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Waterflood Surveillance and Control: Incorporating Hall Plot and Slope Analysis

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Abstract

Waterflood automation at a field scale is a complex coupled problem. In our analysis, data from injecting and producing wells, as well as satellite differential interferograms (InSAR) are used as the inputs. Some information processing is carried out on-line automatically, and other needs personnel expertise. Dynamic adaptive control is performed in the mixed open-loop-feedback mode. Our surveillance-control system is being implemented in Sections 32 and 33 of the Lost Hills diatomite field, CA, USA.

Introduction

Automation of waterflood surveillance and control helps to make oil recovery operations more efficient and reduce the costs related to early water breakthrough and well failure. Early warnings about possible trouble spots help to make corrective actions in a timely manner. Automation is an attractive, but challenging task¹. Automated data acquisition and storage technologies have made impressive advances over the past decade². However, it is insufficient to only collect and store the exponentially growing volumes of often meaningless data. The focus should be shifted to the development of robust on-line data analysis and quality control. In waterflood operations, this analysis should result in injection set points that can be sent to the wellhead controllers to close the control loop.

The paper is organized as follows. First, the principles of dynamic adaptive control are discussed. Then, several on-line and off-line methods of monitoring performance of an injection well are reviewed and evaluated. After that, examples of simultaneous analysis of the InSAR subsidence maps³ and maps based on performance analysis of the individual wells in the project are presented. Two Appendices include brief background material related to the Hall plot,

slope analysis, and the frequency-domain asymptotic estimates of time-dependent formation properties.

Dynamic adaptive control

Waterflood projects affect reservoir dynamics over large portions of oilfields. However, oil is produced and water is injected locally through individual wells. Therefore, it is natural to control an entire waterflood project by adjusting injection rates and pressures individually at each well. Clearly, the injection rates and pressures are coupled parameters: An increasing injection pressure results in an increased rate, and vice versa. In a moving car, the driver adjusts the accelerator pedal to increase or decrease the torque passed from the engine to the wheels to maintain the desired speed. Similarly, the force driving a waterflood, the injection pressure, is regulated to maintain the desired injection rate. In a car, the engine power is regulated by opening and closing a fuel throttle. At a well, the pressure is regulated by a valve installed at the wellhead. Therefore, the objective of the control at each individual well is to set up the pressure in such a way that the injection rate is maintained at the desired level. How to select the target rates for each well depends on an analysis of performance of a group of wells or the entire field. This analysis includes oil, water, and gas rates at producing wells, subsidence and consequent well failure, rock mechanics and physics, oil prices, etc. Below, a subsidence case is analyzed using satellite InSAR images³; see also Ref. 3.

The formation conditions near the wellbore change in the course of operations. Especially, this is the case when the reservoir rock is low-permeability, soft, and prone to damage, like the diatomite^{4,5}. The injection pressure must be adjusted according to these changing conditions; therefore, control must be dynamic. There are two major types of regulation: open-loop and closed-loop control. The former means that the control set points are planned in advance for a substantial period of time, whereas the latter one means that the set points are generated from the current measurements of available parameters. In fact, for injection control, neither of these two modes is suitable in its pure form. The open-loop control requires a reliable model of the process with accurately specified parameters that are almost never available for subsurface fluid flow. The closed-loop control or, otherwise, the feedback regulator, is also not suitable because the current injection conditions are the result of the history of well

³ InSAR images are produced by Vexcel Corporation.

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David Grimaldi, Michael S. Engel



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Vertebrate Paleontological Techniques: Volume 1 Patrick Leiggi, Peter May, 2005-06-02 Everything that amateur and professional fossil hunters will ever need to know about modern palaeontological techniques and practice *Geological Survey Professional Paper* Geological Survey (U.S.), 1953 **Ururumaco and Venezuelan Paleontology** Marcelo R. S  nchez-Villagra, Orangel A. Aguilera, Alfredo A. Carlini, 2010-07-16 Ururumaco and Venezuelan Paleontology offers a synthesis of the paleontological record of Venezuela including new discoveries on stratigraphy paleobotany fossil invertebrates and vertebrates Besides providing a critical summary of the record of decapods fishes crocodiles turtles rodents armadillos and ungulates several chapters introduce new information on the distribution and paleobiology of groups not previously studied in this part of the world Given its position in the northern neotropics close to the Panamanian land bridge Venezuela is a key location for understanding faunal exchanges between the Americas in the recent geological past The book reviews the recent paleobotanical and vertebrate fossil record of the region provides an understanding of Pleistocene climatic change and biogeography for the last few thousand years and integrates new information with summaries of Spanish language works on Venezuelan geology and paleontology **Geological Survey Professional Paper** ,1976 *U.S. Geological Survey Professional Paper* ,1951 **Paleontology of the Greenhorn Cyclothem (Cretaceous: Late Cenomanian to Middle Turonian) at Black Mesa, Northern Arizona** James Ian Kirkland, *Special Papers - Palaeontological Society of Japan* Nihon Koseibutsu Gakkai, 1990 *Palaeontological Society of Japan Special Papers* ,1991 **Conodont Stratigraphy, Facies-related Distribution Patterns and Stable Isotopes (carbon and Oxygen) of the Uppermost Silurian to Lower Devonian Seewarte Section (Carnic Alps, Carinthia, Austria)** Thomas James Suttner, 2007 **Dawn of the Age of Mammals in the Northern Part of the Rocky Mountain Interior, North America** Thomas M. Bown, Kenneth David Rose, 1990 *Evolution of the Insects* David Grimaldi, Michael S. Engel, 2005-05-16 Insects are the most diverse group of organisms in the 3 billion year history of life on Earth and the most ecologically dominant animals on land This book chronicles for the first time the complete evolutionary history of insects their living diversity relationships and 400 million years of fossils Whereas other volumes have focused on either living species or fossils this is the first comprehensive synthesis of all aspects of insect evolution The book is illustrated with 955 photo and electronmicrographs drawings diagrams and field photos many in full colour and virtually all of them original The book will appeal to anyone engaged with insect diversity professional entomologists and students insect and fossil collectors and naturalists **Bulletins of American Paleontology** ,2002 **Geologically Storing Carbon** Peter Cook, 2014-08-18 Carbon capture and geological storage CCS is presently the only way that we can make deep cuts in emissions from fossil fuel based large scale sources of CO2 such as power stations and industrial plants But if this technology is to be acceptable to the community it is essential that it is credibly demonstrated by world class scientists and engineers in an open and

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The Secret History of Sharks John Long, 2025-07-01 From ancient megalodons to fearsome Great Whites this book tells the complete untold story of how sharks emerged as Earth's ultimate survivors by world leading paleontologist John Long Will keep you on the edge of your seat from its first page to its last page Jared Diamond Pulitzer Prize winning author of *Guns Germs and Steel* Sharks have been fighting for their lives for 500 million years and today are under dire threat They are the longest surviving vertebrate on Earth outlasting multiple mass extinction events that decimated life on the planet But how did they thrive for so long By developing superpower like abilities that allowed them to ascend to the top of the oceanic food chain John Long who for decades has been on the cutting edge of shark research weaves a thrilling story of sharks unparalleled reign *The Secret History of Sharks* showcases the global search to discover sharks largely unknown evolution led by Long and dozens of other extraordinary scientists They embark on digs to all seven continents investigating layers of rock and using cutting edge technology to reveal never before found fossils and the clues to sharks singular story As the tale unfolds Long introduces an enormous range of astonishing organisms a thirty foot long shark with a deadly saw blade of jagged teeth protruding from its lower jaws a monster giant clams crusher and bizarre sharks fossilized while in their mating ritual The book also includes startling new facts about the mighty megalodon with its sixty six foot long body massive jaws and six inch serrated teeth With insights into the threats to sharks today how they contribute to medical advances and the lessons they can teach us about our own survival *The Secret History of Sharks* is a riveting look at scientific discovery with ramifications far beyond the ocean **Special Papers**, 1934 **Relationships in the Patterns of Bibliographic Devices** John II Gribbin, 1958 *Telychian Rocks of the British Isles and China (Silurian, Llandovery Series)* Charles Hepworth Holland, Michael G. Bassett, 2002 **Stratigraphic Evolution of Foreland Basins** Steven L. Dorobek, Gerald M. Ross, 1995 A strong case can be made that foreland basins are where the casual links between sedimentation and tectonic

events were first recognized as evidenced by the interpretations of geologists working in classic foreland areas This Special Publication was derived from a Research Symposium entitled Stratigraphic Sequences in Foreland Basins held at the AAPG SEPM joint annual meeting on June 1992 in Calgary Alberta Canada This volume provides a well balanced perspective of current research on foreland basin stratigraphy and also serves as another element in the evolving framework that comprises our understanding of foreland basins Given that so many of earth s resources are found in foreland basins and that foreland basin strata often provide the only preserved record of the tectonic events that led to basin development the impetus for continued studies of foreland basin strata should remain for many generations of geologists to come

Geology of the Precambrian Superior and Grenville Provinces and Precambrian Fossils in North America S.B. Lucas,M.R. St-Onge,1998 This volume contains a description of the geology and mineral deposits of the Superior Province of the Canadian Shield an overview of Grenville Province geology and a synopsis of Precambrian fossil occurrences in North America Six large plates include a geological map of Canada geological map of the Grenville Province lithotectonic map of the Superior Province Archean mineral deposit map of the Superior Province and more

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