Click to view slide presentation (5.6 MB).

Geological Cross Sections; Combining Geologic Models and Best Practices to Finding and Exploiting Reserves*

Robert Shoup[1]

Search and Discovery Article #42150 (2017)**
Posted November 27, 2017

*Adapted from extended abstract based on oral presentation given at AAPG Asia Pacific Region Technical Symposium, Hidden Potential in Mature Basins: Play Analogs and Best Practices, Bandung, Indonesia, September 13-14, 2017

[1]Subsurface Consultants & Associates LLC, Houston, TX, United States (bshoup@suburfacecompanies.com)

Abstract

Cross section construction and interpretation seems to be a declining art form. Yet geologic cross sections are easy to construct, even without software or well control. When those cross sections are interpreted with the appropriate structural and depositional models, they can be a powerful tool for not only understanding the subsurface, but also adding reserves and ensuring optimal development strategies. Basin scale cross-sections can not only help the geoscientist understand the basin history and charge timing by palinspastically reconstructing those cross sections, they can highlight the potential for stratigraphic pinch outs that could open new plays. Regional or trend-scale cross sections can be used to define reservoir fairways within the trend. Cross sections constructed across prospects cannot only be used for well planning purposes, but to validate the geologic and structural validity of the prospect pre-drill. Multiple cross sections constructed across fields, especially mature fields, can help interpreters find additional attic reserves, identify unproduced compartments, and ensure the maximum efficiency in draining the field.

Introduction

Maps provide interpreters with a horizontal plan view of a formation or an attribute of that formation. Cross sections provide an interpreter with a vertical plan view of multiple horizons or formations. They are, in essence, vertical maps that help interpreters visualize the relationship between formations. Cross sections are especially useful in helping interpreters make valid and consistent correlations and interpretations, examining the relationship between reservoirs and faults and unconformities, validating structural maps and interpretations, and well planning and geosteering. They can also help interpreters understand reservoir connectivity and predict potential flow baffles and barriers.

Cross Section Types

There are three types of cross sections: structural, stratigraphic, and chronostratigraphic. Structural cross sections are hung on a sea-level datum and provide a perspective of the horizons in depth (or elevation). Structural cross sections allow us to understand and validate our structural interpretation and maps; they are particularly useful in examining fluid distributions in fields. Structural cross sections, especially those constructed with the appropriate structural methods provide an excellent means to visualize the structure, validate the interpretation and structure maps, to understand the distribution of fluids in the field, and to help ensure maximum efficiency in development. Structural cross sections are also useful for well planning and for geosteering horizontal wells.

Stratigraphic cross sections are cross sections with a correlative stratigraphic marker as the datum. Stratigraphic cross sections can help ensure that we have properly correlated the reservoirs. They can also help us to see how continuous the reservoirs are across a field or play fairway, and which reservoirs are in communication. We can leverage our understanding of depositional systems combined with cross section interpretation to better understand reservoir distribution and flow baffles to ensure maximum drainage efficiency in developments or in planned enhanced recovery projects.

Chronostratigraphic cross sections are cross sections hung on geologic time. Chronostratigraphic cross sections can help us understand the entire petroleum system of a basin or play, thereby helping us to recognize potential new plays.

Pitfalls

As with all interpretive methods and tools, there are several pitfalls interpreters need to be aware of when construction cross sections. The two most common pitfalls when constructing cross sections are projection of wells and vertical exaggeration. The most common practice, and standard for almost all cross section software packages, is to project wells perpendicularly to the line of section. This often positions the well on the cross section in an incorrect structural position. It is more appropriate to project the well along structural strike (Tearpock and Bischke, 2003) or parallel to the structural plunge (Tearpock and Bischke, 2003, Groshong, 2006). Whenever feasible, structural cross sections should be constructed with the same horizontal and vertical scales so there is no vertical exaggeration. There are times, however, when we want vertically exaggerated cross sections, particularly when examining reservoir distributions. The pitfall associated with vertically exaggerated cross sections is that the exaggeration distorts the structural relief and dip (Tearpock and Bischke, 2003, Groshong, 2006) which gives the interpreter an incorrect view of the structure. Additionally, vertically exaggerated cross sections stretch the height of a structure, but not the length, which makes the limbs of folds appear to be thinner than they actually are.

Best Practices

Use cross sections to validate correlations

Accurate well log correlations are the foundation for all interpretations! If they are wrong, everything else is wrong. Since cross sections give the interpreter a vertical perspective of the relationship of multiple horizons, they are a great tool for validating correlations. Miscorrelated horizons can be recognized by observing geologically unrealistic changes in interval thickness or where pays occur below correlative wet sands.

Construct multiple intersecting cross sections to ensure accurate and consistent correlations

When validating correlations, it is best to construct multiple cross sections in both the strike and dip direction. Not only will this help the interpreter see the structure and reservoir distribution in three dimensions, it will help ensure that the correlations are consistent and three-dimensionally valid (Shoup et al, 2017).

Iterate between cross section types to ensure accurate and consistent correlations

Iterating between structural, stratigraphic, and chronostratigraphic cross sections provide interpreters with different perspectives of the structural and stratigraphic relationships. This can help ensure accurate, consistent, and valid correlations and interpretations.

Use cross sections to ensure development efficiency

Development plans are often based on locating wells on the structure maps of the key horizons. For fields with multiple producing horizons, optimal development well locations for one horizon are typically not optimal locations for other horizons. Construction of cross sections can help development geoscientists see where the field is not being fully drained and can help them design a drilling program to optimally produce the field.

Geologic Models

Countless field observations made over many years have led to the development of depositional, stratigraphic, and structural models. Cross sections that incorporate the appropriate models can provide interpreters a powerful tool for defining the subsurface; helping to add reserves or avoid dry holes.

Walther’s Law

The application of Walther’s Law makes cross sections an excellent tool for helping to interpret the depositional setting of the reservoir you are evaluating. Walther’s Law states that sedimentary environments that started out side-by-side will end up overlapping one another over time due to transgressions and regressions (Walther, 1894). The result is a vertical sequence of beds in which the vertical sequence of facies mirrors the original lateral distribution of sedimentary environments. This is true of all conformable sedimentary successions. In other words, the vertical succession of facies we observe in a well will mirror the lateral distribution of the facies on the cross section. The application of Walther's Law combined with a sound understanding of the distribution of facies in the various depositional environments allows interpreters to use cross sections to make accurate predictions of the reservoir distribution.

Interval thickness

Whereas individual sands may exhibit marked changes in thickness over short distances, depositional sequences generally thicken or thin gradually, such that they appear to maintain a relatively consistent thickness over large distances. The exceptions to this observation are where the section crosses growth faults or unconformities. Changes in interval thickness observed on play or field scale cross sections indicate one of three possibilities; the horizons are impacted by an unconformity, the horizons cross a growth fault, or the correlations are incorrect.

Structural models

Theoretical models of folded structures have existed for over a century (Torvela and Bond, 2010; eg; Suppe, 1983; Jamison, 1987; Suppe and Medwedeff, 1990; Morley and Guerin, 1996). Structural models define a simplified, mathematically constructible solution for a process that is not, in reality, simply explained (Torvela and Bond, 2010). Theoretical models in geology create idealized analogues that can be further used in the interpretation of similar geological systems. Since these models are idealized, they should not be used in the absolute, rather, they should be used to help constrain our interpretations. Interpreters need to be familiar with the structural models for the type of folds they are evaluating. Constructing cross sections constrained by that model can help avoid drilling dry holes or help find reserves that have been missed by the drill bit.

Case Studies

There is simply not enough time in a 30-minute talk, nor space in this extended abstract, to review even a small percentage of the number of examples where cross sections have added significant value. Three case studies have been selected to help illustrate the many ways constructing cross sections have helped understand a basin, avoid drilling dry holes (or explained why a dry hole was dry), added reserves to a field, or have helped define new plays and opportunities.

Case study 1; using cross sections to define charge & migration fairways

In many basins, one of the key risks for prospects is access to charge and migration. Even in basins with proven charge, not all prospects are in the migration fairway. We often use sophisticated models to assess the charge timing and define the migration fairway, but we can achieve the same results by constructing isochore or isopach maps (a recommended best practice) and palinspastically reconstructing cross sections. Two prospective areas were identified in a S. E. Asia rift basin. Although there are producing fields in the basin, charge and migration were considered key risks for the prospective areas. Strike and dip cross sections were constructed across the basin. Using corrected bottom hole temperatures, the depth of the oil and gas windows were determined and posted on the cross section. It was observed that with the exception of the basin margins, all potential source rocks were over mature. Palinspastically reconstructing the cross sections to 15 and 23 mya, we can see when the source rocks passed through the oil and gas windows and using the structure maps and the appropriate isopach maps, we can estimate where the hydrocarbons migrated to after they were generated.

Case study 2; cross section adds reserves to a mature field

A company operating an oil and gas field on the flank of a salt dome felt that the field was near the end of its life and petitioned the regulatory agency for permission to blow down the gas cap. The regulatory agency was not convinced that the oil rim had been fully exploited and asked the company to re-assess the oil rim potential. As part of that reassessment, the operating company constructed a cross section across the field. The cross section indicated that there was an incised valley sequence crossing the field and that the thick incised valley-fill sand had not been penetrated in the oil rim. The company eventually drilled two additional wells in the oil rim and added ~4.5 million barrels of recoverable reserves.

Case study 3; cross sections confirms structural validity

This is a somewhat humorous example, but nicely illustrates how cross sections can be used to ensure that our structure maps are three dimensionally valid. A well was proposed to test a fault block on the flank of a salt diapir. Since the exploration team had not constructed a cross section across the prospect, the drilling team did. Since there were no wells, the drilling team used the contours from the structure map to post the horizons on the section. When the cross section was completed, it indicated that the deeper objective would be penetrated several hundred feet above the shallow objective; a geological and geometrical impossibility. The gridding and contouring algorithms used by the geophysicist to make the final structure maps shifted the interpreted picks such that the final maps were incorrect. Although the well was drilled as a commercial success, it was personally embarrassing for the geophysicist. The moral of the story – construct cross sections. They are easy to make, and can help you assess risk and uncertainty, avoid dry holes, plan wells, optimize development plans and recovery efficiency, and find new reserves.

Selected References

Groshong, R.H., 2006, 3-D Structural Geology: 3-D Structural Geology: A Practical Guide to Quantitative Surface and Subsurface Map Interpretation: Springer-Verlag Berlin Heidelberg, 410 p.

Jamison, W.R., 1987, Geometric analysis of fold development in overthrust terranes: Journal of Structural Geology, v. 9, p. 207-219.

Morley, C., and G. Guerin, 1996, Comparison of gravity-driven deformation styles and behaviour associated with mobile shales and salt: Tectonics, v. 15, p. 1154-1170.

Shoup, R.C., A.J. Filipov, and M. Hiner, 2017, Geological interpretation of the reservoir and pay distribution of the G3.2 and G5.2 series of the Shwe Field, Myanmar: AAPG Search and Discovery Article #20401, Web Accessed November 11, 2027, http://www.searchanddiscovery.com/documents/2017/20401shoup/ndx_shoup.pdf

Suppe, J., 1983, Geometry and kinematics of fault-bend folding: American Journal of Science, v. 283, p. 684-721.

Suppe, J., and D.A. Medwedeff, 1990, Geometry and kinematics of fault-propagation folding: Eclogae Geologicae Helvetiae, v. 83, p. 409-454.

Tearpock, D.J., and R.E. Bischke, 2003, Applied subsurface geological mapping with structural methods, 2nd Edn.: Prentice Hall PTR, Upper Saddle River, 822 p.

Torvela, T., and C.E. Bond, 2010, Do experts use idealised structural models? Insights from a deepwater fold-thrust belt: Journal of Structural Geology, v. 33, p. 51-58.

Walther, J., 1894, Einleitung in die Geologie als historische Wissenschaft: in Lithogenesis der Gegenwart. Jena: G. Fischer, Bd. 3, p. 535-1055.