Available online at www.sciencedirect.com
ScienceDirect
Marine and Petroleum Geology 25 (2008) 131–141
Marine and Petroleum Geology
www.elsevier.com/locate/marpetgeo

Formal description of sedimentary architecture of analogue models for use in 2D reservoir simulation

E.J. Hill*, C.M. Griffiths

CSIRO Petroleum, 26 Dick Perry Avenue, Kensington, W.A. 6151, Australia

Received 21 August 2006; received in revised form 19 April 2007; accepted 3 May 2007

Abstract

A formal method for describing data collected from field studies is used to generate stochastic geological models of sedimentary successions using a method based on syntactic pattern recognition. Using this method an analogue model developed from field data can be encoded as a grammar. The grammar is composed of symbols which represent geological entities. Valid patterns formed by the symbols are described by a set of production rules. In order to demonstrate the potential of the syntactic method, 2D simulations of interpreted cross-sections from Brushy Canyon outcrops are presented here, as well as 2D simulations of seismic facies from the Bengal Fan.

Keywords: Reservoir simulation; Sedimentary architecture; Syntactic pattern recognition

1. Introduction

It is desirable to use knowledge collected from traditional field studies of outcrops to predict the sedimentological architecture in unexposed petroleum reservoirs for which only sporadic data are available. In order to accomplish this, a method is required for the formal description of sedimentological patterns observed from outcrops or from other data sources, such as seismic sections. Ideally, pattern descriptions need to be capable of ongoing modification as active exploration and production provide more data.

In this paper we present a formal method for describing and predicting sedimentary patterns using syntactic pattern recognition (Fig. 1). Syntactic pattern recognition is based on the concepts of formal language theory (Chomsky, 1956; Gonzalez and Thomason, 1978; Fu, 1982; Bunke and Sanfeliu, 1990) and it has been applied to a variety of problems whose patterns cannot be successfully described in simple vector format. Areas of application include molecular biology (Searls, 2002), engineering design (Flasiński, 1995), electrocardiogram analysis (Trahanias and Skordalakis, 1990), seismic oil exploration (Huang, 2002) and the interpretation of sedimentary environments (Griffiths, 1990).

The long-term aim of the research project is to be able to generate 3D facies models from formal descriptions of patterns of sedimentary deposits that can be used as a basis for developing reservoir simulation models. At this stage of the project the aim is simply to test whether syntactic pattern recognition is capable of generating realistic 2D patterns in sedimentary successions. By "realistic" we mean that the output of the algorithm would appear to an experienced geologist to represent the same class of deposit as the one used to provide the formal description. It is not envisaged that the current program will be useful in practical applications until it has been further developed into full 3D capacity.

1.1. Object-based geological modelling for reservoir characterisation

Stochastic models can be divided into two types: discrete and continuous (Haldorsen and Damsleth, 1990; Damsleth et al., 1992). Continuous models are designed to model

*Corresponding author. Tel.: +61 8 64368651; fax: +61 8 64368555.
E-mail addresses: June.Hill@csiro.au (E.J. Hill), Cedric.Griffiths@csiro.au (C.M. Griffiths).

0264-8172/$ - see front matter Crown Copyright © 2007 Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpetgeo.2007.05.001

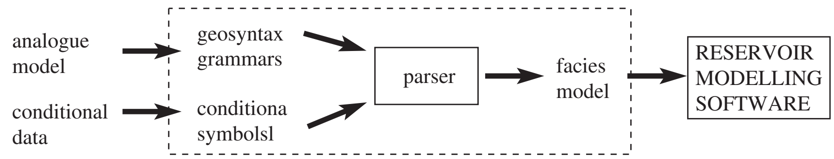

Fig. 1. The aim of the project is to develop a geological syntax (geosyntax) and a program (the parser) which is capable of generating facies models for reservoir modelling. This paper covers the techniques outline in the dashed box for generating a 2D facies model.

properties which vary continuously throughout the reservoir, such as permeability and porosity. Discrete models are designed to describe geological features. The most ubiquitous type of discrete model described in the literature is the marked point process (also called the Boolean process). In this process the volume to be modelled is divided into regular cells and each cell is assigned a particular facies. An object (e.g. a channel) consists of a group of adjacent cells of the same facies arranged in a particular shape.

Examples of computer programs designed to use marked point processes include SESIMIRA, FLUVSIM (Deutsch and Tran, 2002), SISABOSA, FLUREMO and MOHERES (Tyler et al., 1994). In these programs objects which represent sandy facies are predefined by the user and are placed at random locations in a background of shale or other mud-rich facies, or vice versa. Objects of a particular facies are added one at a time until the desired proportion of the facies is achieved. The locations of objects of a particular facies may be made conditional on the location of other facies (e.g. crevasse splays must occur adjacent to channels). Objects may be rejected if they do not conform to well data. Using this method, a 3D volume can be constructed from merged layers (e.g. FLUVSIM) or a 3D volume can be modelled in one step (e.g. SESIMIRA).

Unlike marked point processes, the syntactic method used here to describe sedimentary patterns is not only object-based, it is also object-oriented. This means that each geological object can be represented by a single symbol rather than a collection of cells. This has the advantage that there is no predefined resolution inherent in the model. Furthermore, methods which require data to be compartmentalised into 2D or 3D cells involve a trade-off between fast computing time and high resolution.

The syntactic method has the potential to describe quite sophisticated patterns with a set of very simple rules and then to generate patterns using these rules. We hope that this method will be intuitive to use and provide a simple framework for creating and modifying formal descriptions of facies distributions from a wide variety of sedimentary environments.

1.2. Syntactic modelling in sedimentary successions

In syntactic pattern recognition, the description of each class of pattern is provided by a grammar. A grammar contains all the symbols, rules and other information required to construct a formal description of a class. Phrase structure grammars have been used to successfully describe and analyse vertical 1D sections through sedimentary successions (Griffiths, 1990; Duan et al., 1996, 2001) and to generate cell-based models of simple 2D marine parasequences (Duan et al., 1999). Phrase structure grammars are grammars which describe patterns in terms of an hierarchical structure (Chomsky, 1956). Given that descriptions of sedimentary bodies are usually classified in terms of an hierarchical structure (e.g. Pickering et al., 1995), the use of a phrase structure grammar is a natural choice. Phrase structure grammars have also been used to generate horizontal 1D sections through deep-water fan deposits (Hill and Griffiths, 2007).

The method described here builds on the work of (Hill and Griffiths (2007)) and has been designed to generate simulations of 2D vertical sections through undeformed sedimentary successions. This method is capable of producing sections with a much wider variety of pattern types than those produced by the cell-based 2D grammars of (Duan et al., 1999).

This paper describes the structure of grammars used to characterise common sedimentary environments and briefly introduces the predictive parser which generates the simulations using the grammars and any conditioning data that must be honoured by the simulation. In the final section of the paper we demonstrate the capability of this method using some real-world examples.

2. Grammars

The grammars used here to describe geological patterns are collectively termed *geosyntax*. Geosyntax grammars belong to the context-free class of grammars (Chomsky, 1959). These are relatively simple grammars which are computationally efficient yet can describe a rich variety of patterns, hence they are the most widely used form of grammar for solving problems in syntactic pattern recognition. In addition, the geosyntax grammars are stochastic; i.e. they involve the use of random variables in the process of rule selection. Additionally, random variables are used in the determination of size attributes for sedimentary bodies.

Each geosyntax grammar includes a finite set of terminal symbols (basic pattern elements), a finite set of non-terminal symbols (higher order pattern elements), a single start symbol (highest order symbol) and a finite set of production rules (described below). Each production rule has a probability associated with the application of the