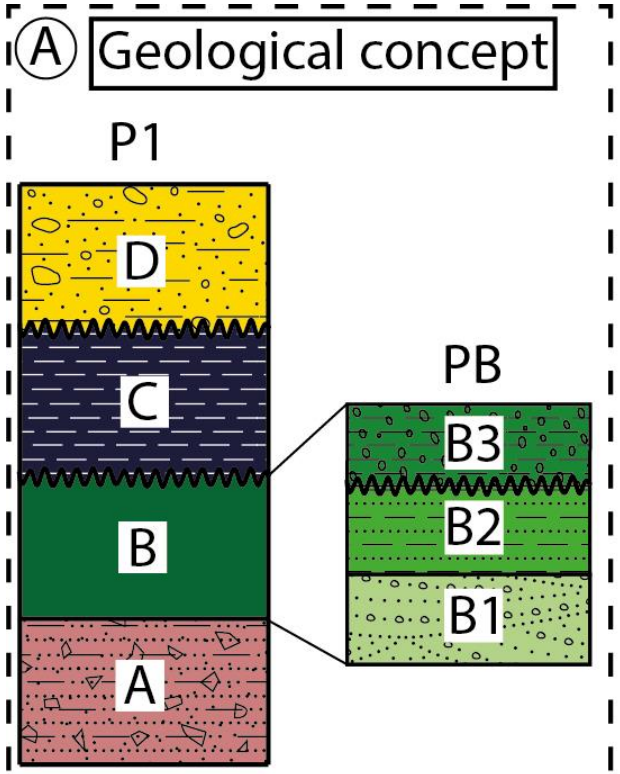


ArchPy : Hierarchical procedure

- Need to define a Stratigraphic Pile that contains all the methods and associated parameters
- Hierarchical simulation:
  - Units
    - Surface interpolation (Kriging, Gaussian Random Functions (GRF), Multiple Points Statistics (MPS), …)
    - Hierarchical simulation of the units available
  - Facies
    - Filling methods (Sequential Indicator Simulations (SIS), MPS, Truncated Plurigaussians (TPGs), etc.)
  - Properties



Stratigraphic Pile



B ArchPy Stratigraphic Pile

Unit	interp method	contact	filling method	list facies
D	DEM	-	MPS	gravel, silt, sand, clay
C	GRF	erode	TPGs	clay, silt
B	GRF	erode	SubPile PB	-
A	GRF	onlap	SIS	gravel, silt

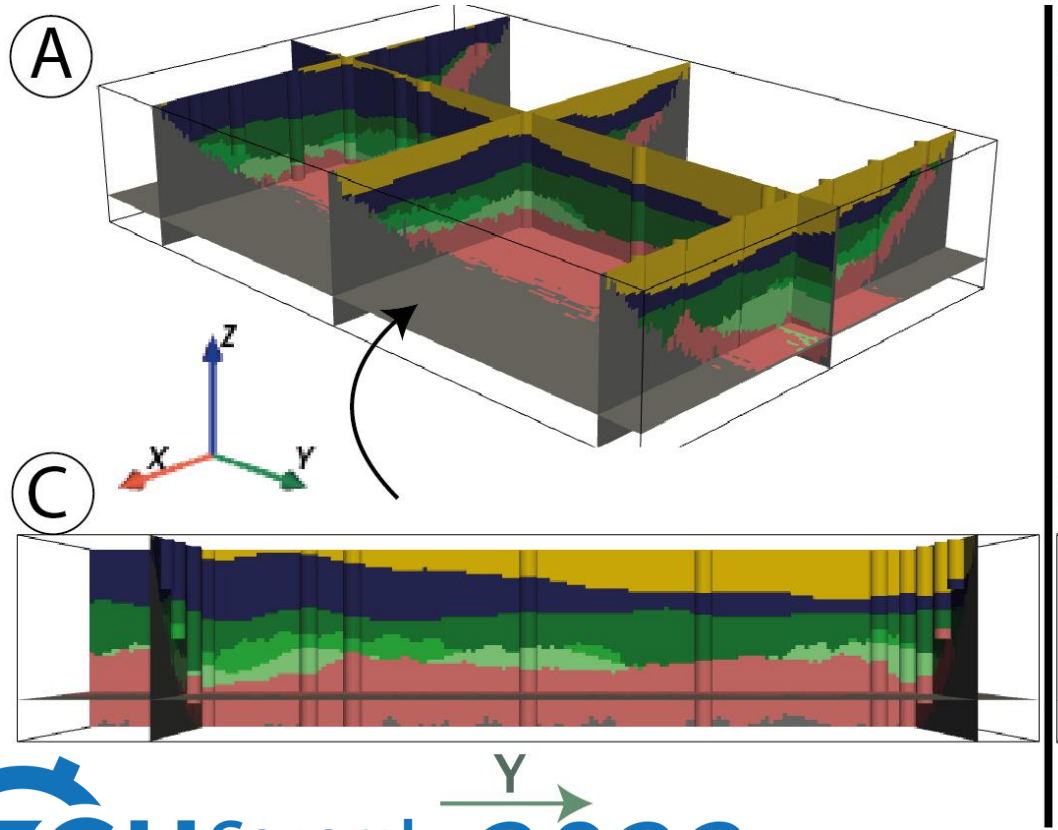
Unit	interp method	contact	filling method	list facies
B3	B top	-	MPS	gravel, clay
B2	GRF	erode	SIS	sand, silt
B1	GRF	onlap	SIS	gravel, sand

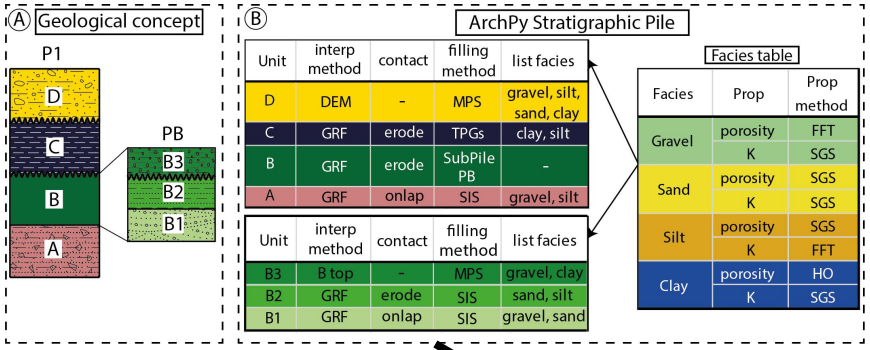
Facies table

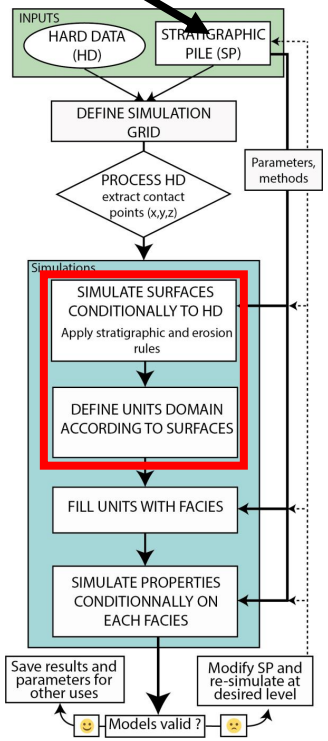
Facies	Prop	Prop method
Gravel	porosity	FFT
	K	SGS
Sand	porosity	SGS
	K	SGS
Silt	porosity	SGS
	K	FFT
Clay	porosity	HO
	K	SGS

Surfaces and units domains

- Results with exemple SP

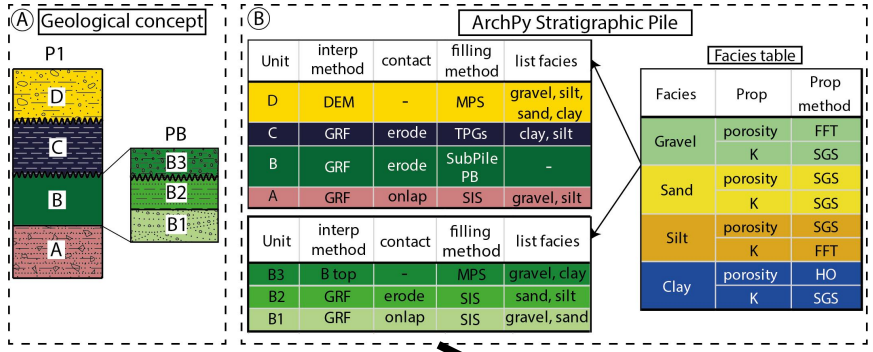


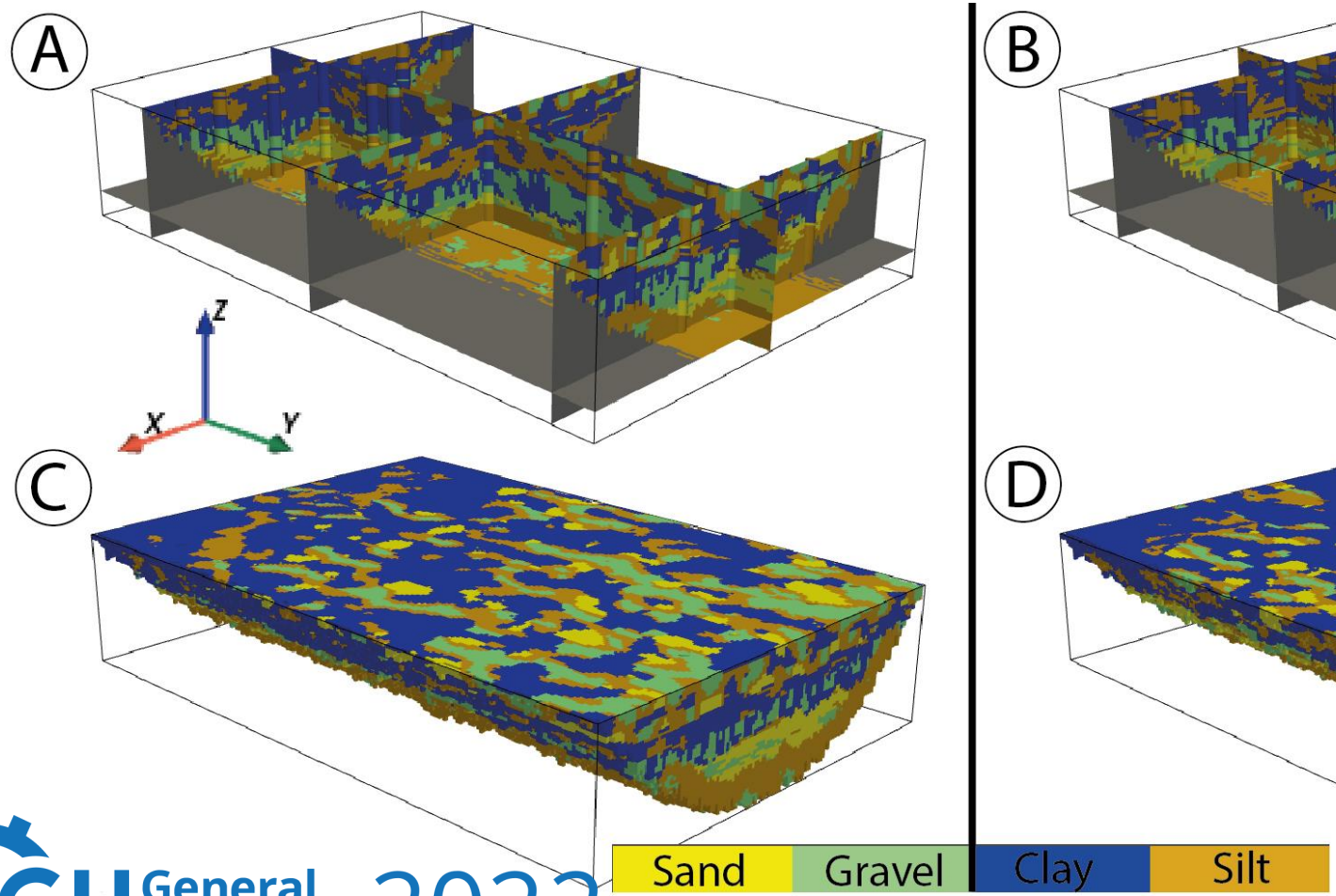


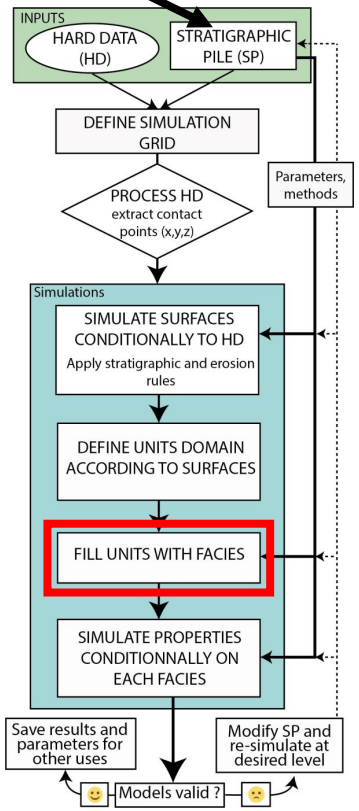


Litho-facies

- Results with example SP

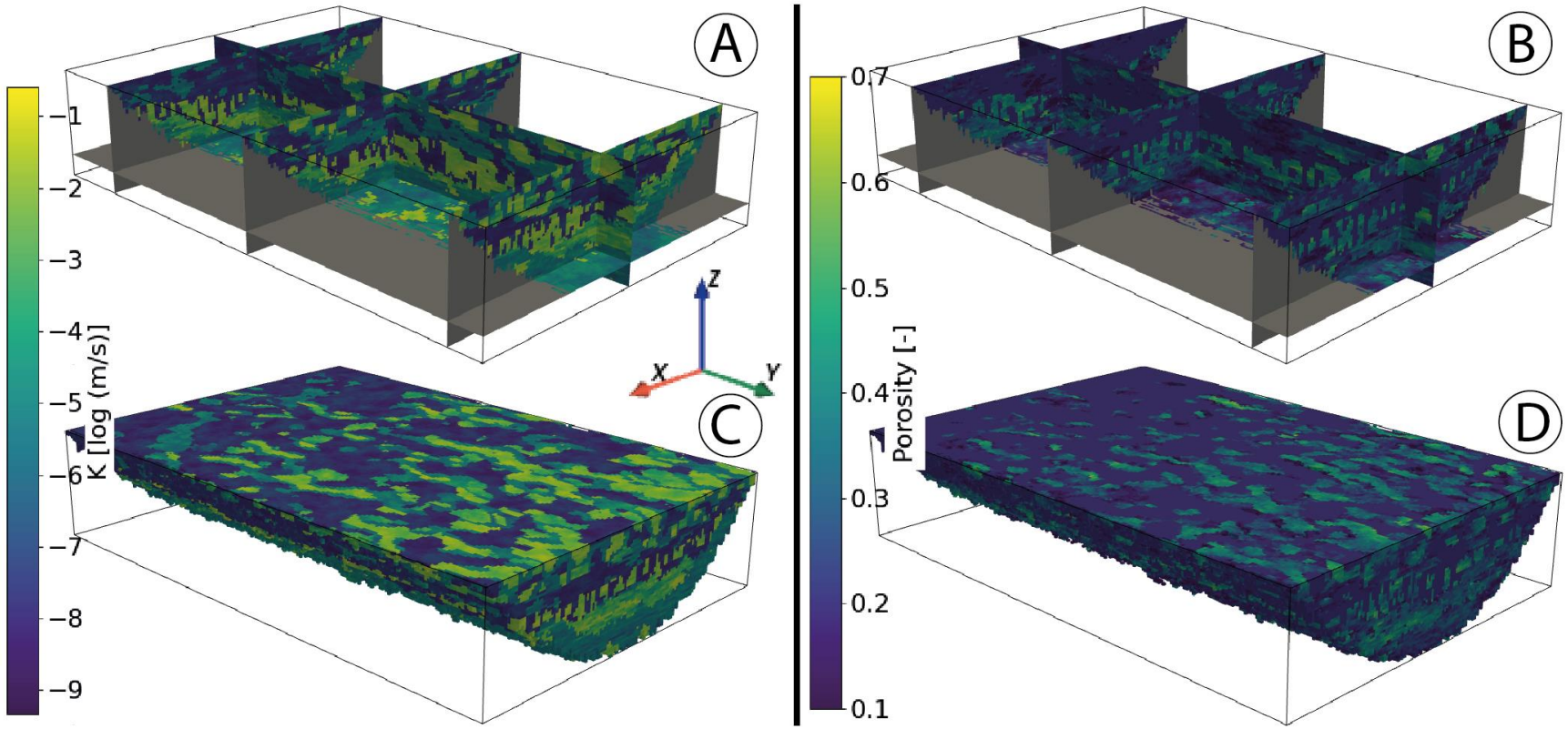


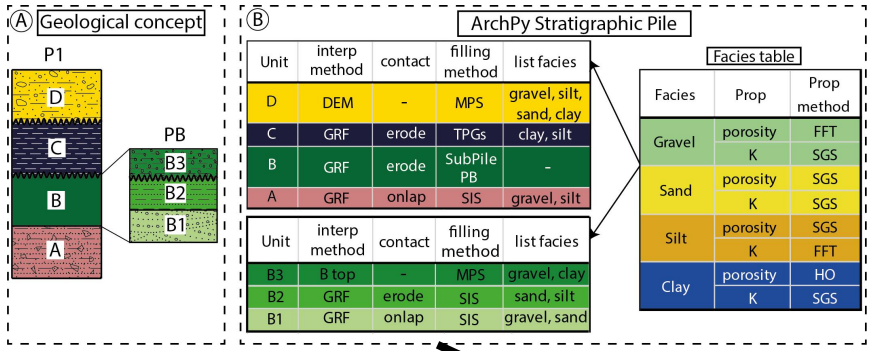


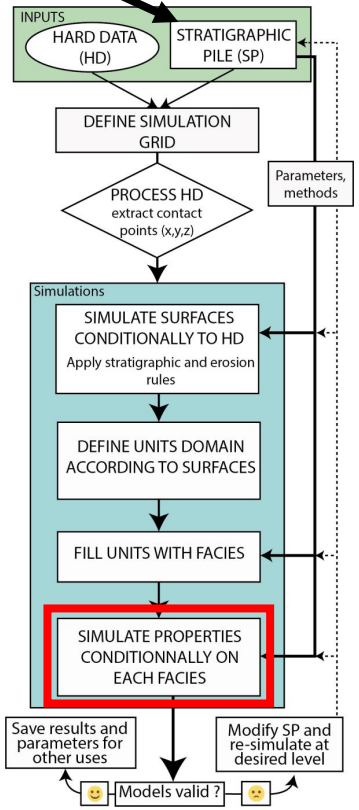


Properties

- Final results with example SP

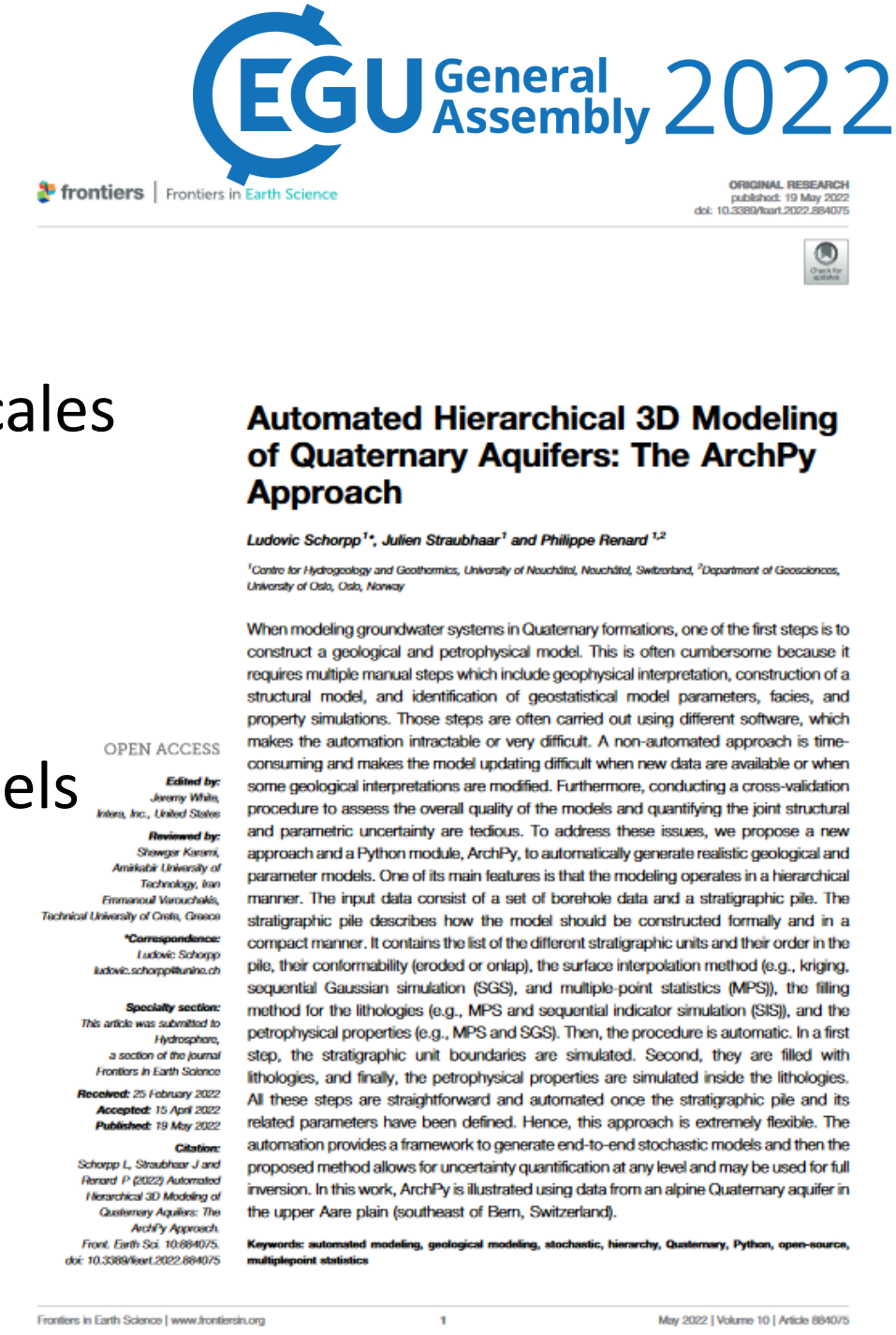






Conclusion

- ArchPy is both an approach and a tool for modeling Quaternary geology at different scales
- Flexible, versatile, and reproducible
- Can produce easily many models with little inputs
- Outputs can serve as inputs to forward models (Hydrogeological, geophysical, …)
- It is open-source and freely available (still actively in development):
  - Github : https://github.com/randlab/ArchPy
- DOI : 10.3389/feart.2022.884075



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Automated Hierarchical 3D Modeling of Quaternary Aquifers: The ArchPy Approach

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When modeling groundwater systems in Quaternary formations, one of the first steps is to construct a geological and petrophysical model. This is often cumbersome because it requires multiple manual steps which include geophysical interpretation, construction of a structural model, and identification of geostatistical model parameters, facies, and property simulations. Those steps are often carried out using different software, which makes the automation intractable or very difficult. A non-automated approach is time-consuming and makes the model updating difficult when new data are available or when some geological interpretations are modified. Furthermore, conducting a cross-validation procedure to assess the overall quality of the models and quantifying the joint structural and parametric uncertainty are tedious. To address these issues, we propose a new approach and a Python module, ArchPy, to automatically generate realistic geological and parameter models. One of its main features is that the modeling operates in a hierarchical manner. The input data consist of a set of borehole data and a stratigraphic pile. The stratigraphic pile describes how the model should be constructed formally and in a compact manner. It contains the list of the different stratigraphic units and their order in the pile, their conformability (eroded or onlap), the surface interpolation method (e.g., kriging, sequential Gaussian simulation (SGS), and multiple-point statistics (MPS)), the filling method for the lithologies (e.g., MPS and sequential indicator simulation (SIS)), and the petrophysical properties (e.g., MPS and SGS). Then, the procedure is automatic. In a first step, the stratigraphic unit boundaries are simulated. Second, they are filled with lithologies, and finally, the petrophysical properties are simulated inside the lithologies. All these steps are straightforward and automated once the stratigraphic pile and its related parameters have been defined. Hence, this approach is extremely flexible. The automation provides a framework to generate end-to-end stochastic models and then the proposed method allows for uncertainty quantification at any level and may be used for full inversion. In this work, ArchPy is illustrated using data from an alpine Quaternary aquifer in the upper Aare plain (southeast of Bern, Switzerland).

Keywords: automated modeling, geological modeling, stochastic, hierarchy, Quaternary, Python, open-source, multiplepoint statistics

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Thank you !

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