A NEW TECHNIQUE FOR 3–D FLEXURAL–SLIP RESTORATION.

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Abstract

A new flexural–slip structural restoration technique for three–dimensional (3–D) digital models has been developed. This technique utilises a slip method that preserves volume in 3–D, line length in a given unfolding direction (of a specified surface and of layers parallel to this surface), and orthogonal bed thickness. These constraints enable the restoration of 3–D fault–propagation, fault–bend and detachment folds.
The 3–D model is comprised of objects such as interpreted horizon and/or fault surfaces that are created from irregular, triangulated meshes. For a given model, a parallel sinuous–slip system is calculated from the geometry of a specified template surface and from a fixed pin surface that passes through all vertices of the triangulated meshes in the specified folding direction. The entire slip system then is folded to a new shape, which is defined by a geometric surface that can be curved or planar. In doing so, all vertices within the system are transformed to their new locations to generate a newly–folded 3–D model.
We demonstrate the 3–D restoration technique by using a case study of an evaporite–cored contractional fold in the NW German Basin. Our restorations depict the 3–D sequential growth of the fold from 146 Ma through late Mesozoic and show that the shortening direction was towards NNE with the main contractional phase initiating during the late Cretaceous.

1. Introduction

A number of techniques have successfully been applied to cross–section and surface restoration of contractional folds (e.g., Geiser et al., 1988; Williams et al., 1997; Hennings et al., 2000). These techniques have been used to study detailed contractional fold geometries and their associated strains. While insightful, these methods require that cross sections be treated independently or that structural surfaces be unfolded separately.

We describe a new 3–D flexural–slip restoration algorithm, which allows the restoration of multiple, geometrically–complex, and non–parallel surfaces within a 3–D digital model in a single modelling increment. This plane–strain algorithm also preserves the connectivity of parallel or non–parallel surfaces using a defined slip system.

To illustrate the method we restored and analysed a folded structure in the NW German Basin.

Due to the 3–D nature of the algorithm, the unfolding direction becomes an important parameter that affects the results of our case study. For this reason, an approach for defining the optimum unfolding direction is also described.

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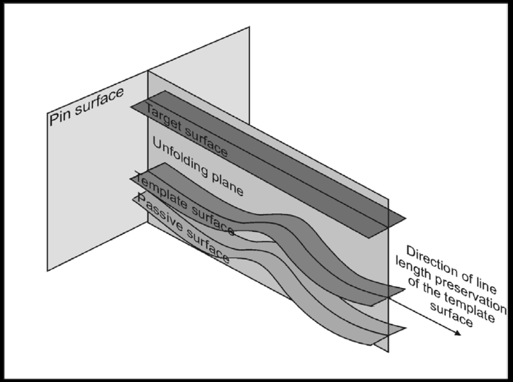

Figure 1. Components of the flexural–slip folding technique. The template surface defines the initial slip system geometry. The target surface defines the final slip system geometry. Passive surfaces are carried with the template surface as it is deformed with the flexural–slip algorithm. The pin surface defines the surface of zero slip during the folding process. The intersection line of the unfolding plane and the template surface defines the folding direction in which the line length of the template surface is maintained.

2a. The 3–D flexural unfolding technique

Model representation

The folding technique utilises a digital geological model that consists of 3–D surfaces, which may represent any geological surface (e.g., faults and/or stratigraphic horizons). These surfaces are composed of sets of data points that are connected to form arrays of regular or irregular triangles. The data structure of the digital model uniquely identifies each node and retains its connection information to other nodes in the surface. This information allows the triangle connectivity to remain the same before and after folding.

In addition to triangulated surfaces, the model may also include 3–D polylines that are composed of connected line segments, and arrays of nodes connected to form volumes that are represented as tetrahedral elements. Although we describe our algorithm using nodes, the technique is generic and may therefore be carried out on any object within the digital model.

Slip system determination

The folding technique is based on the transformation of a flexural–slip system from a folded or flat geometry (template surface) to another folded or flat geometry (target surface). To determine the slip system, a number of model components are required (Figure 1):

1. The template surface, which is a triangulated mesh, may be a folded (including overturned geometries) or planar surface. The geometry of the template surface defines the initial slip system geometry.
2. The target surface, which is either a triangulated mesh or a mathematical plane, may be a folded (including overturned geometries) or a planar surface. The geometry of the target surface defines the final geometry of the slip system.
3. The pin surface, which is either a triangulated mesh or a mathematical plane, may be a geometrically complex or planar surface. The pin surface defines the surface of zero slip during the folding process. Nodes of geological surfaces that intersect this pin surface will not slip during folding. However, a node on the pin surface pre–folding may be translated to another location on the pin surface post–folding.
4. The unfolding plane is a vertical mathematical plane. Nodes are displaced parallel to the unfolding plane as they move along the slip system, relative to the pin, the template surface, and the target surface.

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