A Short Note on Surface-Based Modelling for Integration of Stratigraphic Data in Geostatistical Reservoir Models

YuLong Xie (ylxie@civil.ualberta.ca) and Clayton V. Deutsch (cdeutsch@civil.ualberta.ca)
Department of Civil & Environmental Engineering, University of Alberta

A. S. Cullick (a_stan_cullick@email.mobil.com)
Mobil Technology Company, Dallas, TX

Abstract

Reservoir surfaces reflect changes in the depositional environment. In general, reservoirs consist of a number of sediment packages bounded by time surfaces. Facies and petrophysical properties are more homogenous and predictable within each sediment package. Large scale trends and systematic variations across sediment packages are revealed by the structure of the bounding time surfaces. For these reasons, time surfaces provide very important constraints on the geometrical connectivity and continuity of facies and petrophysical properties in reservoirs. Consideration of time surfaces in reservoir modeling improves the quality of the resulting reservoir models and predictions derived from such models.

This note presents an approach to stochastically model time surfaces. Successive time surfaces are created using the logic of chronological sedimentation. Surfaces are generated with parameterized surface template(s); the shape, dimension, height, orientation and regularity of surfaces are controlled by user-specified distributions. The location of each surface in the reservoir is chosen on the basis of previous events. The addition of volume by the surface is based on sedimentological rules. Local well data, if any, are explicitly honored at the correct depth. A program `surfsim` *for surface-based modeling has been developed. An example based on the geological interpretation of the Wagon Caves outcrop in California is presented.*

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Introduction

Reservoirs were formed by a succession of deposition and erosion events. Over long time periods major changes in accumulation/erosion result in large changes to the sediment distribution. During large-scale changes, there are also more frequent events (e.g., the rising and falling of sea level), which result in cyclical features superimposed on the large-scale architecture of the reservoir. A reservoir consists of several large-scale sediment packages corresponding to big events in ancient geological ages. In a hierarchical way, each large-scale sediment package consists of a number of sediment packages at smaller scales, which reflect depositional events occurring more frequently.

Large-scale time surfaces may be visible with seismic data whereas smaller scale time surfaces, while not visible with seismic data, can be observed from core or well-logs. In general, there are few wells; therefore, smaller scale surfaces cannot be modeled deterministically. The purpose of surface modeling is not to get surfaces *per se*, but to provide constraints for modeling facies and petrophysical properties (Φ/κ). This requires us to know what happens *on* and *inside* the surfaces. Specific facies can be present at surface boundaries. For example, there may be shale on top of a surface, which serves as a barrier to flow; surfaces may control specific grain size/facies trends such as fining/coarsening upward; and "lag deposits" may be present above surface boundaries.

Conventional reservoir modelling makes use of a variety of stochastic simulation methods, including cell-based techniques and object-based approaches. Cell-based techniques are essentially based on the variogram, which is limited in its ability to capture non-linear features. Object-based approaches attempt to follow the rules that govern reservoir architecture; however, they are limited to situations where well-defined geometrical geological objects exist. Our proposal is to extend the set of available techniques by modeling time surfaces first. Then, petrophysical properties can be modeled within the sediment packages. When modeling petrophysical properties within a specific sediment package bounded by surfaces, trends or systematic variations of the petrophysical properties can be considered. The final reservoir model is thus an assemblage of sedimentary packages with bounding surfaces; a complex reservoir model is constructed by a succession of relatively simple models, which are constrained by time surfaces.

The proposed methodology is based on natural sedimentation processes. Reservoirs are built upward by sediment packages bounded by time surfaces. Sediment packages are assumed to be represented by the volume covered by the surface. Parameters defining the dimension, height, orientation, elongation and regularity of the surfaces in the reservoir are stochastically drawn from user-defined distributions. The locations of the successively added surfaces are determined based on the thickness distribution of the reservoir. When local well data are available, the surfaces are constrained to force local well data to be honored. A FORTRN 90 program, `surfsim`, is written for the approach. A data set from Wagon Caves outcrop in California is used to demonstrate the performance of the proposed approach.

Geological/Physical Basis for Surface Modeling

The geological processes that form sediment packages are well described by sequence stratigraphy. Stratigraphic sequences reflect different geological periods (events). Each event has its own time duration, which is determined by the processes controlling the creation and destruction of accommodation space. The time duration of events refers to the time scale of stratigraphic sequences. Sequence stratigraphy can be applied at different scales.

Some general principles exist. Basically, when only deposition processes are considered, (a) time surfaces stack upward just as sediment packages form chronologically; (b) surfaces are quite smooth since the sedimentation happens relatively slowly and abrupt discontinuities are not easily formed; (c) surfaces shapes have upward curvature feature when sediment deposited. The locations where rivers unload their sediment charge receive most of the mass and the sediments cumulates highest, whereas locations in the surrounding area receive less mass and the sediments cumulate less. In an approximate way, surfaces can be described by a shape with largest height in the central location and less thickness in positions further from the center. (d) Surface centers may appear anywhere in the reservoir because sediment packages could start to form at a different position in the reservoirs since the rising and falling of sea level results in the change of locations where rivers unloaded their charges. (e) Natural processes are complex, completely regular surfaces can rarely be present and variability on the surface exists. Understanding the process of sedimentation allows us to model time surfaces in reservoirs by analytical shapes together with an undulation (random perturbation) accounting for irregularities on the surfaces.

Methodology/Surface Parameterization

The reservoir consists of numerous time surfaces that bound sediment packages. Time surfaces are generated with an analytical shape. A simple parametric surface is defined by (1) the central location of the depositional event, (2) an orientation of the depositional event, (3) maximum thickness of the event, and (3) expected undulations about th smoothly varying thickness.

In order to avoid distortion of the surface shapes, the addition of surfaces is based on a classical Boolean formalism, that is, surfaces fill existing topography and are not distorted to unrealistic shape. Surfaces are added until the reservoir has been filled to the maximum thickness. In order to increase the reality of the generated surface, an undulation surface is generated and added to the regular analytical shape. It is assumed that undulations are normally distributed. Undulation surfaces are generated by sequential Gaussian simulation. Conditioning data consist of those data located at the edge of the surface and conditioning data. Surfaces pass through the intersections observed at the wells and there are no intersections appearing between surface intersections observed in the well-logs/core.

Wagon Caves Outcrop

The upper plot of Figure 1 is an image of the Wagon Caves Outcrop and the lower plot of Figure 1 contains surface lines interpreted by Anderson. The surface lines in the lower part of Figure 1 were digitized and converted to global stratigraphic coordinates.

The magnitude of undulation and the variability of the surface range in generating the undulations with `sgsim`) must be calibrated. For this purpose, the residuals of some surface lines are calculated after the original surfaces are fit by the parameter. The histogram and variogram of the residuals is calculated. A Gaussian type variogram model is used.

Conditioning data were then taken from the outcrop itself. Synthesized vertical well(s) are placed on the outcrop. The intersections of the vertical well with the surface lines are regarded as conditioning data. The number of wells was increased from one to five. When conditioning data exist, the undulation surfaces generated by `sgsim` honor both the data points at the edge of the surface and the conditioning data within the surface area. The simulated results with one and five conditioning wells are shown in Figures 2 and 3. It should be pointed out that all simulations are conducted in three-dimensions. The synthesized wells were assumed to be located along a line parallel with X-axis having the same Y values.

Discussion and Future Work

The simulated surfaces look very close to the real surface lines. This is precisely our goal. Even with advances in geostatistics, numerical models derived from geostatistics have not had geological features that are consistent with geological concepts. Conceptual geological knowledge must be used in the process of modeling. The surface modeling approach developed in this note is a first step in that direction.

Each realization looks quite close to the target image, however, it is difficult to quantitatively judge how good the simulations are, i.e., what is the real advantage of surface modelling? Some quantitative criterion is required to evaluate the quality of surface modeling. A flow simulation study will be conducted.

Another aspect of future work will be hierarchical modeling. With the available seismic, well-log and core data, it is supposed that time surfaces in large scale may be partially known. With the aid of surface modeling approach developed in this report, large-scale time surfaces are considered known. Then, each stratigraphic layers bounded by large-scale surfaces will be extracted and surfaces modeled at a smaller scale. This process can be continued to a reasonable small scale.

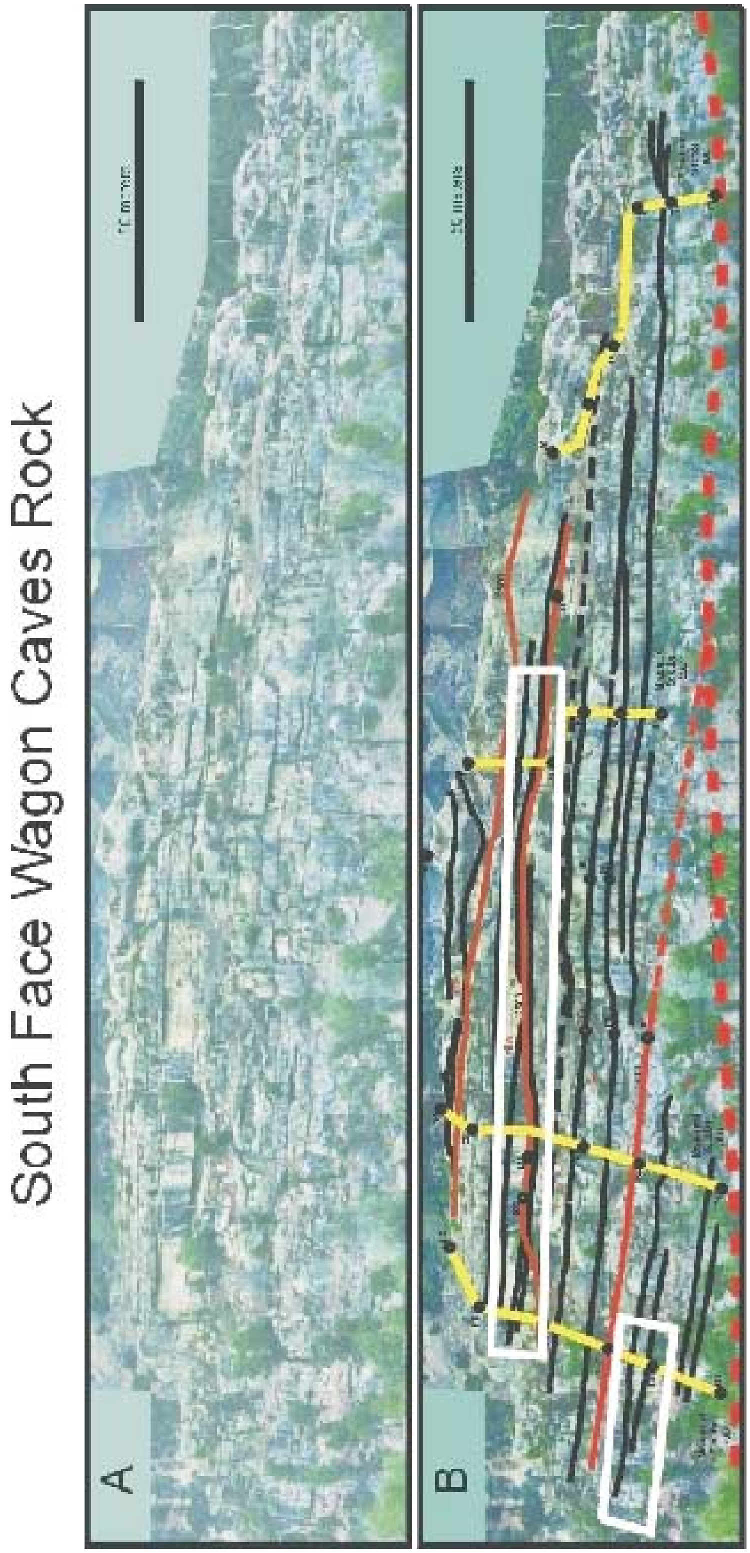

Figure 1: Wagon Caves Rock Outcrop.

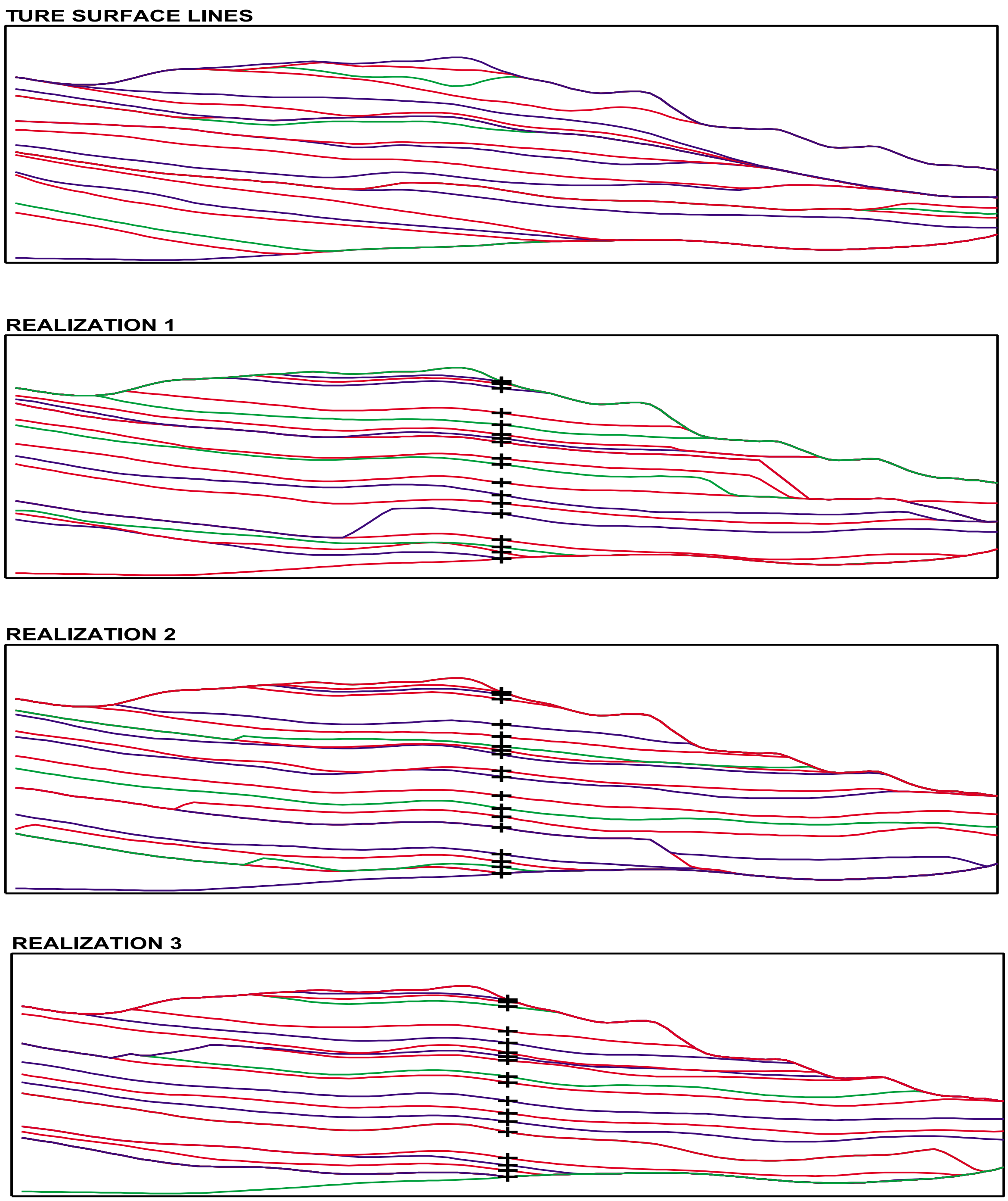

Figure 2: Simulation conditional to one well.

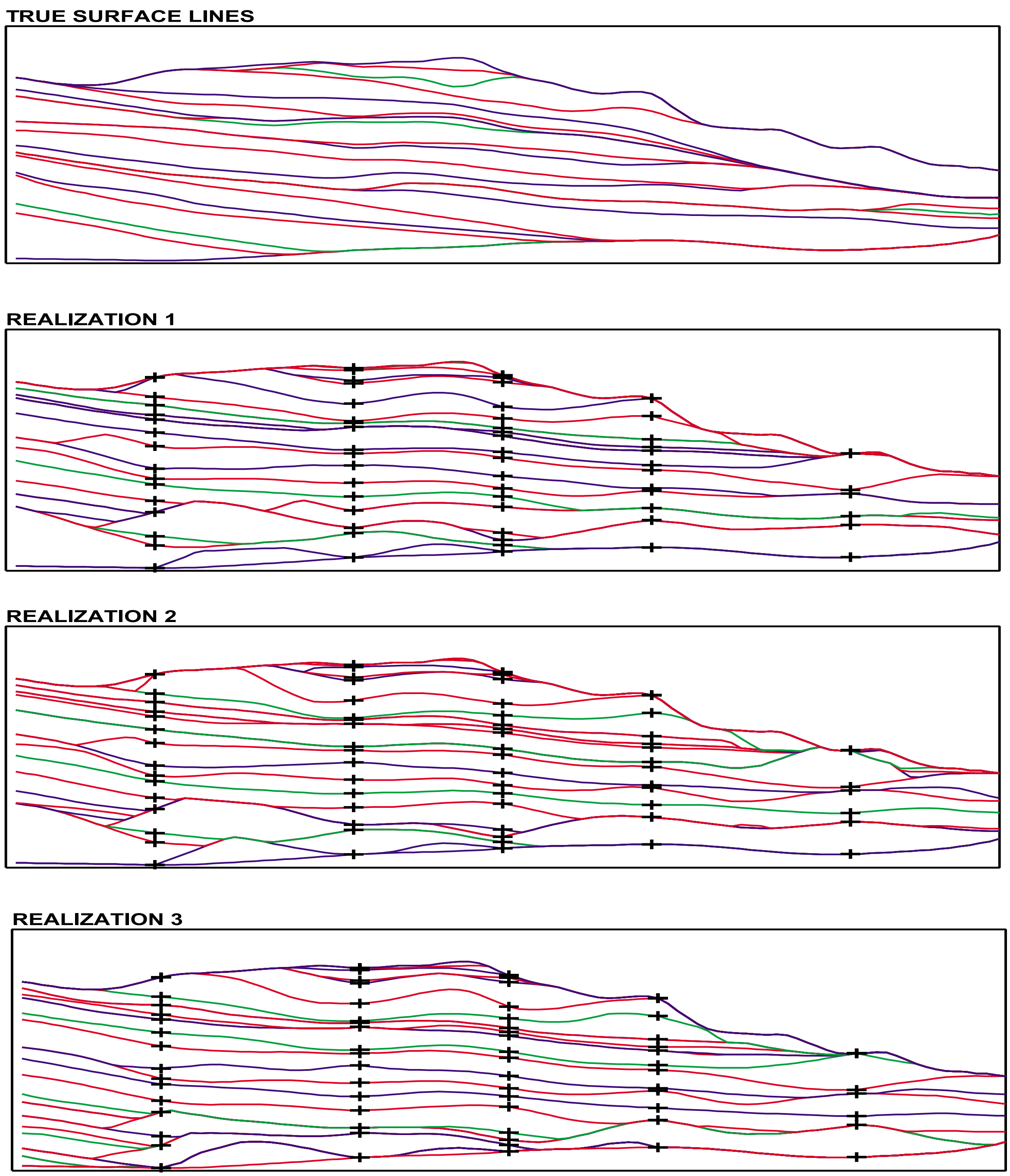

Figure 3: Simulation conditional to five wells.