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Framework for multiple hypothesis testing improves the use of legacy data in structural geological modeling

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ABSTRACT

Geological models, as structural representations of the subsurface, are increasingly used for regional scale geological analyses and research studies. In this context, it is often essential to use geological legacy data, for example in the form of printed well logs, seismic sections, or maps and interpreted cross-sections from previous reports. A problem when using this type of data is that standard modeling methods and workflows are optimized towards applications in hydrocarbon and mineral exploration where data are usually newly acquired and of a high quality. Although recent developments address the modeling side for regional models with novel concepts and ideas, the possibility to change the workflow on a conceptual level has, to date, not been addressed.

We examine here how we can use legacy data more efficiently and sustainably, in a model construction workflow that leaves the typical sequential path of model development. In the common approach, a single best-fit model is continuously updated or refined when additional data become available. We test here the application of a parallel type of model construction where multiple models can be generated on the basis of different input data sets. Geological data and models are strictly separated, and this allows us to (a) use geological models to test quickly the spatial consistency of different geological data sets, and (b) to allow for an approach where we finally obtain multiple geological models as different hypotheses about the subsurface structural setting. Both aspects are especially important for the application of legacy data, as the data quality is always difficult to assess.

The concept is applied to a geological model project of the Perth Basin, Australia, where we show how it enables us to quickly revise and update the (previously constructed) model with additional data (e.g. newly available digitized legacy data), to evaluate the spatial consistency between different legacy data sets and interpretations, and to test different hypotheses. In our point of view, this is an important aspect towards a sustainable approach for geological modeling as it allows a very flexible and transparent use of different data sets for model construction – and therefore a more sustainable use of legacy data itself in the increasing use of subsurface representations using 3D geological models.

1. Introduction

Geological models are widely used to represent the setting of main geological structures in the subsurface, and therefore they are often considered the logical extension of a geological map into the third dimension [27]. Methods and workflows to construct these models were, to date, mainly tailored towards applications in hydrocarbon reservoir and mine scale studies where geological data are usually abundant and of high quality [15]. However, geological models are increasingly used in other fields and on different scales, from scientific studies to the general visualization for education and outreach. In addition, geological survey organizations worldwide are adapting 3-D geological models as a standard to visualize and communicate the geological setting of entire states and countries [2,27]. Where no new high quality data is available for the model in these types of applications, all available information and data has to be taken into account, including a wide range of geological legacy data.

Based on these requirements, several novel modeling methods have been developed to incorporate multidisciplinary datasets into consistent 3D geological models, and examples are presented and

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discussed in [31,22,32,6,2,15]. Although the development of these methods marks a step change in the process of the model generation itself, the general workflow of model construction has not been revised. The commonly used workflow in geological model construction can be summarized with the following steps: (1) integration of all available geological data in a data base, (2) the definition of a stratigraphy, (3) construction of cross-sections (usually based on geophysical information), (4) interpolation of the data to obtain a full 3-D geological model, and finally (5) validation of the model with additional information (for example through forward calculated gravity response). Detailed examples of this workflow are, for example, presented in [2]. The described workflow follows a logical and sequential path from raw data to final model, schematically represented in Fig. 1a. Usually, the employed methods are flexible enough to revise and extend a model when additional geological data become available (Step 2 in Fig. 1a). This workflow can therefore be understood as an iterative refinement of one geological model that best fits the data and additional geological constraints.

However this approach has several severe limitations if the typical problems of legacy data are considered. Legacy data in the context of geological modeling range from digital or printed geological logs and seismic cross-sections to maps published in reports. These legacy data sets typically contain significant uncertainties and, furthermore, different data sets might be geologically inconsistent. For example, analogue information has to be digitized, quality controlled and assigned with a correct spatial reference. A further special consideration in the case of geological data is that the naming convention for geological formations (defined in the stratigraphy) may have changed over time and then

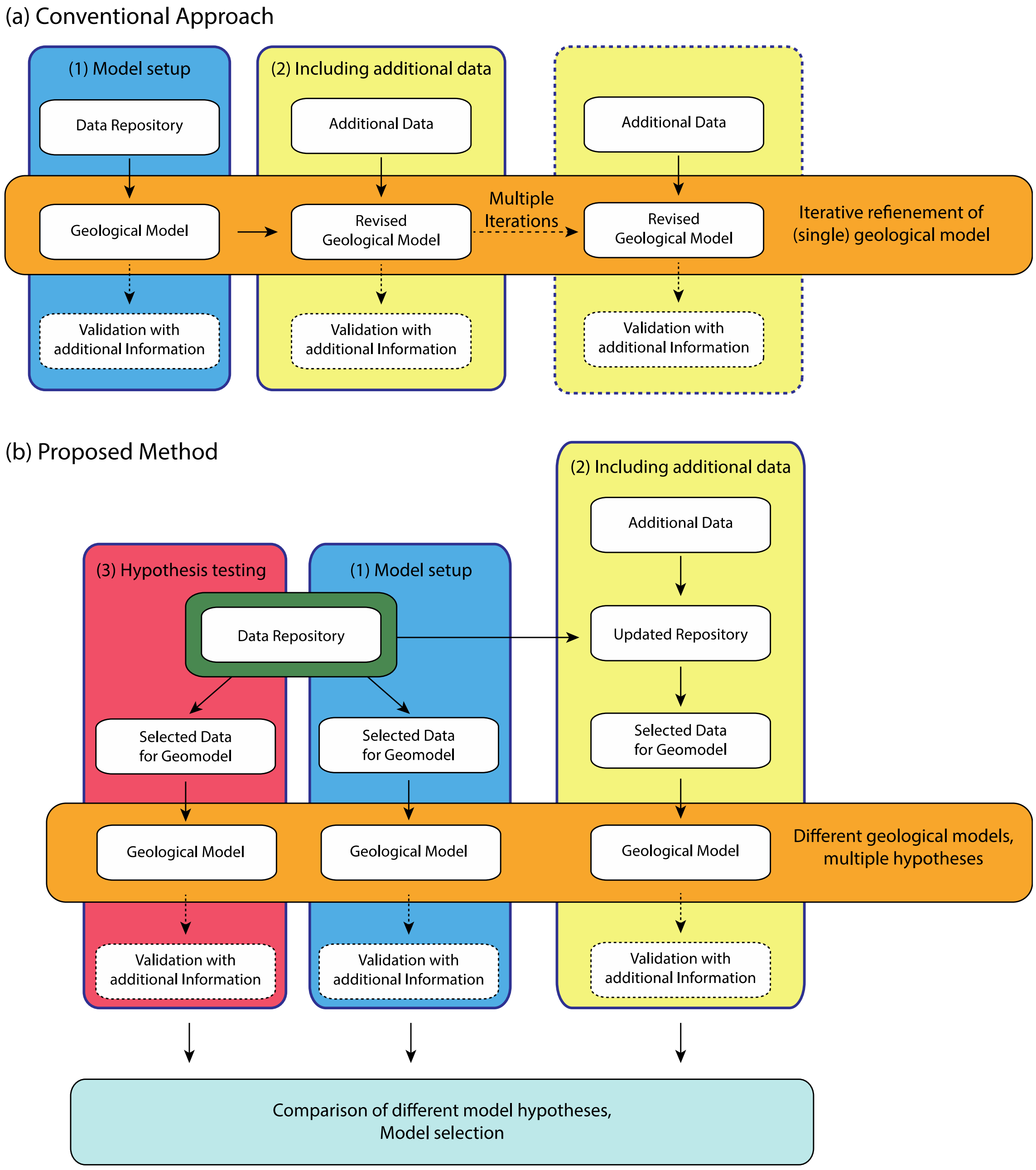

Fig. 1. Comparison of sequential approach to geological model construction based on iterative refinement of a single model with the proposed method of multiple geomodel hypotheses.