Small County: Web-Based Instruction in the Geological Characterization of Petroleum Reservoirs

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Project Summary

Intellectual Merit: Traditional programs of geological education continue to be focused primarily on the evaluation of surface or near-surface geology accessed at outcrops and shallow boreholes. However, most students who graduate to careers in geology work almost entirely on subsurface problems. Increasingly, in their professional life the major sources of their information from the subsurface will be petrophysical (wireline) logs, digital records of various rock properties measured using a string of probes lowered into a well. Although their university training will probably have introduced students to the use of logs in correlation, the result is a limited rendition of subsurface geology as a topology of bounding surfaces. However, modern petrophysical logs contain a wealth of geological information that is recognized by the oil and gas industry, but rarely explored in a university geology curriculum. Thus, college graduates commonly find themselves ill-prepared when they enter the petroleum industry and require specialized training in petrophysical log interpretation. Opportunities for petrophysical training are not universally available and are often rudimentary in nature. To aid in this training process, we propose to develop, as a Phase 1 CCLI project, a web-based environment for interactive instruction in the geological aspects of petroleum reservoir characterization employing a virtual subsurface closely reflecting the geological characteristics of the US mid-continent, in the fictional setting of Small County, Kansas. Thus we will build an environment in which undergraduate students can gain experience in this critical realm of petroleum exploration through classroom exercises and/or assignments. Although the simulation techniques we propose to use to develop the virtual subsurface are commonly used by the petroleum industry for characterization of real-world reservoirs, this project would represent an innovative use of these techniques for educational purposes. The initial target audience for this web-based educational tool will be upper-level undergraduate students, with a simplified version incorporating additional introductory material developed for lower-level courses. We plan to field test it in log analysis courses taught by the Co-PI at the University of Kansas, assessing its effectiveness using pre- and post-tests, and in a lower level introductory physical geology course at Iowa State University, taught by the external evaluator on the project.

Broader Impact: This project pushes the envelope for web-based geoscience education resources in terms of the detail and realism of the simulated subsurface. Through dissemination on the Kansas Geological Survey web site, through conference presentations and papers in appropriate education literature, on the "Teach the Earth" web site, and through DLESE, this material will be available for use by a wide audience, allowing its use in a broad range of settings, including junior colleges and professional development training. Furthermore, geology faculty looking to improve their own understanding of log analysis could also find the Small County exercise very useful.

Project Description

Introduction: Educational researchers have long recognized that active engagement in problem solving enhances students' ability to retain domain-specific knowledge, along with aiding the development of cognitive skills that enhance the students' general problem-solving capabilities across domains (Craik and Lockhart, 1972; Craik and Tulving, 1975; Renshaw et al., 1998). The primary task for most professional geologists employed in either the petroleum or environmental industries is characterization of the earth's subsurface, developing three-dimensional representations of distributions of various properties of the subsurface, including surfaces bounding different geological formations or representing significant geological events and the distributions of properties governing the flow and transport of fluids and contaminants in the subsurface. Depending on the needs of a particular study, these models of the subsurface may range from conceptual models, residing purely in the mind of the investigator, to large, data-rich digital models developed in special-purpose software packages for subsurface characterization. Regardless of the representational nature of the model or the exact realm of application (petroleum, environmental, paleontological, etc.), development of such a model requires certain common skills: the ability to recognize patterns in one-dimensional sequences of data observed in outcrops or wells, the ability to correlate such patterns laterally in order to tie together sequences of observations at different locations, and the ability to develop mental images of alternative possible three-dimensional subsurface configurations that could give rise to those observations (Tearpock and Bischke, 1991; Black, 2005). These skills have always been a fundamental part of geological mapping, which has traditionally involved observing stratigraphic sequences in outcrop and projecting those observations back into the subsurface. Thus, in many geology curricula, the geology field trip has been considered the ultimate hands-on problem solving experience, engaging students directly in the traditional process of developing geological maps, along with interpretations of the underlying geological history, from outcrop observations, as highlighted in a special issue of the Journal of Geoscience Education (Manduca and Carpenter, 2006; Knapp et al., 2006; Lathrop and Ebbet, 2006; Anderson and Miskimins, 2006).

Ironically, when these students begin their careers in the petroleum or environmental industries, they find that the traditional field mapping exercise is in fact fairly academic. Their daily work life involves analysis of various kinds of data measured in wells or boreholes or obtained through geophysical surveys (Tearpock and Bischke, 1991; Selley, 1995). In fact, relative to the typical subsurface characterization approaches practiced in industry, outcrops are now considered "analogs" of the subsurface (Caers, 2005; Pringle et al., 2006), whose characteristics can be used to help develop geologically plausible interpretations of borehole and geophysical data, the latter being considered the more direct observations of actual subsurface conditions. Yet most geology curricula provide students with little or no training in the interpretation of borehole or geophysical data.

Perhaps the most common source of digital data employed in petroleum reservoir characterization studies are petrophysical well logs, records of mechanical, electrical, and nuclear properties of the sequence of rock types encountered in a borehole and of the fluids contained in the pore spaces of those rocks (Doveton, 1986, 1994; http://www.kgs.ku.edu/PRS/ReadRocks/portal.html). These properties are generally measured using a string of sensors enclosed in a tool which is lowered down a borehole after it has been drilled, or using a string of tools installed in the drill rod, allowing logging while drilling. Unfortunately, although many professional geologists work with petrophysical well log data on a daily basis, undergraduate geology curricula rarely provide students with any exposure to or training in petrophysical log interpretation. In this project we propose to develop a web-based system that will help to fill that educational gap, providing students with a means to explore a virtual subsurface over a county-sized region by siting exploratory wells, evaluating the petrophysical logs and other data obtained from those wells, and making management decisions regarding further exploration and development of the petroleum resources in the region. Stochastic and deterministic simulation algorithms will be used to generate the subsurface geological structure in the region and the distributions of rock and fluid properties within that structural framework. These three-dimensional property distributions will be used to generate synthetic sequences of well logs and other data at every location where a student chooses to site a well. The software will allow students to examine these data at individual wells and in cross-section, using displays closely mimicking petroleum industry standards. The student will make further exploration and production decisions based on examination of the data, providing a near real-world experience in petroleum exploration.

The PI and Co-PI, both of whom have considerable experience in the development of analytical tools and web-based resources for petrophysical data analysis, will be responsible for design of this pilot project and the PI will be primarily responsible for development of the computational engine for generating the virtual subsurface and exploring it. A graduate research assistant will be primarily responsible for development of the web interface. An external evaluator with extensive experience in the development of web- and computer-based educational tools is going to aid in the assessment of the project's educational impact.

A report by the American Geological Institute (Baker, 2006, http://www.earthscienceworld.org/careers/gw-06-002.pdf) discusses the pending shortage of skilled employees in the petroleum industry. It states, "Representatives from the petroleum industry have indicated that they will need to replace over 50% of their geoscience technical workforce within the next ten years, a level that represents close to 40,000 jobs. . . . The current production of geoscientists from US colleges and universities that are considered part of the potential employment pool, namely graduates with masters and doctorates, is about 1,200 per year." It also reports the relative lack of popularity of the petroleum industry as a potential employer among current geoscience students. Of the students responding to an AGI survey, the petroleum industry ranked fourth or fifth among preferred career paths (depending on degree level). This trend does not bode well for the US petroleum industry. It is possible that part of the reason for students' lack of interest in petroleum industry employment is a lack of exposure to the intellectually engaging problems that are involved in petroleum exploration and production. Development and distribution of educational materials such as the Small County exercise proposed here would help to spark interest in this field of employment. Furthermore, petrophysical and geophysical techniques show great promise for advancing aquifer characterization studies (Bridge and Hyndman, 2004; Rubin and Hubbard, 2005). Thus, experience in petrophysical log analysis could be of great value to students heading into environmental careers as well.

The primary focus of this Phase 1 pilot project will be the development of **learning materials**, namely the Small County exercise, aimed at providing students with engaging instruction in petrophysical log analysis. This material will be freely available on the web, allowing its use in a broad range of settings and thus reaching a diverse audience. Although the simulation procedures employed in the exercise are used in reservoir characterization studies, their use to generate a synthetic reality for the sake of instruction represents an **educational innovation**, which will help advance the development of virtual environments in earth science education. In addition, the exercise will be of use in the **development of faculty expertise**, providing resources for geology faculty who wish to expand their own knowledge of log analysis prior to teaching the topic. We have included funding for a workshop in the spring or summer of 2009 for the sake of introducing geology faculty and other interested parties to the Small County exercise. The exercise will include **assessment of student achievement** through pre- and post-tests designed with the assistance of the external evaluator and through logging of students' actions and responses to queries within the exercise itself.

Project design: Recent decades have seen the development of stochastic simulation techniques that allow the creation of compellingly realistic simulations of the spatial distribution of properties that influence the distribution and movement of fluids (water, oil, and gas) in the subsurface. These properties include lithofacies (rock type), porosity, and permeability (a measure of the rock's ability to transmit fluid), with lithofacies exerting a significant control on the distribution of the other two properties. As summarized in Deutsch (2002), techniques appropriate for modeling categorical variables like lithofacies include sequential indicator simulation and object-based simulation, while continuous variables like porosity and permeability are typically modeled using sequential Gaussian simulation. Markov chain simulation provides an alternative approach to lithofacies modeling. Markov chain analysis involves quantifying the juxtapositional tendencies or preferred ordering of lithofacies based on sequences observed in outcrops or in cores extracted from boreholes. The juxtapositional tendencies of the observed sequences are summarized in terms of a set of transition probabilities and mean thicknesses for each lithology. Vistelius (1949) first applied Markov chain concepts to the descriptive analysis of sedimentary sequences and work in this field includes publications by the Co-PI (Doveton, 1970; Doveton and Duff, 1984; Doveton, 1995). Although Harbaugh and Bonham-Carter (1970) discuss the use of Markov chain techniques in generating synthetic lithological sequences, serious application of these ideas did not appear until the 1990's, when computing power began to catch up with the promise of the concepts. Carle and Fogg (1996; 1997) and Weissman et al. (1999) present applications of three-dimensional Markov chain simulation of lithofacies distributions, demonstrating that the transition probability approach provides a more geologically intuitive means of specifying the spatial structure than sequential indicator simulation.

Stochastic simulation techniques now see widespread use in reservoir characterization projects due to their incorporation into industry-standard software packages. However, the goal of these projects is to reproduce the characteristics of a real-world petroleum reservoir as closely as possible for the sake of predictive modeling. The educational potential of these techniques, through their ability to generate a synthetic subsurface for virtual exploration, remains untapped. The investigators on this project have recently developed an interactive, online exercise in geological interpretation of geophysical well logs based on synthetic lithofacies sequences generated using a Markov chain. This interactive exercise, the Oz Machine, is implemented as a Java applet and accompanies a brief online tutorial in geological log analysis. Both are available online at http://www.kgs.ku.edu/PRS/ReadRocks/portal.html and the Oz Machine is the subject of a recent paper (Bohling and Doveton, 2006). The statistical properties of the lithological sequences generated by the Oz Machine have been selected so that the simulated sequences are broadly similar in character to real sequences in the US mid-continent, including sequences representing three broad depositional environments: deltaic, marine, and evaporitic.

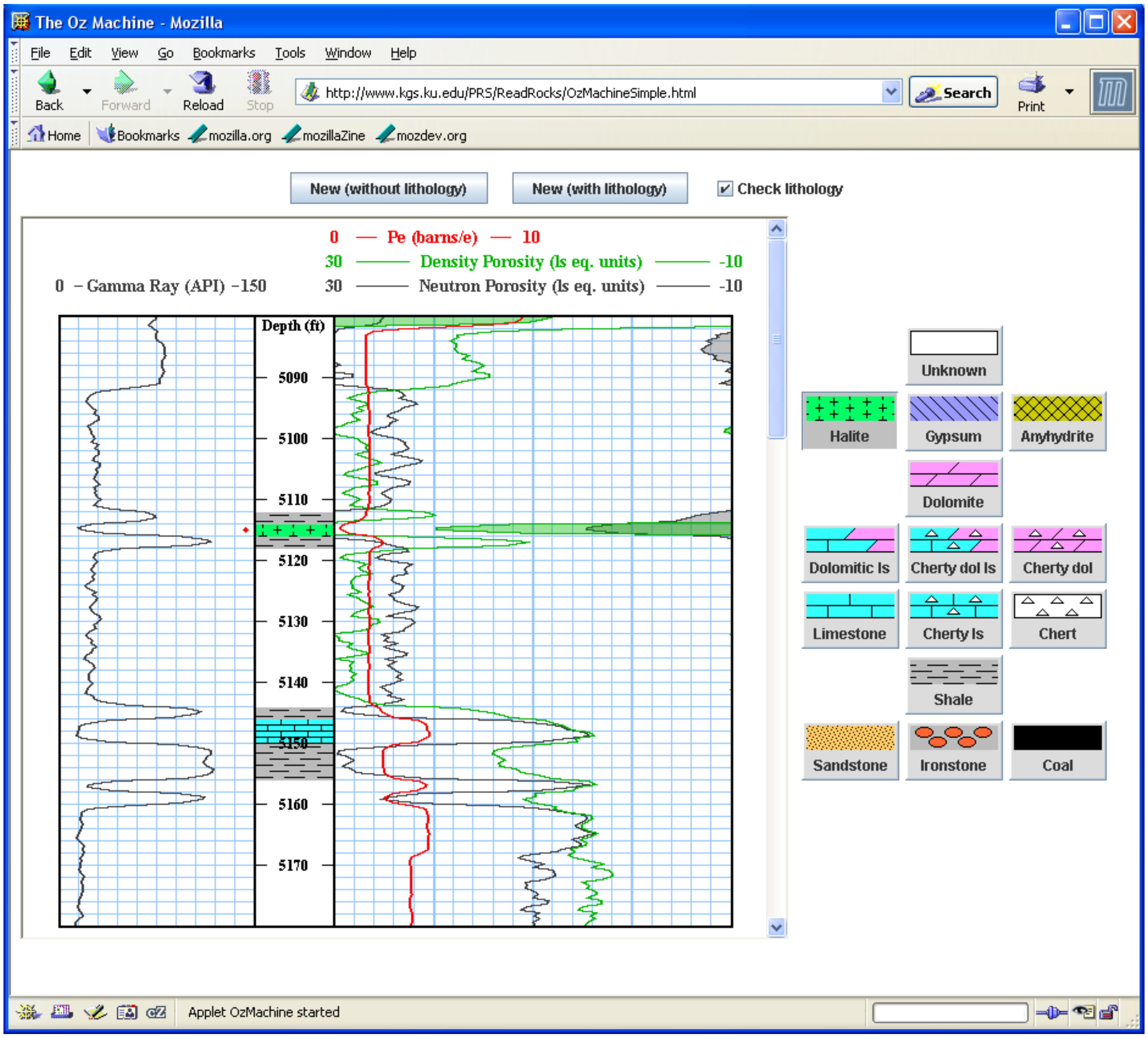

Figure 1. The Oz Machine in action. On each invocation, the software generates a new synthetic sequence of lithologies (rock types) and a corresponding sequence of petrophysical logs. The student's task is to interpret the lithological sequence from the logs.

Figure 1 depicts the Oz Machine in use. At the start of each exercise, the Markov chain simulation code generates a new synthetic sequence of lithologies and a corresponding sequence of well logs, displaying the latter in a format closely following petroleum industry standards. In Figure 1, the student is in the process of interpreting the lithologic sequence from the logs, filling in the center depth track of the display with rock types selected from the palette at right. Because the underlying true lithological sequence has been synthetically generated and is therefore known, the software can give the student feedback on incorrect picks, such as the halite placed between 5114 and 5116 feet depth, flagged with a red diamond to the left. Alternatively, the student can choose to develop the lithological sequence without this feedback. In addition, the student can click the "New (with lithology)" button to generate a display with the true lithological sequence already displayed in the depth track, allowing the generation of any number of sequences for study purposes.

In this pilot project we propose to expand on the approach implemented in the Oz Machine, developing code for generating a fully three-dimensional virtual subsurface and allowing interactive exploration of this volume for oil and gas. We will use existing Markov chain simulation code (Carle, 1999) to generate a three-dimensional distribution of lithologies (rock types) in the Small County subsurface, sequential Gaussian simulation to generate distributions of porosity and permeability within each lithology, and deterministic algorithms to fill the pore space with a realistic distribution of water, oil, and gas (Doveton, 2006). Figure 2 shows an example of a Markov chain simulation of lithology in a particular stratigraphic interval throughout a county-wide region. The Small County exercise will be based on similar 3D simulations, providing the virtual subsurface that the students will explore. Stochastic simulation techniques will also be used to generate 2D grids representing the spatially varying elevation of the top and base of the stratigraphic interval, imparting a realistic geologic structure to the simulated volume.

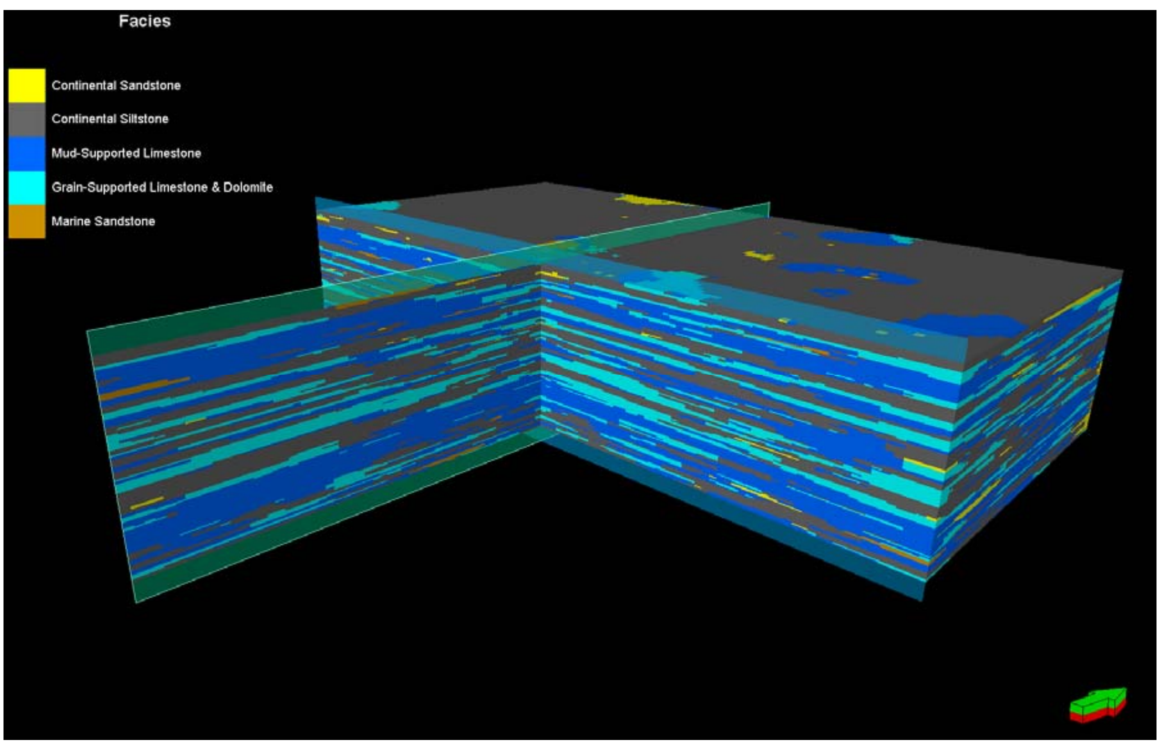

Figure 2. Markov chain simulation of facies distribution in a particular stratigraphic interval throughout a countywide region.

The web interface will provide the student with tools for siting exploratory wells and viewing the information obtained from them (mudlogs, geophysical well logs), for selecting locations for more extensive testing of formation properties and viewing the results of those tests, and finally, for deciding where to perforate wells for production and examining the resulting production rates. The interface will include a map display of the county to assist in the placement of wells. The individual-well petrophysical log display component of the interface will be designed to match industry standards, much like the Oz Machine, so that the student's experience in well log interpretation will be immediately transferable to industry settings. The fundamental feedback supplied to the student would be essentially the same as the feedback supplied by a real-world reservoir characterization exercise: How much money has been spent on the project so far and how much oil or gas has been produced. The simplified version for introductory courses will provide fewer options and require fewer decisions, focusing more on the lithological interpretation of the logs, as in the Oz Machine, with less emphasis on the assessment of fluid-related characteristics.

In many respects, the exercise will expand on the ideas currently implemented in the PlumeBusters Java application (http://www.kgs.ku.edu/Hydro/GWtutor/) developed by Bohling. This application provides students with an interactive exercise in locating and cleaning up a contaminant plume in a synthetic aquifer (Macfarlane et al., 2006). The PlumeBusters software simulates the transport of a contaminant plume in an alluvial aquifer, from a break in a pipeline towards a river. The student plays the role of an environmental consultant who has been hired by the pipeline owner to clean up the plume before it reaches the river. A set of html files explains the basic problem setting and problem-solving approach to the student and also provides background resource material on groundwater flow and transport in aquifers. The Java application provides the interactive exercise, in which the student first attempts to locate the plume by siting observation wells and then to remediate the plume using one of three different remediation options. The software provides the tools for siting wells on the map, guides the student through the steps in the process, and generates a log of the student's actions, along with tracking the student's expenditures to date. Figure 3 shows a snapshot of the PlumeBusters software in use. For the Small County exercise, we will develop code to provide similar interaction and guidance, but with greatly expanded feedback, including display of logs and cross-sections, and tools for display and analysis of the results of well tests requested by the student.

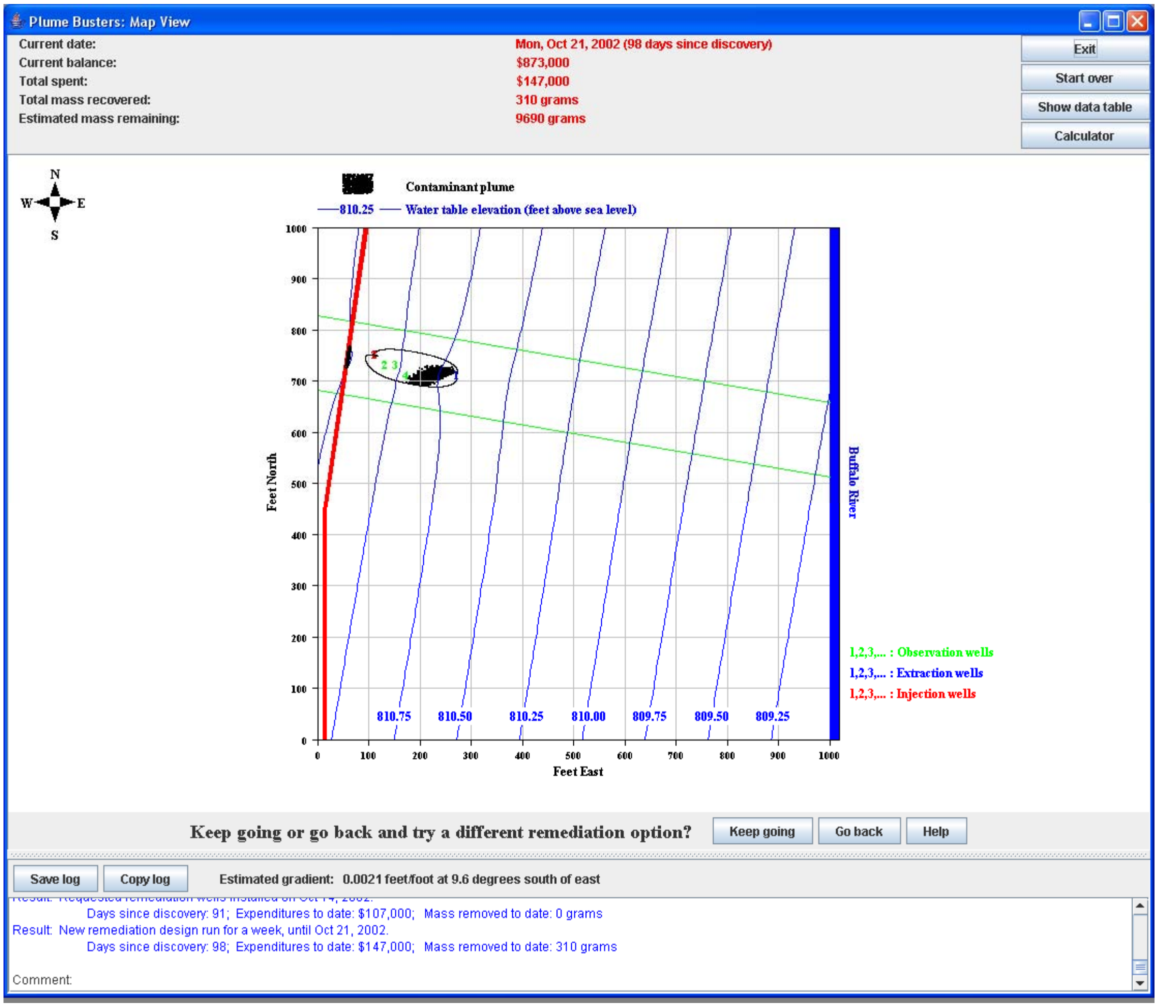

Figure 3. The PlumeBusters software in action. The student has successfully located the contaminant plume through the placement of several observation wells and is now attempting to clean up the plume using an extraction/injection pump and treat system.

The Kansas Geological Survey has a wealth of resources for development and support of web software, including several Oracle database servers with ample storage and nine web servers. These machines run an Apache Web Server, along with Cold Fusion for database connectivity and ESRI ArcIMS for mapping services. This project will employ these components in a fairly standard fashion. Each time a student starts an exercise, the geostatistical simulation programs running on the server will generate a distinct "realization" of the virtual subsurface, including two-dimensional grids representing the elevations of the top and base of the stratigraphic interval of interest and three-dimensional grids of the property distributions (lithology, porosity, permeability, fluid saturations) between those surfaces. These data and data associated with the student's exploration activities (placement of wells, etc.) would be maintained between sessions, so that a student could log out and log back in later to continue working on the same exercise (although the larger grids could be regenerated at the beginning of each session by retaining only the random number generator seed used in their initial generation). The browser-based user interface will be implemented as Java applets or in a scripting language such as JavaScript or PHP, and Cold Fusion would be employed to manage the interface to the database.

Precedents (Virtual Environments and Games in Geological Education):

Exploiting the ability of stochastic simulation techniques to generate a virtual subsurface for educational purposes, rather than their ability to mimic specific real-world reservoirs, would represent an innovative use of these techniques. Due to the inaccessibility of the subsurface and the expense of geological field trips, the use of fictional and virtual environments in earth science education is on the increase. A number of these exercises address the shallower subsurface, providing instruction in aquifer characterization for groundwater flow and contaminant transport problems. Renshaw et al. (1998) describe development and assessment of computer-aided instruction materials aimed at helping students understand Darcy's law, a fundamental physical principle governing fluid flow in the subsurface, and describe how they assessed the effectiveness of these materials based in part on their effect on students' ability to transfer the knowledge gained to problems concerning similar (linear proportionality) principles in other application domains. Li and Liu (2004) describe Interactive Groundwater, an extensive online laboratory allowing students to investigate numerous aspects of groundwater flow and transport modeling. Siegel and McKenzie (2004) report on an exercise in which students examine data from a simulated contaminant plume, with students divided into teams representing consulting firms for the three parties involved in a court case, two manufacturers whose operations have caused the contamination and an environmental group that is suing the two manufacturers. In order to prepare its case, each consulting team purchased field data, extracted from a model representing the true contamination event, from the instructors, with each team allotted a different operating budget. The exercise culminated in a daylong mock trial. Lev (2004) describes a similar but less extensive exercise, not involving a mock trial.

Publicly available instructional materials concerning the general task of petroleum reservoir characterization seem to be fairly rare. Soreghan and Soreghan (2003) describe a combined field and classroom reservoir characterization exercise involving exploration of an extensive database developed from a real-world saline aquifer, a highly characterized near-surface formation serving as surrogate for a more deeply buried reservoir (http://ags.ou.edu/~msoreg/4113/Res_char/Res_char.html). The data include photomosaics of the outcrop, Excel spreadsheets with porosity and permeability data separated by lithofacies, and gamma-ray logs from 22 boreholes drilled behind the outcrop. Students are asked to interpret these data essentially manually, working on paper and in Excel, in order to characterize the reservoir and determine the best approach to producing it. The American Association of Petroleum Geologists provides some instructional material on their Interactive Online Learning web site (http://www.aapg.org/iolcourse/index.cfm). However, this material must be purchased at a cost of $35 per module and is not designed to provide one continuous reservoir characterization exercise. We are not aware of any other educational project involving as extensive a simulation of the subsurface as we are proposing here.

The PI and Co-PI have considerable experience developing instructional material and software related to reservoir characterization and the external evaluator, Cervato, has considerable experience in development and assessment of computer-assisted instructional materials in the earth sciences, including projects involving development of virtual environments for student exploration (e.g., Gallus et al., 2006). During the 1970's and 1980's, Doveton was one of the instructors for a short course on risk analysis in petroleum exploration (Harbaugh et al., 1977). This course originally included an exploration game played by hand on a paper grid, which later evolved into a computer game that Bohling helped to program. Doveton has also developed numerous Excel spreadsheets as instructional materials in log analysis for both geological interpretation (focused on the rocks) and reservoir characterization (focused on the fluids), including the Log Analysis Yellow Pages (Doveton, 2001). Bohling has recently developed a synthetic dataset representing three different productive layers in a reservoir, serving as a basis for a reservoir characterization exercise in a course taught by John Davis at the Montanuniversität–Leoben in Austria and a tutorial in the use of a geostatistical data analysis package (http://people.ku.edu/~gbohling/geostats/WGTutorial.zip). In addition, the PI and Co-PI have developed two Excel add-ins for well log analysis, PfEFFER (Bohling et al., 1998; http://www.kgs.ku.edu/PRS/software/pfeffer1.html) and Kipling (Bohling and Doveton, 2000; http://www.kgs.ku.edu/software/Kipling/Kipling1.html), which Doveton has used in an instructional setting in short courses. The Oz Machine Java applet, described above, serves as a direct precursor to the proposed project, which will also share some characteristics with the PlumeBusters software, described above.

Cinzia Cervato, Associate Professor in the Department of Geological and Atmospheric Sciences at Iowa State University, will serve as an external evaluator on this project, helping with the assessment of its educational impact. She has extensive experience in the development of web-based and interactive instructional materials for the earth sciences. She has served as PI on NSF-funded projects to develop a calibrated peer review tool in earth sciences and as co-PI on a project involving development of a virtual tornadic thunderstorm, used for instruction in introductory meteorology courses. The latter project is similar in many respects to the project proposed here, giving the students an opportunity to virtually explore and collect data in an essentially inaccessible environment. The graphical user interface for the virtual tornadic thunderstorm allows the student to navigate to various locations within the storm and collect meteorological data, returned as vertical data profiles through the atmosphere at each areal location, making the exercise very analogous to the exploration of the earth's subsurface through boreholes.

Assessment: Although this Phase 1 project would focus primarily on the development of the web software, we would also assess its impact on student learning through pre- and post-tests designed in collaboration with the external evaluator and through the Co-PI's comparison of the performance of students who use the Small County exercise in upcoming semesters to those from previous semesters who have not used the exercise, viewed as an ad-hoc control group. In addition, the web interface will be designed to log student's actions and responses to queries, in order to assess the student's understanding of the concepts being explored.

Dissemination: The Small County exercise will be available on the Kansas Geological Survey's web site, which is already a popular destination for earth scientists searching for software, data, and educational material. We will also distribute it through the "Teach the Earth" web site of the Science Education Research Center (SERC, serc.carleton,edu) and DLESE. In addition, we will host a workshop in the spring or summer of 2009 aimed at introducing geology faculty to the Small County exercise in order to promote its widespread use. Papers in peer-reviewed journals and presentations at professional meetings will also promote awareness of these materials.

Timeline:

Spring-Summer 2008:

Development of initial version of software (PI, Research Assistant, and Co-PI).

Fall 2008:

Initial testing of software in Geol 536 (Geological Log Analysis) at the University of Kansas and Geol 304 (Physical Geology) at Iowa State University (PI, Co-PI, Consultant)

Spring-Summer 2009:

Code modifications in response to initial testing (PI, Research Assistant, Co-PI).

Workshop for geology faculty (PI, Co-PI)

Fall 2009:

Second phase of testing in Geol 536 and Geol 791 (Petroleum Log Analysis) at KU and Geol 304 at ISU (PI, Co-PI, Consultant).

Project features

Quality, Relevance, and Impact: As documented in Baker (2006), the nation is facing a significant shortage of skilled workers in the geosciences, especially in the petroleum industry. Thus, there is an immediate need for geoscience educators to pique students' interest in this field and provide them with experience that will be directly applicable to problems that they would face in professional life. This project will be of direct relevance to this pressing need, providing students with a glimpse of the challenges involved in subsurface characterization. The simulation techniques we will use to generate the virtual subsurface will provide students with a compellingly realistic exercise in subsurface exploration.

Student Focus: The Small County exercise will be directly aimed at providing undergraduate students with a high quality and engaging learning experience. The web-based exercise will meet students "where they live" and provide experience directly applicable to professional work in the geosciences. In addition, a simpler version of the activity will be available to non-STEM-major undergraduate students to give them a first-hand experience of the processes involved in locating and extracting hydrocarbon resources. We will also solicit student input regarding project design in the courses where we test it.

Use of and Contribution to Knowledge about STEM Education: This project will build on earlier educational materials developed by the PI and Co-PI, including the Oz Machine, PlumeBusters, and the various Excel workbooks and add-ins for petrophysical data analysis developed by the PI and Co-PI, which the Co-PI uses on a regular basis in short course settings. We will also survey and build on the experiences of other investigators in order to determine best practices in the use of virtual environments in education. In particular, we will make the activity accessible to the large community of geoscience educators who use the "Teach the Earth" web site (serc.carleton.edu) and solicit their input and recommendations through the SERC listserv.

STEM Education Community-Building: Dissemination of the Small County exercise through the Kansas Geological Survey web site, the Teach the Earth web site and DLESE, and promotion of its use through publications, meeting presentations, and workshops is going to spur community interest and lead to further developments in the use of virtual environments in geoscience education. The Kansas Geological Survey is already well known as a provider of digital data, software, and educational materials. We will announce the availability of the Small County exercise on the KGS's main web page, leading to immediate exposure to a wide audience of geoscientists, both in academia and industry.

Expected Measurable Outcomes: We expect this exercise to increase student's understanding of the use of petrophysical log data in subsurface characterization, in terms of both geological interpretation (rocks) and reservoir characterization (fluids). We will measure this improvement through pre- and post-tests and through logging of the students actions and responses to queries in the exercise itself.

Project Evaluation: The budget includes funding for an external evaluator, Cinzia Cervato of Iowa State University, who has considerable experience in the development of geoscience education materials. She will assist us in assessing the effectiveness of the Small County exercise, which we plan to measure through the pre- and post-tests mentioned above and student and community feedback regarding the design of the exercise.

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