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GEOPLAY, A Knowledge-Based Expert System—A Model for Exploration Play Analysis

By Betty M. Miller

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A knowledge-based expert system designed to perform as a diagnostic consultant to assist geologists to define potential petroleum plays, prospects, and reservoirs as input to an exploration play-analysis model used in the assessment of hydrocarbon resources

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GEOPLAY, A Knowledge-Based Expert System—A Model for Exploration Play Analysis

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ABSTRACT

GEOPLAY is a knowledge-based expert system designed to perform as a diagnostic consultant or intelligent guide to assist the geologist in the recognition, identification, and characterization of the geologic conditions used to define potential petroleum plays, prospects, and reservoirs as input to an exploration play-analysis model. It also provides the geologist with capabilities to document major basin components such as stratigraphy, structural geology, and sedimentation in order to evaluate the traditional concepts of source, reservoir, and trapping mechanisms.

GEOPLAY incorporates three basic sets of unique geologic conditions to characterize play-specific, prospect-specific, and reservoir-specific properties for the play-analysis model. These specific geologic conditions are evaluated for each identified play within a basin and constitute the basic geologic data for the expert-system's model. These geologic data are defined in terms of characteristics such as geologic age, lithology, environment of deposition, depositional systems, stratigraphy, structural style, organic types, and effective porosity used to evaluate source-bed and reservoir-bed conditions and trapping mechanisms.

GEOPLAY is a knowledge-based hierarchical system that follows the order of geologic reasoning used by an experienced geologist to arrive at a logical set of conclusions relative to the favorability of the geologic conditions under evaluation for prospective plays and prospects within a basin.

The knowledge-based structures in GEOPLAY are made up of classes, objects, attributes, values, IF-THEN Rules, and Goals, the concepts and constructions of which are described in this report. These elements work together to represent the knowledge and relationships linking the various geologic criteria within GEOPLAY's knowledge-based system.

The GEOPLAY expert system results in a better knowledge representation of the geologic relationships among basin, play, and prospect characteristics than do other methodologies currently available. It also provides a better means for the geologist to more effectively incorporate inexact information into the expert system to accommodate the uncertainties inherent in the geological data used for play analysis.

INTRODUCTION

Exploration and assessment of most of the world's energy and mineral resources require an understanding of their relations to the host strata and to the geologic and paleogeographic evolution of the sedimentary basins in which they occur. The most important product of the study of these host strata is a comprehensive basin analysis that demands an interpretation of data from many specialties, such as sedimentology, stratigraphy, geophysics, structural geology, and geochemistry, as well as the ability to assess and relate many types of multivariate spatial data.

The concepts and methods of sedimentary basin analysis and energy resource assessment have evolved from fairly simplistic geologic studies that employ primarily qualitative and semiquantitative techniques to studies of ever-increasing complexity that make use of quantitative evaluations of total basin systems within three-dimensional frameworks. One of the more popular techniques used for petroleum resource assessments is play analysis. In play analysis a basin is divided into prospective resource areas called plays. The resource-appraisal technique focuses on the play as a basic unit of geologic analysis in which one or more prospects are present in a common or fairly homogeneous geologic setting. A fundamental assumption is that geologic characteristics are significantly correlated within the play but show substantially less correlation between plays.

Computer assistance is essential in performing integrated basin and play-analysis procedures. New applications of knowledge-based expert-systems techniques adapted from Artificial Intelligence (AI) can be interfaced with computer mapping and data-analysis techniques, known as Geographic Information Systems (GIS) (Miller, 1992), to provide the tools needed to define new strategies and technologies for conducting and automating the complex tasks common to sedimentary basin analysis and exploration play analysis.

In this report I discuss current research in the application of expert systems and knowledge-acquisition techniques to (1) the design and development of an expert system model, called GEOPLAY, for characterizing exploration plays and (2) the geologic analysis of exploration plays for diagnosing geologic conditions favorable to the occurrence of petroleum resources.

Acknowledgments.—The work described in this report was mostly funded by the U.S. Geological Survey Director's GIS Sweepstakes award to the author in 1988 from funds to support GIS research and related computer techniques for geologic applications.

EXPLORATION PLAY ANALYSIS

Exploration play-analysis methods described in this report were first used by the U.S. Geological Survey in 1979 to assess the petroleum resources of the National Petroleum Reserve in Alaska (NPRA) (U.S. Department of the Interior, 1979). A Monte Carlo simulation model based on an exploration play-analysis approach was used to produce an appraisal of the conventional petroleum resources.

In the exploration play-analysis method used in the NPRA, the oil and gas resource base was simulated by the integration of two independent submodels: (1) a geologic submodel based on a probabilistic assessment of the most important geologic variables or attributes in a province or basin related to the occurrence of hydrocarbons, and (2) an exploration submodel that simulated the search for oil and gas in the basin, producing a sequence of discoveries that provided an inventory of pools for subsequent evaluation with the petroleum development and economic submodels. A detailed explanation of these submodels is given in White (1981).

The geologic submodel produced a list of prospects (potential drilling targets) and a resource appraisal of the oil and gas in-place by using subjective probability distributions for the values of the geologic variables estimated by experts familiar with the geology of the area. The original basic geology submodel designed for the NPRA study was modified and used for the basic geology model as the framework for the expert system GEOPLAY.

GEOLOGIC MODEL BASED ON THE PLAY-ANALYSIS APPROACH

The geologic assessment procedure devised specifically for application to the NPRA resource assessment focuses on the play as a basic unit of geologic analysis. A play is an area within a basin in which the geology and geophysics indicate that any prospects present may have similar combinations of the major assessable geologic attributes: hydrocarbon sources, reservoir beds, and traps. Equally important, but more difficult to assess, are the attributes of thermal history and the relative timing of oil generation, migration, and entrapment. In brief, a play consists of one or more prospects in an common or fairly homogeneous geologic setting that can be explored using geologic, geochemical, and geophysical techniques.

The play is a useful analytical concept that allows the analysis to be sensitive to the physical processes involved in the entrapment of oil and gas and in the discovery of oil and gas accumulations. A fundamental assumption is that the geologic characteristics are significantly related within a play but show substantially less correlation between plays. Thus, if all the regional geologic characteristics necessary for the occurrence of trapped hydrocarbons are present within the play area, the play probably will contain accumulations of oil or gas or both; however, if one or more of the significant geologic characteristics is missing or unfavorable, all the prospects within the play probably will be unsuccessful. The primary output for the geologic model is a probabilistic appraisal of oil and gas resources in-place for each play.

The play approach divides the geologic characteristics of a potential deposit into three categories: play-specific, prospect-specific, and reservoir-specific (Eckbo and others, 1978). Therefore, for each play, three sets of probabilistic judgments are elicited from experts familiar with the local geology. Figure 1 is an example of the data form for recording these judgments used in the geologic model and is referred to later in this report for the basic framework used in the expert system.

Play-specific attributes consist of geologic characteristics common to the play as a unit and include favorable lithology, hydrocarbon source, timing, migration, reservoir rock, and number of drillable prospects. The product of the single-value probability estimates for hydrocarbon source, timing, migration, and potential reservoir facies is termed the marginal-play probability; that is, the joint probability that all regional geologic characteristics necessary for the existence of oil or gas deposits or prospects in the play are simultaneously favorable.

Prospect-specific attributes are the geologic characteristics common to the individual prospects within the play and include trapping mechanism, minimum effective porosity, and hydrocarbon accumulation. The probability judgment of the presence or absence of these geologic characteristics is made conditional on the favorable existence of all four play attributes. The product of the three prospect-attribute probabilities is termed the conditional deposit probability; that is, the probability that a particular prospect is an actual accumulation of oil or gas, given that all the play attributes are favorable.

Reservoir-specific attributes are the reservoir characteristics of an individual deposit of oil or gas in the play and include area of closure, reservoir thickness, effective porosity, trap fill, reservoir depth, water saturation, and

Oil and Gas Appraisal Data Form

Evaluator: ____________________ Play Name ____________________

Date Evaluated: ____________________

Attribute			Probability of Favorable or Present	Comments
Play Attributes	Hydrocarbon Source			
	Timing			
	Migration			
	Potential Reservoir Facies			
	Marginal Play Probability			
Prospect Attributes	Trapping Mechanism			
	Effective Porosity (>3%)			
	Hydrocarbon Accumulation			
	Conditional Deposit Probability			
Hydrocarbon Volume Attributes	Reservoir Lithology	Sand		
		Carbonate		
	Hydrocarbon	Gas		
		Oil		

Attribute \ Fractiles	Probability of equal to or greater than							Comments
	100	95	75	50	25	5	0	
Area of Closure ($\times 10^3$ Acres)								
Reservoir Thickness/vertical closure (Ft)								
Effective Porosity %								
Trap Fill (%)								
Reservoir Depth ($\times 10^3$ Ft)								
No. of drillable prospects (a play characteristic)								

Proved Reserves ($\times 10^6$ Bbl; TCF) (If known production)	

Figure 1. Oil and gas appraisal data form used to assess resources in the play-analysis system for the National Petroleum Reserve in Alaska study. From U.S. Department of the Interior (1979, p. 121) and Miller (1993, p. 14).

hydrocarbon type. The reservoir-volume characteristics jointly determine the volume of oil or gas present in the reservoir or pool for a simulated deposit.

These three basic sets of subjective judgments—play-specific, prospect-specific, and reservoir-specific—are made for each of the identified plays within a basin and constitute the basic geologic data that were entered in the geologic submodel used in the 1979 NPRA petroleum assessment study (Bird, 1988; Miller, 1988).

PROBLEMS INHERENT IN THE APPLICATION OF THE EXPLORATION PLAY-ANALYSIS APPROACH

Problems inherent in the application of exploration play analysis to petroleum resource appraisal were recognized during the time of the NPRA study. One problem concerns the amount and kinds of available data necessary for credible input by the geologists for each attribute. In frontier areas where few data are available, the subjective evaluations for the attributes are usually based on comparisons with analogs. The resulting resource assessments are only as good as the geologic analogs or the geologic assumptions made by the geologists in arriving at the subjective evaluations for the attributes as recorded on the form illustrated in figure 1. In addition, there is no means by this method to document the geologic assumptions made or the uncertainties involved in the decision-making procedures to arrive at the subjective evaluations recorded as input to the geologic submodel.

Another serious problem recognized in the NPRA study is that many geologists are unfamiliar with the basic principles relative to probability distributions. Additional concerns expressed by geologists relate to their acceptance of the geologic assumptions built into the model and to the uncertainties in arriving at assigning values as input on the data form for specific probabilities for the individual attributes. A related concern is the assumption that all the attributes in the play-specific- and prospect-specific-analysis models are independent, when in fact, many of the geologic and reservoir attributes are interrelated.

Additional problems of concern in the exploration play-analysis procedures used in the NPRA study, but which are not applicable to this study, are summarized in Miller (1988). Those relative to the play-analysis procedures cited above are addressed in this report. Some solutions to these problems are discussed in the application of an expert system's model for play-analysis procedures.

EXPERT-SYSTEMS TECHNOLOGY

In recent years, research in applied artificial intelligence has achieved considerable success, especially in the industrial and business world. Among the most significant of these successes—and one that has attracted both business and research interests since the mid-1960's—is the development of powerful computer software programs known as expert systems or knowledge-based systems. These programs are designed to present and apply factual knowledge and rules drawn from experts in specific areas to solve complex problems. This area of artificial intelligence research concentrates on constructing high-performance software that uses symbolic programming to replicate the knowledge, reasoning, and linguistic skills of people in specialized professional domains. These knowledge-based systems are different from conventional programming techniques used to create the large data-processing systems that we commonly associate with computers. By means of complex algorithms, conventional systems collect and process large volumes of factual data to build information data bases. In contrast, knowledge-based systems combine facts, specialized knowledge, and the expert's subjective judgment, as well as any levels of uncertainty relative to the available knowledge.

Even though numerous uses for expert systems are now considered feasible for many domains of expertise, these systems are not currently in wide use nor are they readily available in the public domain. Some better known expert systems are used as diagnostic tools in the medical profession, such as INTERNIST and MYCIN (Hayes-Roth and others, 1983); for chemical analyses, such as DENDRAL (Hayes-Roth and others, 1983) and AAexpert (Lahiri and Stillman, 1992); and as exploration tools in mineral prospecting, such as PROSPECTOR (Duda and others, 1981). Several prototype expert systems have been designed by the USGS for microcomputers, such as muPETROL (Miller, 1986, 1987a, b, 1991) for classification of sedimentary basins for petroleum assessment and an abbreviated version of PROSPECTOR, called muPROSPECTOR (McCammon, 1986, 1990). In general, however, very few expert systems presently being used in the earth sciences are available for public use. A more detailed discussion of various expert systems and expert-systems technology is given in Miller (1993).

KNOWLEDGE-BASED SYSTEMS

An expert system is defined as a reasoning system that uses a knowledge base to capture and replicate the problem-solving ability of human experts. Knowledge-based systems contain structured data and reasoning rules that link the evidence about a problem to derived conclusions or hypotheses. The domain knowledge is a data base that contains the facts and rules of the problem domain (such as play analysis) as described by the human expert. The inference engine, that part of a knowledge-based system that contains the general problem-solving knowledge or inference and the control strategies, solves problems and deduces results or diagnoses conditions based on user input and information contained in the knowledge base. In expert systems, separation of the knowledge base from both the inference engine and the user interface allows the knowledge base to be maintained, updated, and expanded without changing the entire control structure.

Knowledge in most specialties, and particularly in the earth sciences, is usually derived from both public and private sources. Public knowledge includes published definitions, facts, and theories typically contained in textbooks, references, and maps in the domain of study. Expertise in research, government, and industry, however, generally calls for access to confidential records, techniques, and methodologies and requires possession of private knowledge that is not part of the published literature. This unpublished expert knowledge frequently consists of rules of thumb, based on experience, that have come to be called heuristic rules, or heuristics.

Heuristics enable the expert to make decisions or educated quesses when necessary, to recognize promising solutions to problems, and to deal effectively with incomplete or uncertain data. Techniques now being developed in artificial intelligence research are capable of dealing with inexact reasoning in expert systems. These various schemes, with their ability to simulate reasoning under uncertain conditions, provide an ideal tool for applications in the geologic sciences. The capabilities of these expert systems in dealing with reasoning under uncertainty are essential to the geologist, who must work with information that is frequently incomplete, inferred or interpretive, often uncertain, and sometimes unreliable and who must bridge the unknown with little or no information in frontier areas. For a more detailed discussion of knowledge-based expert systems and knowledge acquisition techniques see Miller (1993).

Sound expert systems must also accommodate several types of uncertainty inherent in earth-science problem solving. The first type of uncertainty is associated with factual knowledge. For example, geologic evidence may be difficult to observe or is unavailable. It may be ill-defined or may have been measured using unreliable techniques or equipment. Most expert systems associate numeric values such as probabilities or certainty levels with factual information to account for this type of uncertainty.

The second type of uncertainty is present in the inference rules or heuristics themselves. For example, inference rules represent the experience, judgment, or intuition inherent in the interpretive reasoning of experienced geologists. Even the judgment of experts can contain a degree of uncertainty. Most expert systems deal with this type of uncertainty by assigning a value to each rule that expresses the degree or probability for which an expert believes an inference rule to be valid.

The third type of uncertainty is the user's own measure of belief in a particular piece of evidence. An example is a geologist's belief in the reliability of his data as to the certainty of occurrence of any essential geologic attribute used for the analysis. Some expert systems allow the user to personally assign the degree of uncertainty for an answer (Lecot and Parker, 1986).

OBJECT-ORIENTED DATA BASES

A new concept in data bases is gaining acceptance in the application of expert systems. This concept is the object-oriented data base, which can store, retrieve, and manage any type of graphic, text, numeric, or functional information.

Broadly speaking, an object refers to any physical or conceptual entity that may have many attributes (properties or characteristics) and that is an elementary unit of description of anything—a thing, a concept, or an event (Harmon and King, 1985). A collection of objects that usually share attributes is called a class. Class, the first fundamental concept of object orientation, is the hierarchical construct most commonly used to define abstract data types in object-oriented systems. Figure 2 illustrates part of an expert system in which all interactions with information relative to basin stratigraphy are through the protocol or interface operations of the class Basin Stratigraphy (Miller, 1993). The objects' attributes define the structure or state of the basin's stratigraphy. They correspond to properties or characteristics in relational data bases.

Inheritance, the second fundamental concept in object-oriented data bases, allows the expert to design and explore the properties inherited by objects and classes in relation to the rules. Within an existing hierarchy, an ordered network of concepts or objects in which some are subordinate to others, the expert can build new classes that can inherit behavior (such as operations or methods), attributes, and specific values for variables from existing classes. For example, in figure 2 each class has a set of objects covering various geologic characteristics, such as lithology and geologic age. All classes in the hierarchy share these objects because they all inherit from superclass Basin Types. The third fundamental concept of object orientation is object identity, the property that distinguishes each object from all others. With this property, objects can contain or refer to other objects. Object identity organizes the objects manipulated by an object-oriented program.

Object-oriented knowledge representation is an ideal methodology for applying expert systems to the earth sciences. It has an intuitive appeal because it provides better concepts and tools with which to model and represent the real world than does the more simplistic rule-based approach to expert systems, which only focuses on representing the reasoning steps for the particular problem to be solved (Sacerdoti, 1991). Object-oriented systems offer the means to identify the physical and conceptual objects that characterize the decision-making process by providing a data-modeling method that identifies and documents physical and conceptual entities, events, and their relationships to one another. Such systems allow the user to identify classes and objects,

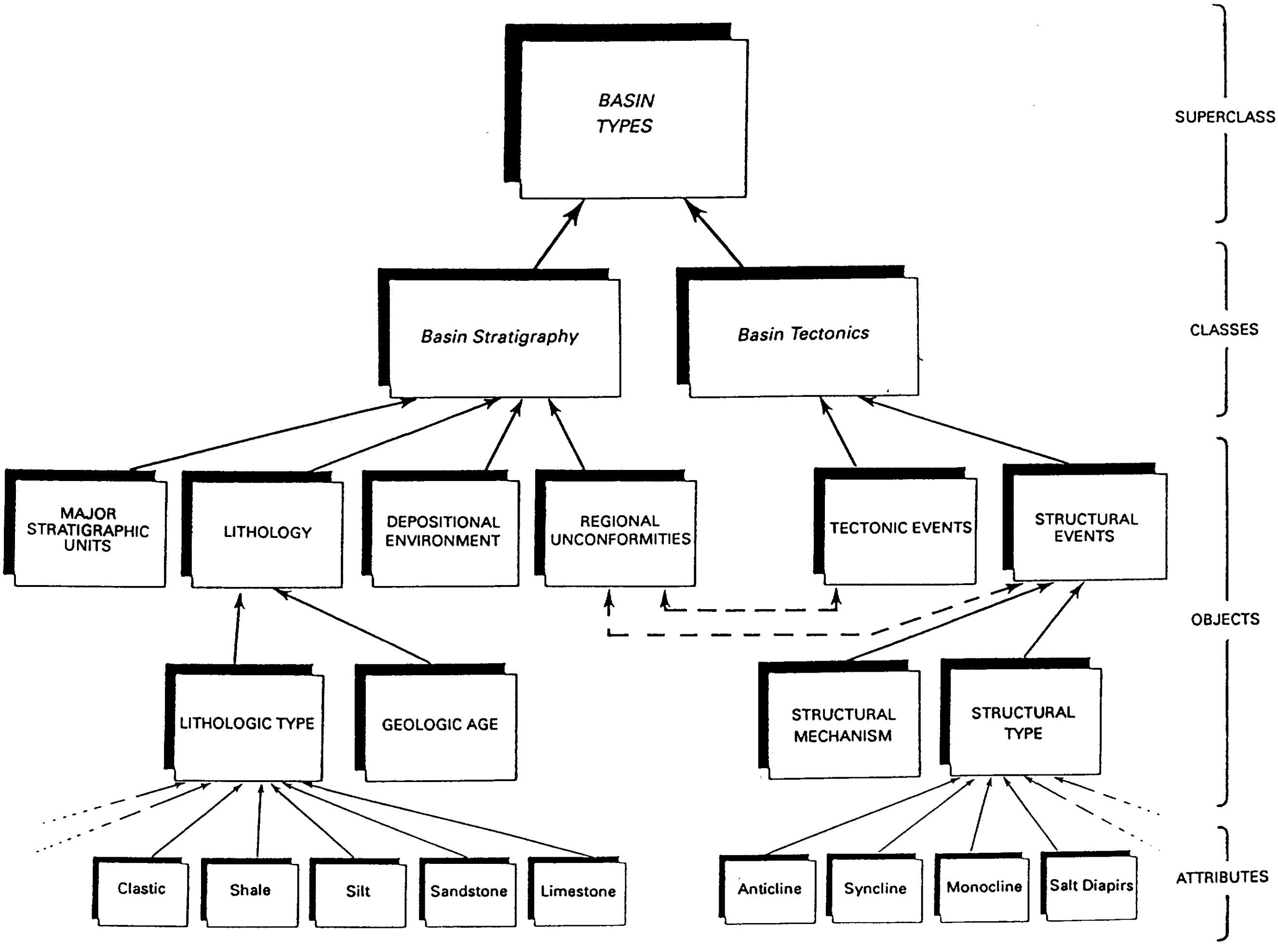

Figure 2. Partial hierarchy within an object-oriented sedimentary basin expert system. Modified from Miller (1993, p. 5).

and their attributes and relationships, and to define the behavior and interactions between objects and classes. Object-oriented systems also reveal the reasoning processes used by the experts and many of the rules, procedures, and constraints used in the decision-making process. Class-object-attribute relationships are ideal for characterizing the geologic conditions used to define decision-making procedures in basin and play analysis. For a more detailed description of object-oriented data-based systems see Miller (1993).

EXPERT-SYSTEM SHELL FOR PLAY ANALYSIS

The basic architecture of an expert system can be divided into two parts. The knowledge base and working memory make up one part of the system, and the inference engine and all of the subsystems and interfaces constitute the second part (fig. 3). The knowledge base contains the facts, rules, and heuristics that embody expert knowledge. The inference engine contains the inference strategies and controls, explanations, and user-interface subsystems that experts employ when they manipulate facts and rules to reach a decision or conclusion.

A major effort in the world of commercial software is the development of off-the-shelf expert-system shells—computer programs that provide the framework for developing expert systems. Using shells greatly reduces the task of developing a new expert system. These products differ from programming languages in that they already contain the inference engine and various interface and knowledge-acquisition aids that determine how they will apply reason to reach a conclusion; however, they lack the rules and facts contained in the knowledge base. Thus the primary attention in working with an expert-system's shell is focused on the acquisition of the knowledge and development of the rules that make up the construction of the knowledge base.

In this report I describe the development and implementation of GEOPLAY, an expert system for characterizing exploration plays and diagnosing the geologic conditions favorable for the occurrence of potential plays, prospects, and reservoirs within a basin. GEOPLAY is built using an

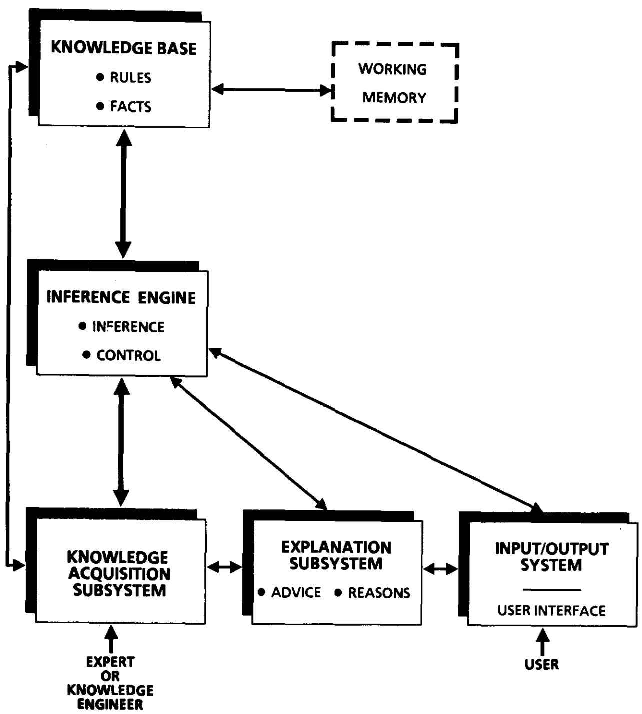

Figure 3. Basic architecture of an expert system. Modified from Harmon and King (1985, p. 34).

expert-system development tool or shell called MAHOGANY (Emerald Intelligence, Ann Arbor, Mich.). Other expert-system shells that have been developed for object representation and that have a rule-based reasoning mechanism were reviewed for this project: KEE (Knowledge Engineering Environment, by IntelliCorp, Mountain View, Calif.), KEYSTONE (Technology Applications, Jacksonville, Fla.), and NEXPERT OBJECT (Neuron Data, Palo Alto, Calif.) (Miller, 1993).

MAHOGANY was selected for this project for many reasons. It is a user-friendly system, especially for the geologist who is not a computer programmer in the LISP or C programming languages. One of its most promising features is that it allows the experts to assign certainties directly to the rules and to the data values used within the knowledge base. It also allows the geologist as the user to assign certainty values to his or her answers. The geologist may also set priorities for the goals or decision-making sequences. This basic feature allows the geologist to deal with the uncertainties that are a significant part of the geologic knowledge base.

MAHOGANY includes the following specific features that are essential to the design of GEOPLAY (Emerald Intelligence, 1990):

- Dealing with problems that have many variables or pieces of information that affect the answer, situations that have no single right answer, but for which the best solution must be selected, and problems that have some contributing factors that are unknown or uncertain
- Representing knowledge using a class-object-attribute hierarchy and multiple inheritance for objects and attributes
- Storing knowledge by the use of a rule-based structure composed of an IF, a THEN, an ELSE, and an UNKNOWN clause; using AND and OR binding in complex multiple IF clauses in designing rule structures
- Reasoning and inferencing strategies for deriving geologic characteristics for play analysis based on information provided by the geologist
- Inference strategies based on forward chaining (data driven), backward chaining (goal driven), and synergistic inference, which combines both backward- and forward-chaining to provide a more complete set of conclusions
- Interfacing with the user (geologist) to acquire essential information relative to the characteristics defined in the geologic model. Interface options are menu driven and graphics oriented
- Assigning certainties to the rules and facts within the knowledge base and to the geologist's answers
- Selecting options for statistical methods to calculate the certainties or probabilities that conclusions or goals are correct. These methods include average, cumulative, highest, lowest, or product (joint probability) techniques for calculating certainties
- Setting probability thresholds below which a rule will not be considered in arriving at a conclusion
- Designing goals to answer the questions or arrive at a conclusion, to determine the path of the decision-making process, and to retrieve and document specific information from the geologist or the knowledge base
- Editing and creating the knowledge-base elements through specific editors; that is, Rule Editor, Word Editor, Object Editor, and Goal Editor

In order to use the GEOPLAY expert system the MAHOGANY expert-system shell is needed to provide the inference engine that runs the program.

GEOPLAY—A MODEL FOR EXPLORATION PLAY ANALYSIS

GEOPLAY is a diagnostic consultant or intelligent guide to assist the geologist in organizing, documenting, and analyzing, in a consistent manner, geologic data to differentiate petroleum plays, prospects, and reservoirs. These data are defined in terms of the essential geologic characteristics needed to describe source-bed and reservoir-bed conditions and trapping mechanisms and include properties such as geologic age, lithology, environments of deposition, depositional systems, stratigraphy, and structural style.

GEOPLAY allows the geologist to assign numeric values in terms of certainties or beliefs to record the level of confidence in the essential geologic criteria used to characterize the petroleum plays and prospects under evaluation. The relations between the essential geologic characteristics and the favorability of the play and prospect qualities are set by the geologic rules of thumb and may also have associated certainty values provided by the geologic experts. Combinations of certainty or belief values in essential criteria, together with the relations supplied by the experts in the rule base, establish the overall belief in the derived conclusions relative to the favorability of the play and prospect characteristics. Less experienced geologists are able to follow the play-analysis concepts and understand and focus on the essential geologic characteristics needed to arrive at the subjective judgments required in the play-analysis model.

BUILDING THE KNOWLEDGE BASE

In GEOPLAY three basic sets of unique geologic conditions are identified to characterize the play-specific, prospect-specific, and reservoir-specific properties for the play-analysis model. These specific geologic conditions are evaluated for each of the identified plays within a basin and constitute the basic geologic data in the model.

To arrive at the subjective judgments elicited to complete the data form shown in figure 1, the geologist must, however, call upon considerable background experience and additional supportive data relative to the geologic conditions within the respective basin or play in order to record the single values on the data form expressing probabilities of occurrence or favorability for each of the respective attributes. It is in the role as a consultant to the geologist that GEOPLAY provides the means to explore and evaluate the basic geologic framework of the basin and plays to arrive at the subjective judgments recorded in the play-analysis model.

GEOPLAY's knowledge base is a hierarchical scheme based on a multilinked structure or decision tree showing the relations between the various geological criteria defining a play, prospects, and reservoir conditions. The hierarchical scheme attempts to follow the order of geologic reasoning used by an experienced geologist to arrive at a logical set of conclusions relative to the geologic conditions under evaluation.

Knowledge-based structures developed within the MAHOGANY system are made up of Classes, Objects, Attributes, Values, Rules, and Goals. These elements work together to represent the knowledge and the relationships linking the various geologic criteria within the knowledge-based system.

OBJECT-ORIENTED HIERARCHY

Figure 4 illustrates GEOPLAY's hierarchy by means of a Class-Object-Attribute-Value decision-tree structure or network. Incorporating the terminology used on the data form (fig. 1) in designing the hierarchical scheme, there are three superclasses: Play Attributes, Prospect Attributes, and Hydrocarbon Volume Attributes. The use of the expression "attributes" within the superclass names is taken directly from the data form and should not be confused with its usage in the object-attribute relationship as referred to in the hierarchical structure. In the superclass Play Attributes (fig. 4), there are four classes: Hydrocarbon Source, Timing, Migration, and Potential Reservoir Facies, which reflect the design of the data form. Under the class Hydrocarbon Source there is one major object, Probable Source Beds, and 13 attributes. These 13 attributes are:

Direct Evidence
Geologic Age
Lithology
Environment of Deposition
Structural Form for Basin Development
Maturity Level of Source Beds
Type of General Kerogens
Percent of Total Organic Carbons (TOC)
Quality of Source Beds
Proximity to Reservoir Beds
Areal Extent of Source Beds
Average Depth to Source Beds
Average Total Thickness of Source Beds

Each of the 13 attributes has its own set of values. These values are entered by the geologist either as a single numeric value or from an automatic-value selection provided for the geologist to answer the query as presented in a text field (see fig. 5). For example, tracing this hierarchical structure one level lower, under the attribute Geologic Age of Source Beds there are eight age categories for value selection by the geologist.

Geologic age	Percentage[1]
Quaternary/Oligocene/Upper Cretaceous	15.3
Middle through Lower Cretaceous	31.6
Upper Jurassic through Upper Permian	26.2
Lower Permian/Pennsylvanian/Middle Mississippian	8.4
Lower Mississippian through Devonian	8.3
Silurian	9.0
Ordovician through Cambrian	1.0
Upper Proterozoic (Vendian)	0.2

[2] Age "* * * distribution of effective source rocks given as a percentage of the world's original petroleum reserves generated by these rocks." These percentage distributions are used in the construction of the rules to determine source-rock favorability (Klemme and Ulmishek, 1991, p. 1810).

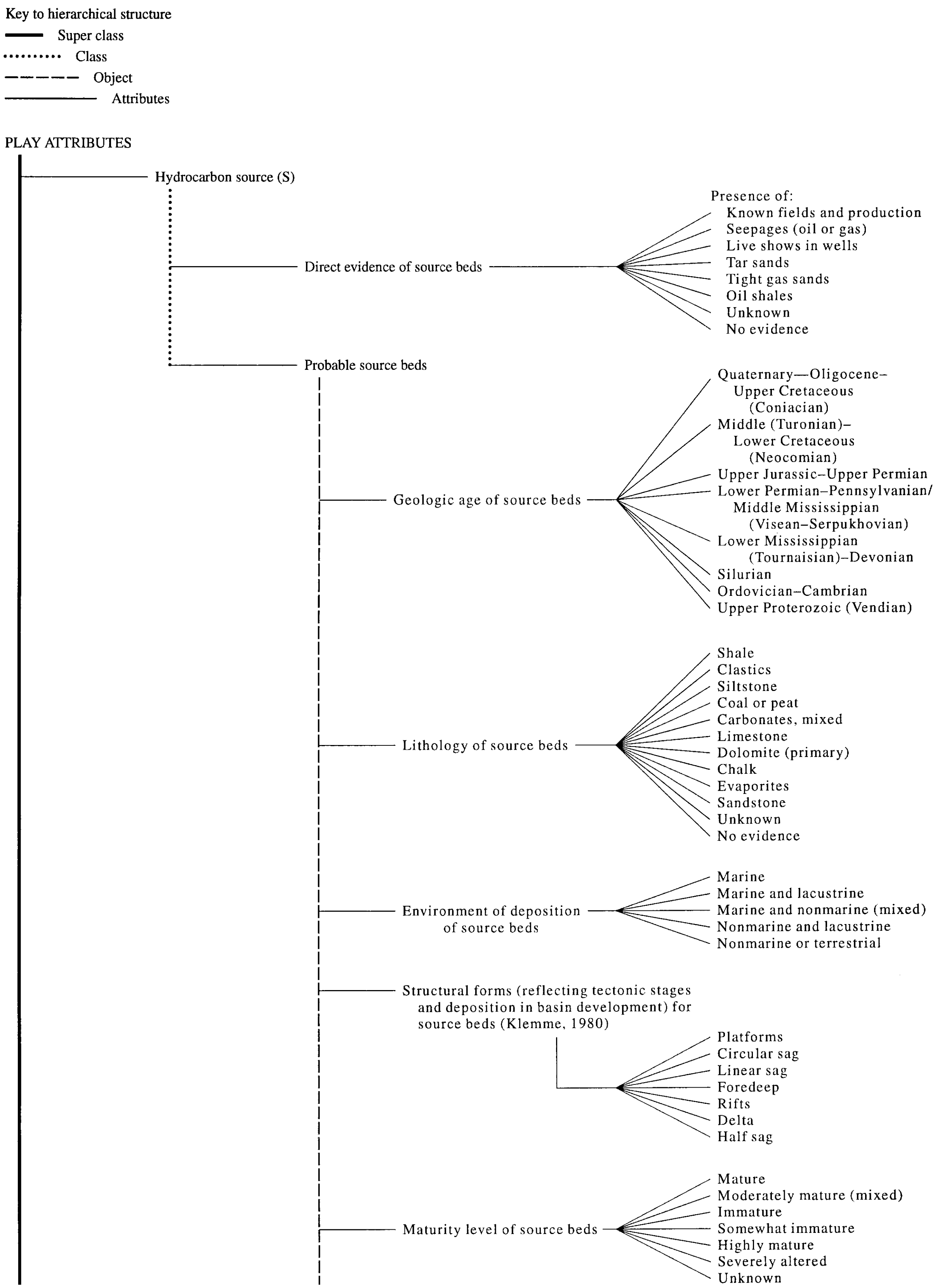

Figure 4 (above and following pages). GEOPLAY's hierarchy using the Class-Object-Attribute-Value format to define the decision-tree structure.

- Probable source beds
  - Type of general kerogens (organic material) predominant in source beds
    - Type I. Alginite (sapropelic or lipid-rich)
      Properties:
      - Hydrogen rich, H/C >0.5–1.5
      - Oxygen low, O/C <0.1
      - Vitrinite reflectance, >0.5–0.7
      - Low reflectance
      - High fluorescence
      - Marine and lacustrine
      - Oil prone
    - Type II. Exinite (phytoplankton, zooplankton, other microorganisms)
      Properties:
      - Hydrogen rich, H/C 0.7–1.3
      - Oxygen low, O/C 0.05–0.2
      - Vitrinite reflectance, 0.45–0.6
      - Intermediate reflectance
      - No fluorescence (usually)
      - Mainly marine, some lacustrine
      - Both oil and gas prone
    - Types I and II (both)
    - Type III. Vitrinite and huminite (terrestrial plant debris)
      Properties:
      - Hydrogen poor, H/C <1.0
      - Oxygen rich, O/C 0.09–0.30
      - Vitrinite reflectance, 0.75–1.10
      - High reflectance
      - No fluorescence
      - Terrestrial, marginal marine, or marginal lacustrine
      - Gas prone (methane)
    - Type IV. Inertinite "dead carbon"
      Properties:
      - Low H/C (can't generate hydrocarbons)
      - High O/C
  - Total organic carbon in source beds ____________ (numeric single value, in percent)
    - Good >1.0
    - Fair 0.5
    - Poor <0.5
  - Quality of source beds
    - Good
    - Fair
    - Poor
    - Unknown
  - Proximity to reservoir beds
    - Highly favorable
    - Favorable
    - Unfavorable
    - Unknown
  - Areal extent of source beds ____________ (numeric single value, in square miles)
  - Average depth to source beds ____________ (numeric single value, in feet)
  - Average total thickness of source beds ____________ (numeric single value, in feet)
- Timing (T)
  - Geologic indicators for timing
    - Highly favorable
    - Favorable
    - Unfavorable
    - Unknown
- Migration (from source beds to reservoir beds) (M)
  - Geologic indicators for migration
    - Highly favorable
    - Favorable
    - Unfavorable
    - Unknown

- Potential reservoir facies (R)
  - Potential reservoir beds
    - Geologic age of reservoir beds
      - Quaternary—Oligocene–Upper Cretaceous (Coniacian)
      - Middle (Turonian)–Lower Cretaceous (Neocomian)
      - Upper Jurassic–Upper Permian
      - Lower Permian–Pennsylvanian/ Middle Mississippian (Visean–Serpukhovian)
      - Lower Mississippian (Tournaisian)–Devonian
      - Silurian
      - Ordovician–Cambrian
      - Upper Proterozoic (Vendian)
    - Reservoir lithology
      - Sandstone
      - Carbonates, mixed
      - Limestone
      - Dolomite, mixed
      - Siltstone
      - Evaporites
      - Shale
      - Igneous
      - Metamorphic
      - Unknown
      - No evidence
    - Environment of deposition of reservoir beds
      - Marine
      - Marine and lacustrine
      - Marine and nonmarine (mixed)
      - Nonmarine and lacustrine
      - Nonmarine or terrestrial
    - Structural forms (reflecting tectonic stages and deposition in basin development for reservoir facies) Klemme, 1980)
      - Platforms
      - Circular sag
      - Linear sag
      - Foredeep
      - Rifts
      - Delta
      - Half sag
    - Quality of reservoir beds
      - Good
      - Fair
      - Poor
      - Unknown
    - Average effective porosity of reservoir beds in play (numeric single value, in percent) ____________
    - Average depth to reservoir beds in play (numeric single value, in feet) ____________
    - Average total thickness of reservoir beds in play (numeric single value, in feet) ____________
    - Probable areal extent of reservoir bed in play (numeric single value, in acres) ____________
- Marginal play probability (MP), calculated ($S \times T \times M \times R = MP$) ____________
- Number of drillable prospects (a play characteristic)
  - FRACTILE LEVELS
    Probability of equal to or greater than
    (numeric single value)
    - 100% ____________
    - 95% ____________
    - 75% ____________
    - 50% ____________
    - 25% ____________
    - 5% ____________
    - 0% ____________

PROSPECT ATTRIBUTES

- Trapping mechanism (TM)
  - Trap type
    - Structural
      - Structural relations
        - Block (Extension: horst, tilted fault blocks, uplifts, fault traps, arches, combinations)
        - Fold (Compression: symmetrical to asymetrical, overthrust folds, fold belts, thrust zones, combinations)
        - Growth (Extension and vertical load: listric growth faulting, rollover anticlines, slump features, topographic subsidence-depression, combinations)
        - Flow (Vertical load commonly related to compression: flowage of salt, evaporites, shale, and igneous in form of diapir, dome, swell)
        - Reef (Carbonate buildup, depositional, combination stratigraphic and drape traps)
        - Unknown
        - No evidence
    - Stratigraphic
      - Stratigraphic relations
        - Channels, lenses, bars
        - Facies changes, porosity, permeability variations
        - Unconformity related
        - Onlap, transgressive facies
        - Offlap, regressive facies
        - Paleorelief, truncations, compaction
        - Impermeable seals
        - Hydrodynamic conditions
        - Diagenetic conditions
        - Unknown
        - No evidence
    - Combination
      - Yes
      - No
      - Unknown
  - Status of traps
    - Number tested (numeric single value) ________________
    - Number untested (numeric single value) ________________
    - Unknown
    - No evidence
- Effective porosity (>3 percent) (P) (numeric single value) ________________
- Hydrocarbon accumulation (HCA)
  - Conditions
    - Favorable
    - Unfavorable
  - Evidence
    - Known accumulations
      - Oil prone
      - Gas prone
      - Both
    - Unknown
    - No evidence
- Conditional deposit probability (CP), calculated (TM x P x HCA = CP) ____________

HYDROCARBON VOLUME ATTRIBUTES

- Area of closure (× 10^3 acres)
  - FRACTILE LEVELS
  - Probability of equal to or greater than (numeric single value)
    - 100% ________
    - 95% ________
    - 75% ________
    - 50% ________
    - 25% ________
    - 5% ________
    - 0% ________
- Reservoir thickness / vertical closure (feet)
  - FRACTILE LEVELS
  - Probability of equal to or greater than (numeric single value)
    - 100% ________
    - 95% ________
    - 75% ________
    - 50% ________
    - 25% ________
    - 5% ________
    - 0% ________
- Effective porosity (percent)
  - FRACTILE LEVELS
  - Probability of equal to or greater than (numeric single value)
    - 100% ________
    - 95% ________
    - 75% ________
    - 50% ________
    - 25% ________
    - 5% ________
    - 0% ________
- Trap fill (percent)
  - FRACTILE LEVELS
  - Probability of equal to or greater than (numeric single value)
    - 100% ________
    - 95% ________
    - 75% ________
    - 50% ________
    - 25% ________
    - 5% ________
    - 0% ________
- Water saturation (percent)
  - FRACTILE LEVELS
  - Probability of equal to or greater than (numeric single value)
    - 100% ________
    - 95% ________
    - 75% ________
    - 50% ________
    - 25% ________
    - 5% ________
    - 0% ________
- Reservoir depth (× 10^3 feet)
  - FRACTILE LEVELS
  - Probability of equal to or greater than (numeric single value)
    - 100% ________
    - 95% ________
    - 75% ________
    - 50% ________
    - 25% ________
    - 5% ________
    - 0% ________
- Reservoir engineering equation for volume of hydrocarbons (calculated) = ________

Proved reserves

Oil (× 10^6 barrels)
(numeric single value) ________

Gas (trillion cubic feet)
(numeric single value) ________

These geologic-age categories for source beds are based on the studies of Klemme and Ulmishek (1991). The "ages" of Klemme and Ulmishek (1991) are not geochronologic ages (early, middle, late) but rather are chronostratigraphic assignments (lower, middle, upper). Furthermore, their use of "Middle Cretaceous" and "Middle Mississippian" does not follow conventional usage. Their "Middle Cretaceous through Lower Cretaceous" category apparently comprises the interval from the Upper Cretaceous Turonian Stage through the Lower Cretaceous Berriasian Stage. The base of their "Middle Mississippian" appears to fall within the Lower Mississippian Osagean of conventional usage. Finally, the formal geochronologic subdivisions of the Archean and Proterozoic in the United States have no formal chronostratigraphic counterparts. Thus, the latest formal subdivision is the Late Proterozoic Era, but there is no formal "Upper Proterozoic" Erathem (USGS, Geologic Names Unit, 1994).

OBJECT AND ATTRIBUTE EDITORS

The construction of the class and member objects quickly develops into a hierarchy or network of knowledge. MAHOGANY's Object Editor allows the expert to create this object hierarchy. Although MAHOGANY creates objects and attributes automatically as rules are being built, the user can also build objects and attributes directly giving additional flexibility to developing the knowledge base. I chose this method of developing the object hierarchy as a natural step after the design of the hierarchical structure illustrated in figure 4.

The Attribute Editor gives the expert more specific control over the design of each attribute in the knowledge base. It provides the expert with the means to fine tune the inferences involving a particular attribute, to create new attributes, and to preset values for each attribute in the knowledge base. Values represent the actual working answers by the geologist on which the inference engine bases its conclusions. Values can be expressed as a constant or numeric answer, an expression (such as a selection from a list of responses such as the geologic age categories), or a reference to another attribute (fig. 5). Appendix 1*A* displays the Object-Attribute-Value hierarchy created by the expert for the superclasses Play Attributes and Prospect Attributes from the GEOPLAY knowledge-base file. The Object-Attribute-Value hierarchy created for the superclass Hydrocarbon Volume Attributes from the GEOPLAY knowledge base is listed in appendix 1*B*. This knowledge-base file, providing the geologist's input to the probability distributions for the reservoir attributes, interfaces with the Monte Carlo simulation methods as used in the original play-analysis procedures. Input from the knowledge-base file, in the form of probability distributions, can also be used in the current probabilistic methodology being used by the USGS for estimation of petroleum resources by play analysis (Crovelli, 1992).

RULE-BASED SYSTEM

GEOPLAY uses rules as the building blocks to store the expert's knowledge structures in the knowledge base. Each rule consists of a discrete category of expert knowledge, usually implying a relationship between two or more distinct objects. Rules represent the knowledge statements composed of interrelated facts and rules of thumb that are used to solve problems; in this case, the characterization of the geologic criteria essential to the favorability of the occurrence of prospective plays and prospects. A rule consists of two parts. The first part, consisting of one or more IF clauses, establishes antecedent conditions or the premise that must apply or be true if a second part, consisting of one or more THEN clauses with consequent propositions, is to be concluded or acted upon. The rules are used to support the deductive processes, and they form the basis of knowledge formation.

All of the knowledge-base design for GEOPLAY focuses on a consultation process that assists the geologist in assigning probabilities for the essential geologic attributes as being favorable or present. This consultation process is designed to address the three groups of rules: (1) play-specific, (2) prospect-specific, and (3) reservoir-specific or hydrocarbon volume accumulation, as shown in figure 1.

The first group of rules focuses on play-specific characteristics and lists the relationships between hydrocarbon source, timing, migration, and potential reservoir facies. The second group of rules, focusing on prospect-specific characteristics, distinguishes the trapping mechanism, effective porosity, and hydrocarbon accumulation attributes. The third group of rules, directed to the hydrocarbon volume parameters or reservoir-specific attributes, provides a means for estimating the area of closure, reservoir thickness, effective reservoir porosity, trap fill, reservoir depth, and water saturation of reservoirs. The queries in this last group request estimates from the geologist at the percent fractile levels (100, 95, 75, 50, 25, 5, 0), providing input for probability distributions for each of the attributes as an interface to the Monte Carlo simulation model for estimating the size and number of drillable prospects.

The acquired knowledge is structured into an object-attribute-value format as shown in figure 4. Twenty-four key geologic criteria characterize such information as geologic age, lithology, environments of deposition, basin history, organics, and volumes and depths of source and reservoir beds for prospective plays and prospects. Seven additional criteria characterize the trapping mechanism for the prospect attributes. Queries are associated with each of the 31 criteria and are presented to the geologist through a menu-based window interface when specific information is required. Responses to the queries appear as a menu of choices in the

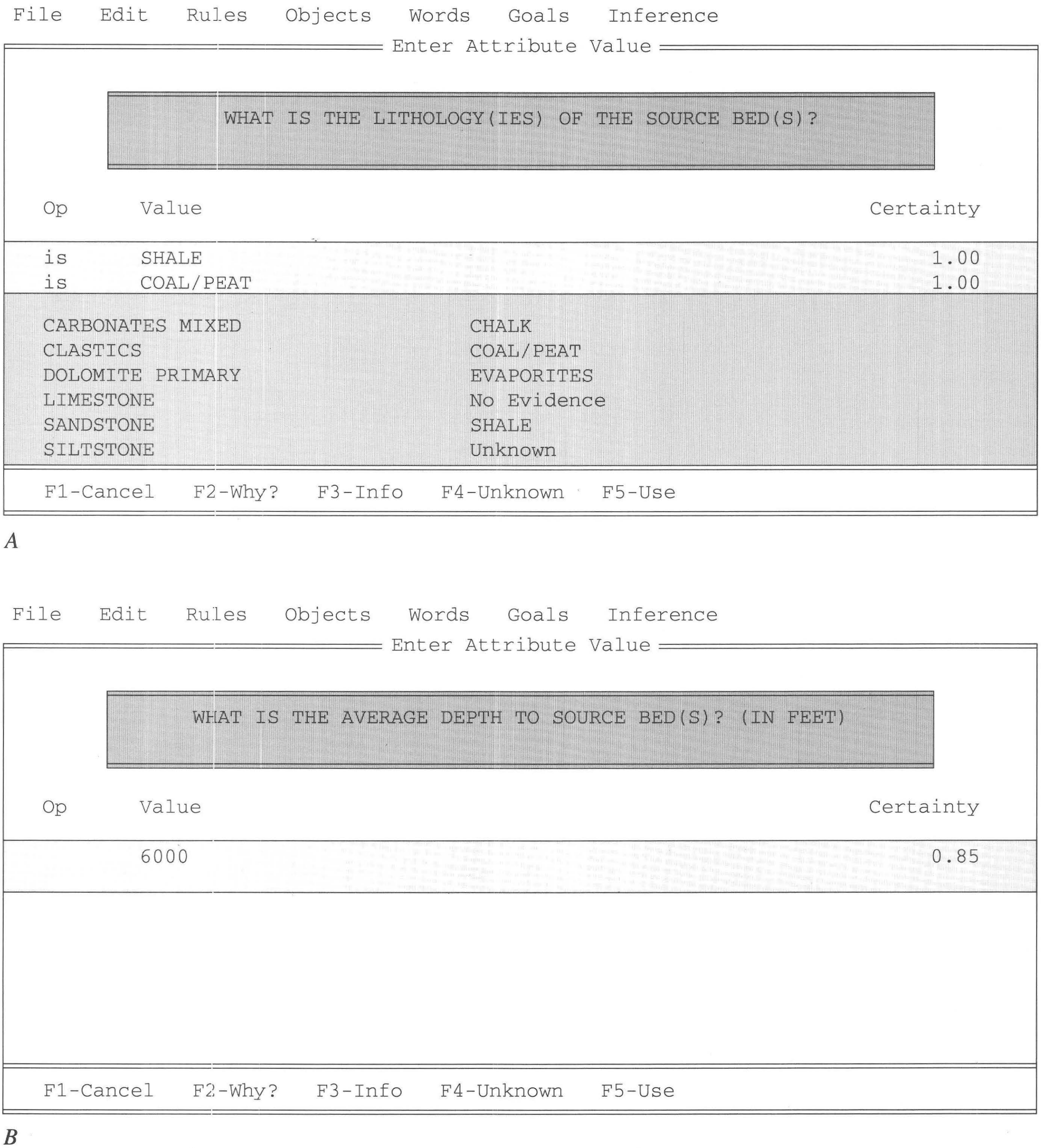

Figure 5. Enter Attribute Value window in GEOPLAY. *A*, Example of automatic-value selection provided for geologist to answer query regarding lithology of source beds. The geologist has selected SHALE and COAL/PEAT as the entry values with a 100 percent certainty. *B*, Example of query requesting direct entry from user in form of single numeric value to the question, what is the average depth to source beds (in feet)? The geologist has entered the value of 6,000 ft with an 85 percent certainty.

window, and the geologist can either select the appropriate answers or enter numeric values, as requested. At this time the geologist can indicate belief or certainty in the answers to record his or her level of confidence in the response to the query. The Rule Editor incorporates the certainty values with the rules and their respective certainties as created by the geologic experts. Certainties and threshold values do not have to be entered by the geologist if the automatic defaults of 1.00 for certainty values and 0.20 for threshold values are acceptable.

The expert geological knowledge was compiled and organized by me and later modified after running repeated test cases. Application of GEOPLAY by the geologist is discussed in greater detail later in this report.

STRUCTURE OF A RULE

Each rule is composed of four major parts: an IF, a THEN, an ELSE, and an UNKNOWN part. The IF part of a rule is basically a test. IF clauses specify conditions that must be satisfied under the current circumstances for the THEN part to be activated. THEN clauses do the work. When the IF conditions are satisfied, the THEN clauses initiate a task or store the knowledge.

When the IF clause conditions are not satisfied, the ELSE clause takes action and performs its function. ELSE is an optional clause. When the IF conditions cannot be found to be true or false due to a lack of information, the UNKNOWN clause is activated. UNKNOWN is also an optional clause.

A rule takes on the basic form as shown below.

Connector	Object	Attribute	Operator	Value
IF	______	______	____	______
AND	______	______	____	______
OR	______	______	____	______
THEN	______	______	____	______
AND	______	______	____	______
ELSE	______	______	____	______
UNKNOWN	______	______	____	______

Connectors within the IF part of the rule are AND or OR. Connectors are used to attach multiple clauses using Boolean logic. The object and attribute fields in each part of the rule designate which object and which attribute of that object is being used by that part of the rule. These are the same objects and attributes shown in the object-attribute hierarchy. Operators in IF clauses define the condition that must exist between the object-attribute and a specific value. This is the condition that will be tested when the rule is activated. These operators include Is, Is Not, > (greater than), ≥ (greater than or equal to), < (less than), ≤ (less than or equal to), = (equal), and <> (not equal). Additional operators are available in THEN, ELSE, and UNKNOWN clauses such as TEXT, which displays a text file that contains only ASCII text, and SHOW, which displays a graphic image and must be in a.pcx graphic format along with its file name.

The IF and THEN, IF and ELSE, and IF and UNKNOWN parts of the rule structure together can define three distinct relationships between two or more objects or conditions. This rule-structure format provides a powerful tool for creating the logic and deductive processes followed by a geologist in conducting geologic evaluation procedures.

An example of a fairly simple rule in GEOPLAY's knowledge base is shown below as written in the Rule Editor.

Rule 1 Priority 50 Highly Favorable Direct Evidence of Hydrocarbons

IF --

(1) the HYDROCARBON SOURCE DIRECT EVIDENCE OF SOURCE BEDS is "Known Fields/Production" [threshold 0.20]

(2) OR the HYDROCARBON SOURCE DIRECT EVIDENCE OF SOURCE BEDS is "Live Shows in Wells" [threshold 0.20]

(3) OR the HYDROCARBON SOURCE DIRECT EVIDENCE OF SOURCE BEDS is "Seepages" [threshold 0.20]

(4) AND the MIGRATION (from source to reservoir beds) GEOLOGIC INDICATORS FOR MIGRATION is "Highly Favorable" [threshold 0.20]

(5) AND the TIMING GEOLOGIC INDICATORS FOR TIMING is "Highly Favorable" [threshold 0.20]

THEN --------------------------------------

(1) the PLAY PROPERTY is "Highly Favorable with Good Direct Evidence of Hydrocarbons"

Note: HYDROCARBON SOURCE, MIGRATION (from source to reservoir beds), TIMING, and PLAY are Objects; DIRECT EVIDENCE OF SOURCE BEDS, GEOLOGIC INDICATORS FOR MIGRATION, GEOLOGIC INDICATORS FOR TIMING, and PROPERTY are Attributes; and "Known Fields/Production," "Live Shows in Wells," "Seepages," and "Highly Favorable" are Values for the respective Attributes.

Rule 1 is read in the following manner. IF a *hydrocarbon source* assumed to be present as expressed by the *direct evidence of source beds* such as the presence of *known fields/production*, or by the presence of *live shows in wells*, or by the presence of oil and(or)gas *seepages*; and by *migration from source to reservoir beds* with *geologic indicators for migration* being *highly favorable*; and the *timing* for the origin and migration of petroleum expressed by *geologic indicators for timing* as being *highly favorable*; THEN the *play property* can be described as *highly favorable with good direct evidence of hydrocarbons* being present in the play. This rule is only the first in a series of rules evaluating the conditions of the hydrocarbon source beds relative to a potential play.

RULE EDITOR

The Rule Editor in MAHOGANY is simple to use and requires no specialized computer programming language skills. As soon as the rule is typed in and saved, that rule is a part of the knowledge base. The Rule Editor allows the expert to quickly create new rules and modify or delete old rules. Appendix 2 displays 18 rules and their respective IF-THEN rule structures showing the Object-Attribute-Value formats and their respective conclusions for the play-specific and prospect-specific evaluations.

GOAL-BASED CONSULTATION

The last phase in the building of GEOPLAY using the MAHOGANY system is its basic goal structure. Goals define the specific categories of information that the geologist wants to retrieve from a knowledge base. Goals are unknowns, or questions that the geologist wants GEOPLAY to address and to resolve. All goals are designed to identify an object and its respective attribute for GEOPLAY and to attempt to find a value for it. This is done by querying the geologist for information and then by applying the rules of thumb built into the knowledge base. All of the certainty or belief values and priority rankings are automatically incorporated as basic information to evaluate the goals to be solved. All goals are designed as requests for information or to aid in decision-making procedures; each goal in the program attempts to find values for the attribute specified in the respective goal.

The goals in GEOPLAY are designed to aid in the consultation process, evaluating the essential geologic criteria that guide the geologist through a decision-making process and assigning probabilities for the play and prospect attributes as being favorable or present as displayed on the data form in figure 1. The outcome of GEOPLAY's search for the requested values in each goal is displayed in the Conclusions window. See appendix 4 for an example of the information shown in the Conclusions window. The content of the Conclusions window is controlled by the goals as designed and by their assigned priorities. In order to include the display of an attribute's value in the Conclusions window, a goal must be created for that attribute. Inference and conclusion procedures are discussed in more detail later in this report.

GOAL EDITOR

The Goal Editor is used to create, edit, and delete goals and contains three data entry fields: Object, Attribute, and Priority. The Object field identifies the object to be tested. The Attribute field identifies the object-attribute to be tested. The Priority field indicates which goal will be solved first if multiple goals exist. If no priority value is entered by the user the priority defaults to 50 (out of 100). Goals having higher priorities are solved first. Appendix 3 displays 15 goals and their objects, attributes, and assigned priorities as currently being used. Goals are easily designed, modified, or deleted using the Goal Editor, and can readily be changed depending on the information or conclusions the geologist is seeking from the knowledge base.

INFERENCE STRATEGIES, CONSULTATION, AND CONCLUSIONS IN GEOPLAY

Inference is the process by which new facts are derived from known facts. The part of the MAHOGANY system that finds these facts and makes decisions as displayed on the Conclusions screen is called the inference engine, as shown in figure 3. The inference process requires steps that vary depending on the method of inference selected by the user.

Inference strategies in an expert system are usually based on either forward- or backward-chaining. In a forward-chaining system, data are retrieved from the knowledge base, and the inference engine reports on any conclusions it can make by using the IF-THEN rules. Thus, a forward-chaining system is said to be data driven. In a backward-chaining system, the inference engine works backward from the goals or the conclusions, trying to determine whether the subject of the rule is true for a particular goal. Backward-chaining systems are thus said to be goal driven.

The forward- or backward-chaining system can be combined with either a depth-first or breadth-first search. Depth-first searches conduct a search through all levels of a decision-tree branch until a conclusion or a contradiction is reached. Breadth-first searches thoroughly search all branches at each level, then search the next level of positive responses only. This process is repeated until a conclusion is reached. Thus, the breadth-first search is a complete strategy, and, if the problem posed by the user has a solution within the knowledge base, this search will find it.

GEOPLAY follows a system for determining the value of an attribute as expressed in the respective goal. It searches the knowledge base for all target attributes in the order of their priorities, looking for an attribute value. Whenever a value cannot be resolved internally, it asks the geologist for a response. An inquiry can be designated for each attribute in the Attribute Editor. As soon as a value is found, GEOPLAY stops searching and uses that value. If GEOPLAY examines all its sources without success, the attribute is considered to be unknown. The effect of an unknown attribute varies from knowledge base to knowledge base.

The consultation phase begins when the GEOPLAY system asks the geologist about relevant data and uses the data to deduce intermediate goals and conclusions. Additional information is collected and combined with existing conclusions and with certainty and belief values. This process continues until all of the attribute-values are found or determined to be unknown and all of the goals satisfied to reach the designated conclusions.

Whenever GEOPLAY requires user input to a query the Enter Attribute Value window is presented on the screen. Figure 5 shows Enter Attribute Value windows with examples of an automatic-value selection provided for the geologist and a direct entry for a numeric answer requested of the geologist.

USER STRATEGIES FOR RESULTS AND CONCLUSIONS

To initiate the GEOPLAY decision-making procedure, the geologist selects from the Inference menu either the option Attempt All Goals or the option Attempt One Goal. Attempt All Goals is a general-purpose inference method used to evaluate all goals created within the Goal Editor. This procedure backchains on multiple goals, backchaining on each goal individually until all goals are resolved. The goal priorities determine the order in which the goals will be solved. The Attempt All Goals process can be made more exhaustive through the use of the Synergistic option on the control panel. When all backchaining is complete, the Synergistic option causes GEOPLAY to forward chain on any updated values in the knowledge base.

The option Attempt One Goal is similar to Attempt All Goals, except that the inference engine only backchains on one pre-set goal. When the geologist selects Attempt One Goal from the Inference menu, a Goal Select window appears so that the user can select a specific goal. In this option the back-chaining process asks the geologist to create a temporary goal for that particular inference pass.

CONSULTATION PROCESS AND APPLICATIONS

As a first approach to applying GEOPLAY's consultation process, which assists the geologist in evaluating the essential geologic criteria in the play- and prospect-analysis procedures, a set of values was defined for each of three favorability classes. These classes were designed specifically for evaluating the geologic characteristics for the direct evidence of hydrocarbons present, for probable source beds, and for potential reservoir beds. These favorability classes are:

Class 1 Highly favorable play and prospect attributes with little known risk. Play favorability range recommended to user 80–100 percent

Class 2 Favorable play and prospect attributes but with a higher degree of risk than in Class 1. Play favorability range recommended to user 30–79 percent

Class 3 Unfavorable play and prospect attributes with a high degree of risk; or many of the geologic attributes are unknown at this time and more information is needed. Play favorability range recommended to user 1–29 percent

Table 1 provides guidelines for the geologist in the choice of values for the source bed and reservoir bed attributes used in the rule-base. These values are used to define the three favorability classes that determine the probability of the play-specific attributes being favorable within a basin or province. The geologist would rarely expect all values to fall consistently within one class but rather would expect a mixture of favorable or unfavorable geologic conditions for the different attributes. Appendix 4 displays an example of the conclusions arrived at by GEOPLAY using the attribute-values illustrated in table 1 as defined for a highly favorable play.

The weighting factors used to aid in assigning the values for each of the geologic attributes for the favorability classes are based on the geologic experience of the experts and on results from published studies addressing many of the geologic criteria. For example, information for the distribution by geologic age of the world's petroleum resources as generated from the source beds and as trapped within the reservoir beds is taken from studies by Klemme and Ulmishek (1991). These values for the geologic age of the source beds and the reservoir beds were assigned to the three favorability classes as follows:

Geologic age	Source bed (percent distribution)	Reservoir bed (percent distribution)
Class 1		
Middle through Lower Cretaceous	31.6	28.1
Upper Jurassic through Upper Permian	26.2	24.9
Quaternary/Oligocene/Upper Cretaceous	15.3	26.9
Class 2		
Silurian	9.0	--
Lower Permian/Pennsylvanian/ Middle Mississippian	8.4	12.7
Lower Mississippian through Devonian	8.3	2.1
Ordovician through Cambrian	--	2.1
Class 3		
Silurian	--	0.2
Ordovician through Cambrian	1.0	--
Upper Proterozoic (Vendian)	0.2	0.1

See table 1 for all the attribute values assigned for each of the three favorability classes. The weighting factors and values assigned to these classes can easily be changed in the rule structures by using the Rule Editor.

Table 1. Guide to values for source-bed and reservoir-bed attributes for each of three favorability classes for GEOPLAY.

CONDITIONS HIGHLY FAVORABLE FOR A PLAY	
I. Probable source beds (rules 4 and 10)	
Geologic age of source beds	
1. Middle through Lower Cretaceous	31.6 percent generated of world's resources
2. Upper Jurassic through Upper Permian	26.2 percent generated of world's resources
3. Quaternary/Oligocene/Upper Cretaceous	15.3 percent generated of world's resources
Environment of deposition of source beds	
*Marine	
*Marine and nonmarine (mixed)	
*Marine and lacustrine	
Lithology of source beds	
*Shale	
*Clastic	
*Siltstone	
Maturity level of source beds	
*Mature	
Proximity to reservoir beds	
*Highly favorable	
Quality of source beds	
*Good	
Structural forms/deposition in basin for source beds	
1. Linear sags	39.2 percent of world's resources
2. Circular sags	19.9 percent of world's resources
3. Platforms	18.6 percent of world's resources
Types of general kerogens in source beds	
*Types I and II, both	
*Type II	
Total organic carbon in source beds	
*$\geq$1.00 percent	
Areal extent of source beds $\geq$750 mi^2	
Average depth to source beds $\geq$5,000 ft AND Average depth to source beds $\leq$15,000 ft	
Average total thickness of source beds $\geq$200 ft	
II. Potential reservoir beds (rules 7 and 13)	
Geologic age of reservoir beds	
1. Middle through Lower Cretaceous	28.1 percent of trapped world's resources
2. Quaternary/Oligocene/Upper Cretaceous	26.9 percent of trapped world's resources
3. Upper Jurassic through Upper Permian	24.2 percent of trapped world's resources
Environment of deposition of reservoir beds	
*Marine	
*Marine and nonmarine (mixed)	
Lithology of reservoir beds	
*Sandstone	
*Carbonates, mixed	
*Limestone	
*Dolomite, mixed	
Quality of reservoir beds	
*Good	

Table 1. Guide to values for source-bed and reservoir-bed attributes for each of three favorability classes for GEOPLAY—Continued.

CONDITIONS HIGHLY FAVORABLE FOR A PLAY—Continued	
II. Potential reservoir beds (rules 7 and 13)—Continued	
Structural forms/deposition in basin for reservoir beds	
1. Linear sags	39.2 percent of world's resources
2. Circular sags	19.9 percent of world's resources
3. Platforms	18.6 percent of world's resources
Probable areal extent of reservoir beds in play ≥1,000 acres	
Average depth to reservoir beds in play ≥5,000 ft AND	
Average depth to reservoir beds in play ≤15,000 ft	
Average total thickness of reservoir beds in play ≥200 ft	
Average effective porosity of reservoir beds in play ≥10 percent	
III. Direct evidence of hydrocarbon source (rules 1, 2, and 3)	
Hydrocarbon source	
Direct evidence of source beds	
*Known fields and production	
*Live shows in wells	
*Seepages	
Migration (from source beds to reservoir beds)	
Geologic indicators for migration	
*Highly favorable	
Timing	
Geologic indicators for timing	
*Highly favorable	
Source bed(s)	
Conditions	
*Highly favorable for HCs potential	
Potential	
*Highly favorable for a successful play	
Reservoir bed(s)	
Conditions	
*Highly favorable for potential reservoirs	
Potential	
*"Highly favorable for a successful play	
Play	
Property	
*Highly favorable with good direct evidence of HCs	
CONDITIONS FAVORABLE FOR A PLAY	
I. Probable source beds (rules 5 and 11)	
Geologic age of source beds	
4. Silurian	9.0 percent generated of world's resources
5. Lower Permian/Pennsylvanian/Middle Mississippian	8.4 percent generated of world's resources
6. Lower Mississippian through Devonian	8.3 percent generated of world's resources
Environment of deposition of source beds	
*Marine and lacustrine	
*Nonmarine and lacustrine	
Lithology of source beds	
*Carbonates, mixed	
*Limestone	
*Coal or peat	

Table 1. Guide to values for source-bed and reservoir-bed attributes for each of three favorability classes for GEOPLAY—Continued.

CONDITIONS FAVORABLE FOR A PLAY—Continued	
I. Probable source beds (rules 5 and 11)—Continued	
Maturity level of source beds	
*Moderately mature, mixed	
*Somewhat immature	
Proximity to reservoir beds	
*Favorable	
Quality of source beds	
*Fair	
Structural forms/deposition in basin for source beds	
4. Foredeep	9.2 percent of world's resources
5. Rifts	5.7 percent of world's resources
6. Deltas	4.5 percent of world's resources
Types of general kerogens in source beds	
*Type I	
*Type III	
Total organic carbon in source beds	
*≥0.5 percent AND	
*≤0.999 percent	
Areal extent of source beds ≥300 mi^2 AND	
Areal extent of source beds ≤749 mi^2	
Average depth to source beds ≥2,500 ft AND	
Average depth to source beds ≤4,999 ft	
OR	
Average depth to source beds ≥15,001 ft AND	
Average depth to source beds ≤24,999 ft	
Average total thickness of source beds ≥50 ft AND	
Average total thickness of source beds ≤199 ft	
II. Potential reservoir beds (rules 8 and 14)	
Geologic age of reservoir beds	
4. Lower Permian/Pennsylvanian/Middle Mississippian	12.7 percent of trapped world's resources
5. Lower Mississippian through Devonian	5.4 percent of trapped world's resources
6. Ordovician through Cambrian	2.1 percent of trapped world's resources
Environment of deposition of reservoir beds	
*Marine and lacustrine	
*Nonmarine and lacustrine	
Lithology of reservoir beds	
*Siltstone	
*Evaporites	
*Shale	
Quality of reservoir beds	
*Fair	
Structural forms/deposition in basin for reservoir beds	
4. Foredeep	9.2 percent of world's resources
5. Rifts	5.7 percent of world's resources
6. Deltas	4.5 percent of world's resources
Probable areal extent of reservoir beds in play ≥100 acres AND	
Probable areal extent of reservoir beds in play ≤999 acres	

Table 1. Guide to values for source-bed and reservoir-bed attributes for each of three favorability classes for GEOPLAY—Continued.

CONDITIONS FAVORABLE FOR A PLAY—Continued	
II. Potential reservoir beds (rules 8 and 14)—Continued	
Average depth to reservoir beds in play ≥2,500 ft AND	
Average depth to reservoir beds in play ≤4,999 ft	
OR	
Average depth to reservoir beds in play ≥15,001 ft AND	
Average depth to reservoir beds in play ≤25,000 ft	
Average total thickness of reservoir beds in play ≥50 ft AND	
Average total thickness of reservoir beds in play ≤199 ft	
Average effective porosity of reservoir beds in play ≥5.0 percent AND	
Average effective porosity of reservoir beds in play ≤9.999 percent	
III. Direct evidence of hydrocarbon source (rules 1, 2, and 3)	
Hydrocarbon source	
Direct evidence of source beds	
*Oil shale	
*Tar sands	
*Tight gas sands	
Migration (from source beds to reservoir beds)	
Geologic indicators for migration	
*Favorable	
Timing	
Geologic indicators for timing	
*Favorable	
Source bed(s)	
Conditions	
*Favorable for HCs potential	
Potential	
*Favorable for a potential play	
Reservoir bed(s)	
Conditions	
*Favorable for potential reservoirs	
Potential	
*Favorable for a successful play	
Play	
Property	
*Favorable with fair direct evidence of HCs	
CONDITIONS UNFAVORABLE OR UNKNOWN FOR A PLAY	
I. Probable source beds (rules 6 and 12)	
Geologic age of source beds	
7. Ordovician through Cambrian	1.0 percent generated of world's resources
8. Upper Proterozoic (Vendian)	0.2 percent generated of world's resources
Environment of deposition of source beds	
*Nonmarine or terrestrial	
Lithology of source beds	
*Dolomite, primary	
*Chalk	
*Evaporites	
*Sandstone	
*No evidence	
*Unknown	

Table 1. Guide to values for source-bed and reservoir-bed attributes for each of three favorability classes for GEOPLAY—Continued.

CONDITIONS UNFAVORABLE OR UNKNOWN FOR A PLAY—Continued	
I. Probable source beds (RULES 6 and 12)—Continued	
Maturity level of source beds	
*Immature	
*Highly mature	
*Severely altered	
*Unknown	
Proximity to reservoir beds	
*Unfavorable	
*Unknown	
Quality of source beds	
*Poor	
*Unknown	
Structural forms/deposition in basin for source beds	
7. Half sag	2.9 percent of world's resources
Types of general kerogens in source beds	
*Type IV	
Total organic carbon in source beds	
*≤0.4999 percent	
Areal extent of source beds ≤299 mi^2	
Average depth to source beds ≤2,499 ft OR Average depth to source beds ≥25,000 ft	
Average total thickness of source beds ≤49 ft	
II. Potential reservoir beds (rules 9 and 15)	
Geologic age of reservoir beds	
7. Silurian	0.2 percent of trapped world's resources
8. Upper Proterozoic (Vendian)	0.1 percent of trapped world's resources
Environment of deposition of reservoir beds	
*Nonmarine or terrestrial	
Lithology of reservoir beds	
*Igneous	
*Metamorphic	
*No evidence	
*Unknown	
Quality of reservoir beds	
*Poor	
*Unknown	
Structural forms/deposition in basin for reservoir beds	
7. Half sag	2.9 percent of world's resources
Probable areal extent of reservoir beds in play ≤99.999 acres	
Average depth to reservoir beds in play ≤2,499 ft OR Average depth to reservoir beds in play ≥25,001 ft	
Average total thickness of reservoir beds in play ≤49.999 ft	
Average effective porosity of reservoir beds in play ≤4.999 percent	

Table 1. Guide to values for source-bed and reservoir-bed attributes for each of three favorability classes for GEOPLAY—Continued.

CONDITIONS UNFAVORABLE OR UNKNOWN FOR A PLAY—Continued	
III. Direct evidence of hydrocarbon source (rules 1, 2, and 3)	
Hydrocarbon source	
Direct evidence of source beds	
*No evidence	
*Unknown	
Migration (from source beds to reservoir beds)	
Geologic indicators for migration	
*Unfavorable	
*Unknown	
Timing	
Geologic indicators for timing	
*Unfavorable	
*Unknown	
Source bed(s)	
Conditions	
*Unfavorable for HCs potential or HCs potential is unknown	
Potential	
*Unfavorable for a potential play, or very risky, or source potential unknown	
Reservoir bed(s)	
Conditions	
*Unfavorable for potential reservoirs or reservoir conditions unknown	
Potential	
*Unfavorable for a successful play	
Play	
Property	
*Unfavorable or has no direct evidence of HCs	
PROSPECT ATTRIBUTES	
Trapping mechanism (TM)	
Trap types	
Structural traps	
*Block (extension: horsts, tilted fault blocks, uplifts, fault traps, arches, combinations)	61 percent
*Fold (compression: fold belts, overthrust folds, thrust zones, combinations)	16 percent
*Growth (extension and vertical load: listric growth faults, rollover anticlines, slump features, topographic subsidence/depression, combinations)	5 percent
*Flow (vertical load commonly related to compression: flowage of salt, evaporites, shale, and igneous in form of diapirs, domes, swells)	7 percent
*Reef (carbonate buildups, depositional, combination stratigraphic and drape traps)	6.5 percent
*Unknown	
*No evidence	
Stratigraphic traps	4.5 percent
*Channels, lenses, bars	
*Facies changes, porosity and permeability variations	
*Unconformity related	
*Onlap, transgressive facies	
*Offlap, regressive facies	
*Paleorelief, trunctions, compaction	
*Impermeabile seals	
*Hydrodynamic conditions	
*Diagenetic conditions	
*Unknown	
*No evidence	

Table 1. Guide to values for source-bed and reservoir-bed attributes for each of three favorability classes for GEOPLAY—Continued.

PROSPECT ATTRIBUTES—Continued
Trapping mechanism (TM)—Continued
Status of traps
*Tested, drilled
Favorable
Unfavorable
*Untested traps
*Unknown
*No evidence of traps
Hydrocarbon accumulation (HCA)
Conditions
*Favorable
*Unfavorable
*Unknown
Evidence
*Known accumulations or direct evidence of HCs
*No direct evidence of HCs
*Unknown

A DYNAMIC SYSTEM

One of the most important aspects of the GEOPLAY expert system is the implementation of an appropriate and user-friendly interface. In an advisory role, communication between GEOPLAY and the geologist must be extremely flexible so that the flow of information is efficient and credible. The flexibility and dynamics of this system, designed to assist the geologist as a diagnostic consultation tool, allows the knowledge base to be readily maintained, updated, and even expanded without changing the control structure.

As the geologist gains experience in the use and applications of GEOPLAY, the need for new solutions to new problems and new goals can be easily added to the rules and goal structures and old goals deleted from the knowledge base. The IF-THEN conditions for the rules can be modified and new values or goals (answers) added to the rule base. The object-attribute-value decision tree (fig. 4) can easily be modified as information or experience from additional basins and plays are added to GEOPLAY's knowledge base.

MAHOGANY is a flexible expert-system shell and through the use of the easy to use editors built into the program for the Object-Attribute-Value formats, rule-based structures, and goals, GEOPLAY can be quickly modified to meet changing knowledge-base needs in the form of additions and updates to the information, and to provide for new interpretative uses.

NEW DEVELOPMENTS IN EXPERT SYSTEMS

Although expert systems are not currently in wide use in the petroleum industry, they have been the object of a large effort in research and development activities. One reason for limited use of expert systems in petroleum exploration and resource assessment studies is that the rules governing the exploration processes and the applications of interpretative exploration geology and geophysics are for the most part subjective.

Recent advances in some areas of research with expert systems, along with the availability of cost-effective and fast computer workstations, offer promising opportunities to overcome some of the obstacles of working with subjective judgments and inexact data. Specific areas of research in dealing with uncertainty in information systems include the use of concepts such as evidential reasoning, fuzzy logic, and neural networks in expert systems that may make the integration of multidisciplinary knowledge sources, the implementation of inexact and qualitative information, and self-learning more practical.

Both evidential reasoning and fuzzy logic provide a means to incorporate more effectively uncertainty in expert systems. Evidential reasoning, based on the Dempster-Shafer theory (Dempster, 1967; Shafer, 1976), is an effective method to represent ignorance, incomplete information, and inexact rules in expert systems (Aminzadeh, 1991). The Dempster-Shafer theory also provides a mechanism to handle conflicting data and rules. Dempster-Shafer techniques are incorporated in the expert system designed by Cheong and others (1993).

In contrast to Boolean true-or-false logic systems, fuzzy logic aims at formalizing modes of reasoning that are approximate rather than exact (Zadeh, 1992). The imprecise and uncertain data that frequently are a part of an object-oriented knowledge base are the primary reason for considering integration of fuzzy logic and expert systems (Miller, 1993). The foundation for approximate reasoning is grounded in fuzzy logic; that is, the logic underlying the mode of approximate or inexact reasoning. A fuzzy logic expert system for identification of minerals in thin section is described by Fang and others (1991).

Another development in computer science that may have a significant impact on expert systems is neural network technology (Wasserman, 1989). Through the self-organizing network capability, an expert system equipped with a neural network can, theoretically, expand the knowledge base through self-learning as more and more problems or analogs are handled. The use of a neural network in a seismic expert system is described by Veezhinathan and others (1991).

All of these alternative techniques when incorporated into near-future expert systems research and development, will pave the way for more practical and useful expert systems in the fields of the interpretative sciences.

CONCLUSIONS

GEOPLAY is a knowledge-based expert system that performs as a diagnostic consultant to assist the geologist in organizing, documenting, and analyzing in a consistent manner geologic data in order to differentiate potential petroleum plays, prospects, and reservoirs as input to an exploration play-analysis model. This play-analysis model is used to conduct probabilistic assessments of the most essential geologic characteristics in a basin and its respective plays that relate to the occurrence and the assessment of hydrocarbon resources.

This report describes the development and implementation of GEOPLAY as an expert-systems model for conducting play-analysis methods. In GEOPLAY three basic sets of unique geologic conditions are identified to characterize the play-specific, prospect-specific, and reservoir-specific properties for the play-analysis model. These specific geologic conditions are evaluated for each of the identified plays within a basin and constitute the basic geologic data in the model. These data are defined in terms of essential geologic characteristics such as geologic age, lithology, environment of deposition, depositional systems, stratigraphy, structural style, organic sources, and effective porosity to evaluate source-bed and reservoir-bed conditions and trapping mechanisms.

GEOPLAY's knowledge base is a hierarchical system based on a multilinked object-oriented structure or decision tree showing the relations between the various geological criteria defining plays, prospects, and reservoir conditions. The hierarchical system follows the order of geologic reasoning used by an experienced geologist to arrive at a logical set of conclusions relative to the geologic conditions being evaluated. The knowledge-based structures in GEOPLAY are made up of classes, objects, attributes, values, IF-THEN rules, and goals. These elements together represent knowledge and the relationships linking the various geologic criteria within the knowledge-based system. This system results in a better knowledge representation of the relationships among basin and play characteristics than is currently available for play-analysis procedures and improves on the accommodation of uncertainties inherent in geological data analysis.

Alternative techniques such as evidential reasoning, fuzzy logic, and neural networks are being investigated as advanced techniques to be incorporated into expert systems. These new techniques may improve on the integration of multidisciplinary knowledge sources, provide the means to incorporate uncertainties and inexact information into expert systems more effectively, and make self-learning knowledge-based expert systems more practical for geologic applications.

GEOPLAY is a flexible and dynamic system when used as a diagnostic consultation tool. It allows the knowledge base to be readily maintained, updated, and expanded with additions by the geologist of new rules, new problems, and new goals. GEOPLAY needs further refinement and a greater expansion of its knowledge base; however, the current GEOPLAY expert system has been demonstrated to be a useful diagnostic tool in defining the occurrence of hydrocarbon resources and in providing the evaluation of hydrocarbon plays, prospects, and reservoir characteristics as input to play-analysis methods for the assessment of petroleum resources.

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APPENDIXES

Appendix 1. Printouts of Object-Attribute-Value hierarchy taken directly from the GEOPLAY-MAHOGANY expert-system program. *A*. Superclasses Play Attributes and Prospect Attributes.

```
     * * *   O B J E C T S   * * *   of   C:\MAHOGANY\PLAYAN.KB
* * *

HYDROCARBON SOURCE (S)

     DIRECT EVIDENCE OF SOURCE BEDS
                    [question] - WHAT IS (ARE) THE DIRECT EVIDENCE OF
HYDROCARBONS IN THE BASIN OR PLAY?
             automatic values:
                    is Known Fields/Production
                    is Live Shows in Wells
                    is Seepages
                    is Oil Shales
                    is Tar Sands
                    is Tight Gas Sands
                    is No Evidence
                    is Unknown

MIGRATION (FROM SOURCE BEDS TO RESERVOIR BEDS)  (M)

     GEOLOGIC INDICATORS FOR MIGRATION
                    [question] - GEOLOGIC INDICATORS FOR MIGRATION FRO
M SOURCE BEDS TO RESERVOIR BED(S) ARE:  ?
             automatic values:
                    is HIGHLY FAVORABLE
                    is FAVORABLE
                    is UNFAVORABLE
                    is Unknown

PLAY

     PROBABILITY

     Property
                    [Auto Values]

POTENTIAL RESERVOIR BED(S)

     AVERAGE DEPTH TO RESERVOIR BED(S) IN PLAY
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE AVERAGE DEPTH TO RESERVOI
R BED(S) IN PLAY? (in feet)

     AVERAGE EFFECTIVE POSOSITY OF RESERVOIR BED(S) IN PLAY
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE AVERAGE EFFECTIVE POROSIT
Y OF RESERVOIR BED(S) IN PLAY? (in percent)

     AVERAGE TOTAL THICKNESS OF RESERVOIR BED(S) IN PLAY
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE AVERAGE TOTAL THICKNESS O
F RESERVOIR BED(S) IN PLAY? (in feet)

     ENVIRONMENT OF DEPOSITION OF RESERVOIR BED(S)
```

Appendix 1A—Continued.

```
              automatic values:
                     is MARINE
                     is MARINE & NONMARINE (MIXED)
                     is MARINE & LACUSTRINE
                     is NONMARINE & LACUSTRINE
                     is NONMARINE/TERRESTRIAL

     GEOLOGIC AGE OF RESERVOIR BED(S)
              automatic values:
                     is QUATERNARY/OLIGOCENE/UPPER CRETACEOUS
                     is MIDDLE THRU LOWER CRETACEOUS
                     is UPPER JURASSIC THRU UPPER PERMIAN
                     is LOWER PERMIAN/PENNSYLVANIAN/MIDDLE MISSISSIPPIA
N
                     is ORDOVICIAN THRU CAMBRIAN
                     is LOWER MISSISSIPPIAN THRU DEVONIAN
                     is SILURIAN
                     is UPPER PROTEROZOIC (VENDIAN)

     PROBABLE AREAL EXTENT OF RESERVOIR BED(S) IN PLAY
                     [Numeric] [Single Value] [No Auto Values]
                     [question] - WHAT IS THE PROBABLE AREAL EXTENT OF
RESERVOIR BED(S) IN PLAY? (acres)

     QUALITY OF RESERVOIR BED(S)
              automatic values:
                     is GOOD
                     is FAIR
                     is POOR
                     is Unknown

     RESERVOIR LITHOLOGY(IES)
              automatic values:
                     is SANDSTONE
                     is CARBONATES MIXED
                     is LIMESTONE
                     is DOLOMITE MIXED
                     is SILTSTONE
                     is EVAPORITES
                     is SHALE
                     is IGNEOUS
                     is METAMORPHIC
                     is No Evidence
                     is Unknown

     STRUCTURAL FORMS/DEPOSITION IN BASIN FOR RESERVOIR BED(S)
              automatic values:
                     is LINEAR SAGS
                     is CIRCULAR SAGS
                     is PLATFORMS
                     is FOREDEEP
                     is RIFTS
                     is DELTA
                     is HALF SAG
```

Appendix 1A—Continued.

```
PROBABLE SOURCE BEDS

     AREAL EXTENT OF SOURCE BEDS
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE AREAL EXTENT OF THE SOURC
E BED(S)? (in sq. miles)

     AVERAGE DEPTH TO SOURCE BEDS
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE AVERAGE DEPTH TO SOURCE B
ED(S)? (in feet)

     AVERAGE TOTAL THICKNESS OF SOURCE BEDS
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE TOTAL THICKNESS OF THE SO
URCE BED(S)? (in feet)

     ENVIRONMENT OF DEPOSITION OF SOURCE BEDS
                    [question] - WHAT IS THE ENVIRONMENT(S) OF DEPOSIT
ION FOR THE SOURCE BED(S)?
             automatic values:
                    is MARINE
                    is MARINE & NONMARINE (MIXED)
                    is MARINE & LACUSTRINE
                    is NONMARINE/TERRESTRIAL
                    is NONMARINE & LACUSTRINE

     GEOLOGIC AGE OF SOURCE BEDS
                    [No Protection]
                    [question] - WHAT IS THE GEOLOGIC AGE(S) OF THE PR
OBABLE SOURCE BEDS?
             automatic values:
                    is QUATERNARY/OLIGOCENE/UPPER CRETACEOUS
                    is MIDDLE THRU LOWER CRETACEOUS
                    is UPPER JURASSIC THRU UPPER PERMIAN
                    is ORDOVICIAN THRU CAMBRIAN
                    is UPPER PROTEROZOIC (VENDIAN)
                    is LOWER PERMIAN/PENNSYLVANIAN/MIDDLE MISSISSIPPIA
N

                    is LOWER MISSISSIPPIAN THRU DEVONIAN
                    is SILURIAN

     LITHOLOGY OF SOURCE BEDS
                    [question] - WHAT IS THE LITHOLOGY(IES) OF THE SOU
RCE BED(S)?
             automatic values:
                    is SHALE
                    is CLASTICS
                    is SILTSTONE
                    is DOLOMITE PRIMARY
                    is CHALK
                    is EVAPORITES
                    is SANDSTONE
```

Appendix 1A—Continued.

```
                         is No Evidence
                         is Unknown
                         is CARBONATES MIXED
                         is LIMESTONE
                         is COAL/PEAT

     MATURITY LEVEL OF SOURCE BEDS
                         [question] - WHAT IS THE MATURITY LEVEL(S) OF THE
PROBABLE SOURCE BED(S)?
                automatic values:
                         is MATURE
                         is HIGHLY MATURE
                         is SEVERELY ALTERED
                         is IMMATURE
                         is Unknown
                         is MODERATELY MATURE MIXED
                         is SOMEWHAT IMMATURE

     PROXIMITY TO RESERVOIR BEDS
                         [No Protection]
                         [question] - WHAT IS THE PROXIMITY OF SOURCE BEDS
TO RESERVOIR BEDS?
                automatic values:
                         is HIGHLY FAVORABLE
                         is UNFAVORABLE
                         is Unknown
                         is FAVORABLE

     QUALITY OF SOURCE BEDS
                         [question] - WHAT IS THE OVERALL QUALITY OF SOURCE
 BED(S)?
                automatic values:
                         is GOOD
                         is POOR
                         is Unknown
                         is FAIR

     STRUCTURAL FORMS/DEPOSITION IN BASIN FOR SOURCE BEDS
                         [question] - WHAT IS (ARE) THE STRUCTURAL FORMS/DE
POSITION IN THE BASIN FOR THE  SOURCE BED(S)?
                automatic values:
                         is LINEAR SAGS
                         is CIRCULAR SAGS
                         is PLATFORMS
                         is HALF SAG
                         is FOREDEEP
                         is RIFTS
                         is DELTAS

     TOTAL ORGANIC CARBON IN SOURCE BEDS
                         [Numeric] [Single Value] [No Auto Values]
                         [question] - WHAT IS THE TOTAL ORGANIC CARBON IN T
HE SOURCE BEDS? (in percent)
```

Appendix 1A—Continued.

```
     TYPES OF GENERAL KEROGENS IN SOURCE BEDS
                    [question] - WHAT IS (ARE) THE TYPE(S) OF KEROGENS
 IN THE SOURCE BED(S)?
             automatic values:
                    is TYPES I AND II BOTH
                    is TYPE II.
                    is TYPE IV.
                    is TYPE I.
                    is TYPE III.

RESERVOIR BED(S)

     CONDITIONS
             automatic values:
                    is Unfavorable for Potential Reservoirs or Reservo
ir Conditions Unknown
                    is Highly Favorable for Potential Reservoirs
                    is Favorable for Potential Reservoirs

     POTENTIAL
             automatic values:
                    is Unfavorable for a successful play
                    is Highly favorable for a successful play
                    is Favorable for a Successful Play

SOURCE BED(S)

     CONDITIONS
             automatic values:
                    is Highly Favorable for HCs Potential
                    is Favorable for HCs Potential
                    is Unfavorable for HCs Potential or HCs Potential
is Unknown

     POTENTIAL
             automatic values:
                    is Unfavorable for a potential play, or very risky
, or source potential unknown
                    is Highly favorable for a successful play
                    is Favorable for a potential play

TIMING (T)

     GEOLOGIC INDICATORS FOR TIMING
                    [question] - GEOLOGIC INDICATORS FOR TIMING RE SOU
RCE BED(S)/RESERVOIR BED(S) ARE:  ?
             automatic values:
                    is HIGHLY FAVORABLE
                    is FAVORABLE
                    is UNFAVORABLE
                    is Unknown

TRAP TYPES
```

Appendix 1A—Continued.

```
     COMBINATION
                         [question] - DO YOU HAVE A COMBINATION TRAP? IF 'Y
ES' THEN ALSO ANSWER RE STRUCTURAL AND STRATIGRAPHIC TYPES.

     STATUS OF TESTED TRAPS
                         [Single Value] [No Auto Values]
                         [question] - WHAT ARE THE NUMBER OF KNOWN TESTED T
RAPS?

     STATUS OF UNTESTED TRAPS
                         [Single Value] [No Auto Values]
                         [question] - WHAT ARE THE NUMBER OF KNOWN UNTESTED
 TRAPS?

     STRATIGRAPHIC
                         [Not Single]
                         [question] - WHAT ARE THE STRATIGRAPHIC CONDITIONS
 FOUND FOR TRAPPING MECHANISMS?
                values:
                         is CHANNELS/LENSES/BARS (1.00)
                         is FACIES CHANGES/POROSITY/PERMEABILITY VARIATIONS
 (1.00)
                         is UNCONFORMITY RELATED (1.00)
                         is ONLAP-TRANSGRESSIVE FACIES (1.00)
                         is OFFLAP-REGRESSIVE FACIES (1.00)
                         is PALEO-RELIEF/TRUNCATIONS/COMPACTION (1.00)
                         is IMPERMEABLE SEALS (1.00)
                         is HYDRODYNAMIC CONDITIONS (1.00)
                         is DIAGENETIC CONDITIONS (1.00)
                         is Unknown (1.00)
                         is No Evidence (1.00)

     STRUCTURAL
                         [info ] -
                         [question] - WHAT TYPE OF STRUCTURAL TRAPS ARE PRE
SENT?
                values:
                         is BLOCK (Extension: fault traps, uplifts, combina
tions) (1.00)
                         is FOLD (Compression: fold belts, overthrust folds
, thrust zones, combinations) (1.00)
                         is GROWTH (Extension and vertical load: listric gr
owth faulting, roll-over anticlines, slump features, topographic subsi
dence/depression, combinations) (1.00)
                         is FLOW (Vertical load often related to compressio
n: flowage of salt, evaporites, shale, and igneous in form of diapir,
dome, swell) (1.00)
                         is REEF (Carbonate build-up, depositional, combina
tion stratigraphic and drap traps) (1.00)
                         is Unknown (1.00)
                         is No Evidence (1.00)

     * * *   O B J E C T S   * * *   of   C:\MAHOGANY\PLAYAN.KB
* * *
```

Appendix 1. Printouts of Object-Attribute-Value hierarchy taken directly from the GEOPLAY-MAHOGANY expert-system program. B. Superclass Hydrocarbon Volume Attributes.

```
     * * *   O B J E C T S   * * *   of   C:\MAHOGANY\RESERVOI.KB
* * *

AREA OF CLOSURE (x 1000 acres) (HVA)

     0 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED AREA OF CLOSURE
 (x 1000 acres) WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT T
HE 0% FRACTILE LEVEL?

     100 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED AREA OF CLOSURE
 (x 1000 acres) WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT T
HE 100% FRACTILE LEVEL?

     25 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED AREA OF CLOSURE
 (x 1000 acres) WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT T
HE 25% FRACTILE LEVEL?

     5 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED AREA OF CLOSURE
 (x 1000 acres) WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT T
HE 5% FRACTILE LEVEL?

     50 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED AREA OF CLOSURE
 (x 1000 acres) WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT T
HE 50% FRACTILE LEVEL?

     75 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED AREA OF CLOSURE
 (x 1000 acres) WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT T
HE 75% FRACTILE LEVEL?

     95 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED AREA OF CLOSURE
 (x 1000 acres) WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT T
HE 95% FRACTILE LEVEL?

EFFECTIVE POROSITY (>3%) (HVA)

     0 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT EFFECTI
VE POROSITY WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 0
% FRACTILE LEVEL?
```

Appendix 1*B*—Continued.

```
      100 % FRACTILE LEVEL (Probability)
                         [Numeric] [Single Value] [No Auto Values]
                         [question] - WHAT IS THE ESTIMATED PERCENT EFFECTI
VE POROSITY WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 1
00% FRACTILE LEVEL?

      25 % FRACTILE LEVEL (Probability)
                         [Numeric] [Single Value] [No Auto Values]
                         [question] - WHAT IS THE ESTIMATED PERCENT EFFECTI
VE POROSITY WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 2
5% FRACTILE LEVEL?

      5 % FRACTILE LEVEL (Probability)
                         [Numeric] [Single Value] [No Auto Values]
                         [question] - WHAT IS THE ESTIMATED PERCENT EFFECTI
VE POROSITY WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 5
% FRACTILE LEVEL?

      50 % FRACTILE LEVEL (Probability)
                         [Numeric] [Single Value] [No Auto Values]
                         [question] - WHAT IS THE ESTIMATED PERCENT EFFECTI
VE POROSITY WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 5
0% FRACTILE LEVEL?

      75 % FRACTILE LEVEL (Probability)
                         [Numeric] [Single Value] [No Auto Values]
                         [question] - WHAT IS THE ESTIMATED PERCENT EFFECTI
VE POROSITY WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 7
5% FRACTILE LEVEL?

      95 % FRACTILE LEVEL (Probability)
                         [Numeric] [Single Value] [No Auto Values]
                         [question] - WHAT IS THE ESTIMATED PERCENT EFFECTI
VE POROSITY WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 9
5% FRACTILE LEVEL?

NUMBER OF DRILLABLE PROSPECTS (play characteristic)

      0 % FRACTILE LEVEL (Probability)
                         [Numeric] [Single Value] [No Auto Values]
                         [question] - WHAT ARE THE ESTIMATED NUMBER OF DRIL
LABLE PROSPECTS IN THE PLAY WITH PROBABILITY OF EQUAL TO OR GREATER TH
AN, AT THE 0% FRACTILE LEVEL?

      100 % FRACTILE LEVEL (Probability)
                         [Numeric] [Single Value] [No Auto Values]
                         [question] - WHAT ARE THE ESTIMATED NUMBER OF DRIL
LABLE PROSPECTS IN THE PLAY WITH THE PROBABILITY OF EQUAL TO OR GREATE
R THAN, AT THE 100% FRACTILE LEVEL?

      25 % FRACTILE LEVEL (Probability)
                         [Numeric] [Single Value] [No Auto Values]
                         [question] - WHAT ARE THE ESTIMATED NUMBER OF DRIL
```

Appendix 1*B*—Continued.

```
LABLE PROSPECTS IN THE PLAY WITH PROBABILITY OF EQUAL TO OR GREATER TH
AN, AT THE 25% FRACTILE LEVEL?

     5 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT ARE THE ESTIMATED NUMBER OF DRIL
LABLE PROSPECTS IN THE PLAY WITH PROBABILITY OF EQUAL TO OR GREATER TH
AN, AT THE 5% FRACTILE LEVEL?

     50 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT ARE THE ESTIMATED NUMBER OF DRIL
LABLE PROSPECTS IN THE PLAY WITH THE PROBABILITY OF EQUAL TO OR GREATE
R THAN, AT THE 50% FRACTILE LEVEL?

     75 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT ARE THE ESTIMATED NUMBER OF DRIL
LABLE PROSPECTS IN THE PLAY WITH THE PROBABILITY OF EQUAL TO OR GREATE
R THAN, AT THE 75% FRACTILE LEVEL?

     95 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT ARE THE ESTIMATED NUMBER OF DRIL
LABLE PROSPECTS IN THE PLAY WITH THE PROBABILITY OF EQUAL TO OR GREATE
R THAN, AT THE 95% FRACTILE LEVEL?

RESERVOIR DEPTH (x 1000 ft) (HVA)

     0 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED RESERVOIR DEPTH
 (x 1000 ft) IN THE PLAY WITH THE PROBABILITY OF EQUAL TO OR GREATER T
HAN, AT THE 0% FRACTILE LEVEL?

     100 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED RESERVOIR DEPTH
 (x 1000 ft) IN THE PLAY WITH THE PROBABILITY OF EQUAL TO OR GREATER T
HAN, AT THE 100% FRACTILE LEVEL?

     25 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED RESERVOIR DEPTH
 (x 1000 ft) IN THE PLAY WITH THE PROBABILITY OF EQUAL TO OR GREATER T
HAN, AT THE 25% FRACTILE LEVEL?

     5 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED RESERVOIR DEPTH
 (x 1000 ft) IN THE PLAY WITH THE PROBABILITY OF EQUAL TO OR GREATER T
HAN, AT THE 5% FRACTILE LEVEL?

     50 % FRACTILE LEVEL (Probability)
```

Appendix 1*B*—Continued.

```
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED RESERVOIR DEPTH
 (x 1000 ft) IN THE PLAY WITH THE PROBABILITY OF EQUAL TO OR GREATER T
HAN, AT THE 50% FRACTILE LEVEL?

     75 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED RESERVOIR DEPTH
 (x 1000 ft) IN THE PLAY WITH THE PROBABILITY OF EQUAL TO OR GREATER T
HAN, AT THE 75% FRACTILE LEVEL?

     95 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED RESERVOIR DEPTH
 (x 1000 ft) IN THE PLAY WITH THE PROBABILITY OF EQUAL TO OR GREATER T
HAN, AT THE 95% FRACTILE LEVEL?

RESERVOIR THICKNESS/VERTICAL CLOSURE (ft) (HVA)

     0 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED RESERVOIR THICK
NESS OR VERTICAL CLOSURE (in ft) WITH THE PROBABILITY OF EQUAL TO OR G
REATER THAN, AT THE 0% FRACTILE LEVEL?

     100 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED RESERVOIR THICK
NESS OR VERTICAL CLOSURE (in ft) WITH THE PROBABILITY OF EQUAL TO OR G
REATER THAN, AT THE 100% FRACTILE LEVEL?

     25 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [Auto Values]
                    [question] - WHAT IS THE ESTIMATED RESERVOIR THICK
NESS OR VERTICAL CLOSURE (in ft) WITH THE PROBABILITY OF EQUAL TO OR G
REATER THAN, AT 25% FRACTILE LEVEL?

     5 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED RESERVOIR THICK
NESS OR VERTICAL CLOSURE (in ft) WITH THE PROBABILITY OF EQUAL TO OR G
REATER THAN, AT THE 5% FRACTILE LEVEL?

     50 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED RESERVOIR THICK
NESS OR VERTICAL CLOSURE (in ft) WITH THE PROBABILITY OF EQUAL TO OR G
REATER THAN, AT THE 50% FRACTILE LEVEL?

     75 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED RESERVOIR THICK
NESS OR VERTICAL CLOSURE (in ft) WITH THE PROBABILITY OF EQUAL TO OR G
REATER THAN, AT THE 75% FRACTILE LEVEL?
```

Appendix 1*B*—Continued.

```
     95 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED RESERVOIR THICK
NESS OR VERTICAL CLOSURE (in ft) WITH THE PROBABILITY OF EQUAL TO OR G
REATER THAN, AT THE 95% FRACTILE LEVEL?

TRAP FILL (%) (HVA)

     0 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT TRAP FI
LL WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 0% FRACTIL
E LEVEL?

     100 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT TRAP FI
LL WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 100% FRACT
ILE LEVEL?

     25 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT TRAP FI
LL WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 25% FRACTI
LE LEVEL?

     5 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT TRAP FI
LL WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 5% FRACTIL
E LEVEL?

     50 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT TRAP FI
LL WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 50% FRACTI
LE LEVEL?

     75 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT TRAP FI
LL WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 75% FRACTI
LE LEVEL?

     95 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT TRAP FI
LL WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 95% FRACTI
LE LEVEL?

WATER SATURATION (%) (HVA)

     0 % FRACTILE LEVEL (Probability)
```

Appendix 1*B*—Continued.

```
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT WATER S
ATURATION WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 0%
FRACTILE LEVEL?

     100 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT WATER S
ATURATION WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 100
% FRACTILE LEVEL?

     25 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT WATER S
ATURATION WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 25%
 FRACTILE LEVEL?

     5 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT WATER S
ATURATION WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 5%
FRACTILE LEVEL?

     50 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT WATER S
ATURATION WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 50%
 FRACTILE LEVEL?

     75 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT WATER S
ATURATION WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 75%
 FRACTILE LEVEL?

     95 % FRACTILE LEVEL (Probability)
                    [Numeric] [Single Value] [No Auto Values]
                    [question] - WHAT IS THE ESTIMATED PERCENT WATER S
ATURATION WITH THE PROBABILITY OF EQUAL TO OR GREATER THAN, AT THE 95%
 FRACTILE LEVEL?

     * * *   O B J E C T S   * * *   of   C:\MAHOGANY\RESERVOI.KB
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Appendix 2. Printouts of IF-THEN rule-structures illustrating 18 rules in the Object-Attribute-Value format for play-specific and prospect-specific evaluations taken directly from the GEOPLAY-MAHOGANY expert system program.

```
     * * *   R U L E S   * * *   of   C:\MAHOGANY\PLAYAN.KB        * *
*

RULE #1 priority 50 - Highly favorable direct evidence of HCs
 IF ------------------------------
     (1)      the HYDROCARBON SOURCE (S) DIRECT EVIDENCE OF SOURCE BED
S is "Known Fields/Production" [threshold 0.20]
     (2) or  the HYDROCARBON SOURCE (S) DIRECT EVIDENCE OF SOURCE BEDS
 is "Live Shows in Wells" [threshold 0.20]
     (3) or  the HYDROCARBON SOURCE (S) DIRECT EVIDENCE OF SOURCE BEDS
 is Seepages [threshold 0.20]
     (4) and the MIGRATION (FROM SOURCE BEDS TO RESERVOIR BEDS)  (M) G
EOLOGIC INDICATORS FOR MIGRATION is "HIGHLY FAVORABLE" [threshold 0.20
]
     (5) and the TIMING (T) GEOLOGIC INDICATORS FOR TIMING is "HIGHLY
FAVORABLE" [threshold 0.20]
 THEN ----------------------------
     (1)      PLAY Property is "Highly Favorable with Good Direct Evid
ence of HCs" [certainty 1.00]

RULE #2 priority 50 - Favorable with Fair Direct Evidence of HCs
 IF ------------------------------
     (1)      the HYDROCARBON SOURCE (S) DIRECT EVIDENCE OF SOURCE BED
S is "Oil Shales" [threshold 0.20]
     (2) or  the HYDROCARBON SOURCE (S) DIRECT EVIDENCE OF SOURCE BEDS
 is "Tar Sands" [threshold 0.20]
     (3) or  the HYDROCARBON SOURCE (S) DIRECT EVIDENCE OF SOURCE BEDS
 is "Tight Gas Sands" [threshold 0.20]
     (4) and the MIGRATION (FROM SOURCE BEDS TO RESERVOIR BEDS)  (M) G
EOLOGIC INDICATORS FOR MIGRATION is FAVORABLE [threshold 0.20]
     (5) and the TIMING (T) GEOLOGIC INDICATORS FOR TIMING is FAVORABL
E [threshold 0.20]
 THEN ----------------------------
     (1)      PLAY Property is "Favorable with Fair Direct Evidence of
 HCs" [certainty 1.00]

RULE #3 priority 50 - Unfavorable or no direct evidence of HCs
 IF ------------------------------
     (1)      the HYDROCARBON SOURCE (S) DIRECT EVIDENCE OF SOURCE BED
S is "No Evidence" [threshold 0.20]
     (2) or  the HYDROCARBON SOURCE (S) DIRECT EVIDENCE OF SOURCE BEDS
 is Unknown [threshold 0.20]
     (3) and the MIGRATION (FROM SOURCE BEDS TO RESERVOIR BEDS)  (M) G
EOLOGIC INDICATORS FOR MIGRATION is UNFAVORABLE [threshold 0.20]
     (4) or  the MIGRATION (FROM SOURCE BEDS TO RESERVOIR BEDS)  (M) G
EOLOGIC INDICATORS FOR MIGRATION is Unknown [threshold 0.20]
     (5) and the TIMING (T) GEOLOGIC INDICATORS FOR TIMING is UNFAVORA
BLE [threshold 0.20]
     (6) or  the TIMING (T) GEOLOGIC INDICATORS FOR TIMING is Unknown
[threshold 0.20]
 THEN ----------------------------
     (1)      PLAY Property is "Unfavorable or has no Direct Evidence
of HCs" [certainty 1.00]
```

Appendix 2—Continued.

```
RULE #4 priority 50 - Conditions highly favorable for HCs potential
 IF -----------------------------
     (1)      the PROBABLE SOURCE BEDS GEOLOGIC AGE OF SOURCE BEDS is
"QUATERNARY/OLIGOCENE/UPPER CRETACEOUS" [threshold 0.20]
     (2) or  the PROBABLE SOURCE BEDS GEOLOGIC AGE OF SOURCE BEDS is "
MIDDLE THRU LOWER CRETACEOUS" [threshold 0.20]
     (3) or  the PROBABLE SOURCE BEDS GEOLOGIC AGE OF SOURCE BEDS is "
UPPER JURASSIC THRU UPPER PERMIAN" [threshold 0.20]
     (4) and the PROBABLE SOURCE BEDS ENVIRONMENT OF DEPOSITION OF SOU
RCE BEDS is MARINE [threshold 0.20]
     (5) or  the PROBABLE SOURCE BEDS ENVIRONMENT OF DEPOSITION OF SOU
RCE BEDS is "MARINE & NONMARINE (MIXED)" [threshold 0.20]
     (6) or  the PROBABLE SOURCE BEDS ENVIRONMENT OF DEPOSITION OF SOU
RCE BEDS is "MARINE & LACUSTRINE" [threshold 0.20]
     (7) and the PROBABLE SOURCE BEDS LITHOLOGY OF SOURCE BEDS is SHAL
E [threshold 0.20]
     (8) or  the PROBABLE SOURCE BEDS LITHOLOGY OF SOURCE BEDS is CLAS
TICS [threshold 0.20]
     (9) or  the PROBABLE SOURCE BEDS LITHOLOGY OF SOURCE BEDS is SILT
STONE [threshold 0.20]
     (10) and the PROBABLE SOURCE BEDS MATURITY LEVEL OF SOURCE BEDS i
s MATURE [threshold 0.20]
     (11) and the PROBABLE SOURCE BEDS PROXIMITY TO RESERVOIR BEDS is
"HIGHLY FAVORABLE" [threshold 0.20]
     (12) and the PROBABLE SOURCE BEDS QUALITY OF SOURCE BEDS is GOOD
[threshold 0.20]
     (13) and the PROBABLE SOURCE BEDS STRUCTURAL FORMS/DEPOSITION IN
BASIN FOR SOURCE BEDS is "LINEAR SAGS" [threshold 0.20]
     (14) or  the PROBABLE SOURCE BEDS STRUCTURAL FORMS/DEPOSITION IN
BASIN FOR SOURCE BEDS is "CIRCULAR SAGS" [threshold 0.20]
     (15) or  the PROBABLE SOURCE BEDS STRUCTURAL FORMS/DEPOSITION IN
BASIN FOR SOURCE BEDS is PLATFORMS [threshold 0.20]
     (16) and the PROBABLE SOURCE BEDS TYPES OF GENERAL KEROGENS IN SO
URCE BEDS is "TYPES I AND II BOTH" [threshold 0.20]
     (17) or  the PROBABLE SOURCE BEDS TYPES OF GENERAL KEROGENS IN SO
URCE BEDS is "TYPE II." [threshold 0.20]
     (18) and the PROBABLE SOURCE BEDS TOTAL ORGANIC CARBON IN SOURCE
BEDS >= 1.000 [threshold 0.20]
 THEN ---------------------------
     (1)      SOURCE BED(S) CONDITIONS is "Highly Favorable for HCs Po
tential" [certainty 1.00]

RULE #5 priority 50 - Conditions favorable for HCs potential
 IF -----------------------------
     (1)      the PROBABLE SOURCE BEDS GEOLOGIC AGE OF SOURCE BEDS is
"LOWER PERMIAN/PENNSYLVANIAN/MIDDLE MISSISSIPPIAN" [threshold 0.20]
     (2) or  the PROBABLE SOURCE BEDS GEOLOGIC AGE OF SOURCE BEDS is "
LOWER MISSISSIPPIAN THRU DEVONIAN" [threshold 0.20]
     (3) or  the PROBABLE SOURCE BEDS GEOLOGIC AGE OF SOURCE BEDS is S
ILURIAN [threshold 0.20]
     (4) and the PROBABLE SOURCE BEDS ENVIRONMENT OF DEPOSITION OF SOU
RCE BEDS is "MARINE & LACUSTRINE" [threshold 0.20]
     (5) or  the PROBABLE SOURCE BEDS ENVIRONMENT OF DEPOSITION OF SOU
RCE BEDS is "NONMARINE & LACUSTRINE" [threshold 0.20]
```

Appendix 2—Continued.

```
     (6) and the PROBABLE SOURCE BEDS LITHOLOGY OF SOURCE BEDS is "CAR
BONATES MIXED" [threshold 0.20]
     (7) or  the PROBABLE SOURCE BEDS LITHOLOGY OF SOURCE BEDS is LIME
STONE [threshold 0.20]
     (8) or  the PROBABLE SOURCE BEDS LITHOLOGY OF SOURCE BEDS is "COA
L/PEAT" [threshold 0.20]
     (9) and the PROBABLE SOURCE BEDS MATURITY LEVEL OF SOURCE BEDS is
 "MODERATELY MATURE MIXED" [threshold 0.20]
     (10) or  the PROBABLE SOURCE BEDS MATURITY LEVEL OF SOURCE BEDS i
s "SOMEWHAT IMMATURE" [threshold 0.20]
     (11) and the PROBABLE SOURCE BEDS PROXIMITY TO RESERVOIR BEDS is
FAVORABLE [threshold 0.20]
     (12) and the PROBABLE SOURCE BEDS QUALITY OF SOURCE BEDS is FAIR
[threshold 0.20]
     (13) and the PROBABLE SOURCE BEDS STRUCTURAL FORMS/DEPOSITION IN
BASIN FOR SOURCE BEDS is FOREDEEP [threshold 0.20]
     (14) or  the PROBABLE SOURCE BEDS STRUCTURAL FORMS/DEPOSITION IN
BASIN FOR SOURCE BEDS is RIFTS [threshold 0.20]
     (15) or  the PROBABLE SOURCE BEDS STRUCTURAL FORMS/DEPOSITION IN
BASIN FOR SOURCE BEDS is DELTAS [threshold 0.20]
     (16) and the PROBABLE SOURCE BEDS TYPES OF GENERAL KEROGENS IN SO
URCE BEDS is "TYPE I." [threshold 0.20]
     (17) or  the PROBABLE SOURCE BEDS TYPES OF GENERAL KEROGENS IN SO
URCE BEDS is "TYPE III." [threshold 0.20]
     (18) and the PROBABLE SOURCE BEDS TOTAL ORGANIC CARBON IN SOURCE
BEDS >= 0.500 [threshold 0.20]
     (19) and the PROBABLE SOURCE BEDS TOTAL ORGANIC CARBON IN SOURCE
BEDS <= 0.999 [threshold 0.20]
 THEN ----------------------------
     (1)      SOURCE BED(S) CONDITIONS is "Favorable for HCs Potential
" [certainty 1.00]

RULE #6 priority 50 - Conditions unfavorable for HCs potential or unkn
own HCs potential
 IF ------------------------------
     (1)      the PROBABLE SOURCE BEDS GEOLOGIC AGE OF SOURCE BEDS is
"ORDOVICIAN THRU CAMBRIAN" [threshold 0.20]
     (2) or  the PROBABLE SOURCE BEDS GEOLOGIC AGE OF SOURCE BEDS is "
UPPER PROTEROZOIC (VENDIAN)" [threshold 0.20]
     (3) and the PROBABLE SOURCE BEDS ENVIRONMENT OF DEPOSITION OF SOU
RCE BEDS is "NONMARINE/TERRESTRIAL" [threshold 0.20]
     (4) and the PROBABLE SOURCE BEDS LITHOLOGY OF SOURCE BEDS is "DOL
OMITE PRIMARY" [threshold 0.20]
     (5) or  the PROBABLE SOURCE BEDS LITHOLOGY OF SOURCE BEDS is CHAL
K [threshold 0.20]
     (6) or  the PROBABLE SOURCE BEDS LITHOLOGY OF SOURCE BEDS is EVAP
ORITES [threshold 0.20]
     (7) or  the PROBABLE SOURCE BEDS LITHOLOGY OF SOURCE BEDS is SAND
STONE [threshold 0.20]
     (8) or  the PROBABLE SOURCE BEDS LITHOLOGY OF SOURCE BEDS is "No
Evidence" [threshold 0.20]
     (9) or  the PROBABLE SOURCE BEDS LITHOLOGY OF SOURCE BEDS is Unkn
own [threshold 0.20]
     (10) and the PROBABLE SOURCE BEDS MATURITY LEVEL OF SOURCE BEDS i
```

Appendix 2—Continued.

```
s "HIGHLY MATURE" [threshold 0.20]
     (11) or  the PROBABLE SOURCE BEDS MATURITY LEVEL OF SOURCE BEDS i
s "SEVERELY ALTERED" [threshold 0.20]
     (12) or  the PROBABLE SOURCE BEDS MATURITY LEVEL OF SOURCE BEDS i
s IMMATURE [threshold 0.20]
     (13) or  the PROBABLE SOURCE BEDS MATURITY LEVEL OF SOURCE BEDS i
s Unknown [threshold 0.20]
     (14) and the PROBABLE SOURCE BEDS PROXIMITY TO RESERVOIR BEDS is
UNFAVORABLE [threshold 0.20]
     (15) or  the PROBABLE SOURCE BEDS PROXIMITY TO RESERVOIR BEDS is
Unknown [threshold 0.20]
     (16) and the PROBABLE SOURCE BEDS QUALITY OF SOURCE BEDS is POOR
[threshold 0.20]
     (17) or  the PROBABLE SOURCE BEDS QUALITY OF SOURCE BEDS is Unkno
wn [threshold 0.20]
     (18) and the PROBABLE SOURCE BEDS STRUCTURAL FORMS/DEPOSITION IN
BASIN FOR SOURCE BEDS is "HALF SAG" [threshold 0.20]
     (19) and the PROBABLE SOURCE BEDS TYPES OF GENERAL KEROGENS IN SO
URCE BEDS is "TYPE IV." [threshold 0.20]
     (20) and the PROBABLE SOURCE BEDS TOTAL ORGANIC CARBON IN SOURCE
BEDS <= 0.499 [threshold 0.20]
 THEN ---------------------------
     (1)      SOURCE BED(S) CONDITIONS is "Unfavorable for HCs Potenti
al or HCs Potential is Unknown" [certainty 1.00]

RULE #7 priority 50 - Highly favorable conditions for potential reserv
oirs
 IF ------------------------------
     (1)      the POTENTIAL RESERVOIR BED(S) ENVIRONMENT OF DEPOSITION
 OF RESERVOIR BED(S) is MARINE [threshold 0.20]
     (2) or  the POTENTIAL RESERVOIR BED(S) ENVIRONMENT OF DEPOSITION
OF RESERVOIR BED(S) is "MARINE & NONMARINE (MIXED)" [threshold 0.20]
     (3) and the POTENTIAL RESERVOIR BED(S) GEOLOGIC AGE OF RESERVOIR
BED(S) is "QUATERNARY/OLIGOCENE/UPPER CRETACEOUS" [threshold 0.20]
     (4) or  the POTENTIAL RESERVOIR BED(S) GEOLOGIC AGE OF RESERVOIR
BED(S) is "MIDDLE THRU LOWER CRETACEOUS" [threshold 0.20]
     (5) or  the POTENTIAL RESERVOIR BED(S) GEOLOGIC AGE OF RESERVOIR
BED(S) is "UPPER JURASSIC THRU UPPER PERMIAN" [threshold 0.20]
     (6) and the POTENTIAL RESERVOIR BED(S) QUALITY OF RESERVOIR BED(S
) is GOOD [threshold 0.20]
     (7) and the POTENTIAL RESERVOIR BED(S) RESERVOIR LITHOLOGY(IES) i
s SANDSTONE [threshold 0.20]
     (8) or  the POTENTIAL RESERVOIR BED(S) RESERVOIR LITHOLOGY(IES) i
s "CARBONATES MIXED" [threshold 0.20]
     (9) or  the POTENTIAL RESERVOIR BED(S) RESERVOIR LITHOLOGY(IES) i
s LIMESTONE [threshold 0.20]
     (10) or  the POTENTIAL RESERVOIR BED(S) RESERVOIR LITHOLOGY(IES)
is "DOLOMITE MIXED" [threshold 0.20]
     (11) and the POTENTIAL RESERVOIR BED(S) STRUCTURAL FORMS/DEPOSITI
ON IN BASIN FOR RESERVOIR BED(S) is "LINEAR SAGS" [threshold 0.20]
     (12) or  the POTENTIAL RESERVOIR BED(S) STRUCTURAL FORMS/DEPOSITI
ON IN BASIN FOR RESERVOIR BED(S) is "CIRCULAR SAGS" [threshold 0.20]
     (13) or  the POTENTIAL RESERVOIR BED(S) STRUCTURAL FORMS/DEPOSITI
ON IN BASIN FOR RESERVOIR BED(S) is PLATFORMS [threshold 0.20]
```

Appendix 2—Continued.

```
 THEN ------------------------------
     (1)      RESERVOIR BED(S) CONDITIONS is "Highly Favorable for Pot
ential Reservoirs" [certainty 1.00]

RULE #8 priority 50 - Favorable conditions for potential reservoirs
 IF ------------------------------
     (1)      the POTENTIAL RESERVOIR BED(S) ENVIRONMENT OF DEPOSITION
 OF RESERVOIR BED(S) is "MARINE & LACUSTRINE" [threshold 0.20]
     (2) or  the POTENTIAL RESERVOIR BED(S) ENVIRONMENT OF DEPOSITION
OF RESERVOIR BED(S) is "NONMARINE & LACUSTRINE" [threshold 0.20]
     (3) and the POTENTIAL RESERVOIR BED(S) GEOLOGIC AGE OF RESERVOIR
BED(S) is "LOWER PERMIAN/PENNSYLVANIAN/MIDDLE MISSISSIPPIAN" [threshol
d 0.20]
     (4) or  the POTENTIAL RESERVOIR BED(S) GEOLOGIC AGE OF RESERVOIR
BED(S) is "ORDOVICIAN THRU CAMBRIAN" [threshold 0.20]
     (5) or  the POTENTIAL RESERVOIR BED(S) GEOLOGIC AGE OF RESERVOIR
BED(S) is "LOWER MISSISSIPPIAN THRU DEVONIAN" [threshold 0.20]
     (6) and the POTENTIAL RESERVOIR BED(S) QUALITY OF RESERVOIR BED(S
) is FAIR [threshold 0.20]
     (7) and the POTENTIAL RESERVOIR BED(S) RESERVOIR LITHOLOGY(IES) i
s SILTSTONE [threshold 0.20]
     (8) or  the POTENTIAL RESERVOIR BED(S) RESERVOIR LITHOLOGY(IES) i
s EVAPORITES [threshold 0.20]
     (9) or  the POTENTIAL RESERVOIR BED(S) RESERVOIR LITHOLOGY(IES) i
s SHALE [threshold 0.20]
     (10) and the POTENTIAL RESERVOIR BED(S) STRUCTURAL FORMS/DEPOSITI
ON IN BASIN FOR RESERVOIR BED(S) is FOREDEEP [threshold 0.20]
     (11) or  the POTENTIAL RESERVOIR BED(S) STRUCTURAL FORMS/DEPOSITI
ON IN BASIN FOR RESERVOIR BED(S) is RIFTS [threshold 0.20]
     (12) or  the POTENTIAL RESERVOIR BED(S) STRUCTURAL FORMS/DEPOSITI
ON IN BASIN FOR RESERVOIR BED(S) is DELTA [threshold 0.20]
 THEN ------------------------------
     (1)      RESERVOIR BED(S) CONDITIONS is "Favorable for Potential
Reservoirs" [certainty 1.00]

RULE #9 priority 50 - Unfavorable conditions for potential reservoirs
 IF ------------------------------
     (1)      the POTENTIAL RESERVOIR BED(S) ENVIRONMENT OF DEPOSITION
 OF RESERVOIR BED(S) is "NONMARINE/TERRESTRIAL" [threshold 0.20]
     (2) and the POTENTIAL RESERVOIR BED(S) GEOLOGIC AGE OF RESERVOIR
BED(S) is SILURIAN [threshold 0.20]
     (3) or  the POTENTIAL RESERVOIR BED(S) GEOLOGIC AGE OF RESERVOIR
BED(S) is "UPPER PROTEROZOIC (VENDIAN)" [threshold 0.20]
     (4) and the POTENTIAL RESERVOIR BED(S) QUALITY OF RESERVOIR BED(S
) is POOR [threshold 0.20]
     (5) or  the POTENTIAL RESERVOIR BED(S) QUALITY OF RESERVOIR BED(S
) is Unknown [threshold 0.20]
     (6) and the POTENTIAL RESERVOIR BED(S) RESERVOIR LITHOLOGY(IES) i
s IGNEOUS [threshold 0.20]
     (7) or  the POTENTIAL RESERVOIR BED(S) RESERVOIR LITHOLOGY(IES) i
s METAMORPHIC [threshold 0.20]
     (8) or  the POTENTIAL RESERVOIR BED(S) RESERVOIR LITHOLOGY(IES) i
s "No Evidence" [threshold 0.20]
     (9) or  the POTENTIAL RESERVOIR BED(S) RESERVOIR LITHOLOGY(IES) i
```

Appendix 2—Continued.

```
s Unknown [threshold 0.20]
     (10) and the POTENTIAL RESERVOIR BED(S) STRUCTURAL FORMS/DEPOSITI
ON IN BASIN FOR RESERVOIR BED(S) is "HALF SAG" [threshold 0.20]
 THEN ---------------------------
     (1)      RESERVOIR BED(S) CONDITIONS is "Unfavorable for Potentia
l Reservoirs or Reservoir Conditions Unknown" [certainty 1.00]

RULE #10 priority 50 - Highly favorable for a successful play
 IF -----------------------------
     (1)      the PROBABLE SOURCE BEDS AREAL EXTENT OF SOURCE BEDS >=
750 [threshold 0.20]
     (2) and the PROBABLE SOURCE BEDS AVERAGE DEPTH TO SOURCE BEDS >=
5000 [threshold 0.20]
     (3) and the PROBABLE SOURCE BEDS AVERAGE DEPTH TO SOURCE BEDS <=
15000 [threshold 0.20]
     (4) and the PROBABLE SOURCE BEDS AVERAGE TOTAL THICKNESS OF SOURC
E BEDS >= 200 [threshold 0.20]
     (5) and the SOURCE BED(S) CONDITIONS is "Highly Favorable for HCs
 Potential" [threshold 0.20]
 THEN ---------------------------
     (1)      SOURCE BED(S) POTENTIAL is "Highly favorable for a succe
ssful play" [certainty 1.00]

RULE #11 priority 50 - Favorable for a potential play
 IF -----------------------------
     (1)      the PROBABLE SOURCE BEDS AREAL EXTENT OF SOURCE BEDS >=
300 [threshold 0.20]
     (2) and the PROBABLE SOURCE BEDS AREAL EXTENT OF SOURCE BEDS <= 7
49 [threshold 0.20]
     (3) and the PROBABLE SOURCE BEDS AVERAGE DEPTH TO SOURCE BEDS >=
2500 [threshold 0.20]
     (4) and the PROBABLE SOURCE BEDS AVERAGE DEPTH TO SOURCE BEDS <=
4999 [threshold 0.20]
     (5) or  the PROBABLE SOURCE BEDS AVERAGE DEPTH TO SOURCE BEDS >=
15001 [threshold 0.20]
     (6) and the PROBABLE SOURCE BEDS AVERAGE DEPTH TO SOURCE BEDS <=
24999 [threshold 0.20]
     (7) and the PROBABLE SOURCE BEDS AVERAGE TOTAL THICKNESS OF SOURC
E BEDS >= 50 [threshold 0.02]
     (8) and the PROBABLE SOURCE BEDS AVERAGE TOTAL THICKNESS OF SOURC
E BEDS <= 199 [threshold 0.02]
     (9) and the SOURCE BED(S) CONDITIONS is "Favorable for HCs Potent
ial" [threshold 0.20]
 THEN ---------------------------
     (1)      SOURCE BED(S) POTENTIAL is "Favorable for a potential pl
ay" [certainty 1.00]

RULE #12 priority 50 - Unfavorable for a potential or source potential
 unknown
 IF -----------------------------
     (1)      the PROBABLE SOURCE BEDS AREAL EXTENT OF SOURCE BEDS <=
299 [threshold 0.20]
     (2) and the PROBABLE SOURCE BEDS AVERAGE DEPTH TO SOURCE BEDS <=
2499 [threshold 0.20]
```

Appendix 2—Continued.

```
     (3) or  the PROBABLE SOURCE BEDS AVERAGE DEPTH TO SOURCE BEDS >=
25000 [threshold 0.20]
     (4) and the PROBABLE SOURCE BEDS AVERAGE TOTAL THICKNESS OF SOURC
E BEDS <= 49 [threshold 0.20]
     (5) and the SOURCE BED(S) CONDITIONS is "Unfavorable for HCs Pote
ntial or HCs Potential is Unknown" [threshold 0.20]
 THEN ---------------------------
     (1)     SOURCE BED(S) POTENTIAL is "Unfavorable for a potential
play, or very risky, or source potential unknown" [certainty 1.00]

RULE #13 priority 50 - Reservoir beds highly favorable for a potential
 play.
 IF ------------------------------
     (1)     the POTENTIAL RESERVOIR BED(S) AVERAGE DEPTH TO RESERVOI
R BED(S) IN PLAY >= 5000 [threshold 0.20]
     (2) and the POTENTIAL RESERVOIR BED(S) AVERAGE DEPTH TO RESERVOIR
 BED(S) IN PLAY <= 15000 [threshold 0.20]
     (3) and the POTENTIAL RESERVOIR BED(S) AVERAGE EFFECTIVE POSOSITY
 OF RESERVOIR BED(S) IN PLAY >= 10 [threshold 0.20]
     (4) and the POTENTIAL RESERVOIR BED(S) AVERAGE TOTAL THICKNESS OF
 RESERVOIR BED(S) IN PLAY >= 200 [threshold 0.20]
     (5) and the POTENTIAL RESERVOIR BED(S) PROBABLE AREAL EXTENT OF R
ESERVOIR BED(S) IN PLAY >= 1000 [threshold 0.20]
 THEN ---------------------------
     (1)     RESERVOIR BED(S) POTENTIAL is "Highly favorable for a su
ccessful play" [certainty 1.00]

RULE #14 priority 50 - Reservoir beds favorable for a potential play.
 IF ------------------------------
     (1)     the POTENTIAL RESERVOIR BED(S) AVERAGE DEPTH TO RESERVOI
R BED(S) IN PLAY >= 2500 [threshold 0.20]
     (2) and the POTENTIAL RESERVOIR BED(S) AVERAGE DEPTH TO RESERVOIR
 BED(S) IN PLAY <= 4999 [threshold 0.20]
     (3) or  the POTENTIAL RESERVOIR BED(S) AVERAGE DEPTH TO RESERVOIR
 BED(S) IN PLAY >= 15001 [threshold 0.20]
     (4) and the POTENTIAL RESERVOIR BED(S) AVERAGE DEPTH TO RESERVOIR
 BED(S) IN PLAY <= 25000 [threshold 0.20]
     (5) and the POTENTIAL RESERVOIR BED(S) AVERAGE EFFECTIVE POSOSITY
 OF RESERVOIR BED(S) IN PLAY >= 5 [threshold 0.20]
     (6) and the POTENTIAL RESERVOIR BED(S) AVERAGE EFFECTIVE POSOSITY
 OF RESERVOIR BED(S) IN PLAY <= 9.999 [threshold 0.20]
     (7) and the POTENTIAL RESERVOIR BED(S) AVERAGE TOTAL THICKNESS OF
 RESERVOIR BED(S) IN PLAY >= 50 [threshold 0.20]
     (8) and the POTENTIAL RESERVOIR BED(S) AVERAGE TOTAL THICKNESS OF
 RESERVOIR BED(S) IN PLAY <= 199 [threshold 0.20]
     (9) and the POTENTIAL RESERVOIR BED(S) PROBABLE AREAL EXTENT OF R
ESERVOIR BED(S) IN PLAY >= 100 [threshold 0.20]
     (10) and the POTENTIAL RESERVOIR BED(S) PROBABLE AREAL EXTENT OF
RESERVOIR BED(S) IN PLAY <= 999 [threshold 0.20]
 THEN ---------------------------
     (1)     RESERVOIR BED(S) POTENTIAL is "Favorable for a Successfu
l Play" [certainty 1.00]

RULE #15 priority 50 - Reservoir beds unfavorable for a potential play
```

Appendix 2—Continued.

```
•
 IF ------------------------------
     (1)      the POTENTIAL RESERVOIR BED(S) AVERAGE DEPTH TO RESERVOI
R BED(S) IN PLAY <= 2499 [threshold 0.20]
     (2) or  the POTENTIAL RESERVOIR BED(S) AVERAGE DEPTH TO RESERVOIR
 BED(S) IN PLAY >= 25001 [threshold 0.20]
     (3) and the POTENTIAL RESERVOIR BED(S) AVERAGE EFFECTIVE POSOSITY
 OF RESERVOIR BED(S) IN PLAY <= 4.999 [threshold 0.20]
     (4) and the POTENTIAL RESERVOIR BED(S) AVERAGE TOTAL THICKNESS OF
 RESERVOIR BED(S) IN PLAY <= 49.999 [threshold 0.20]
     (5) and the POTENTIAL RESERVOIR BED(S) PROBABLE AREAL EXTENT OF R
ESERVOIR BED(S) IN PLAY <= 99.999 [threshold 0.20]
 THEN ----------------------------
     (1)      RESERVOIR BED(S) POTENTIAL is "Unfavorable for a success
ful play" [certainty 1.00]

RULE #16 priority 50 - Highly favorable play conditions
 IF ------------------------------
     (1)      the SOURCE BED(S) CONDITIONS is "Highly Favorable for HC
s Potential" [threshold 0.20]
     (2) and the SOURCE BED(S) POTENTIAL is "Highly favorable for a su
ccessful play" [threshold 0.20]
     (3) and the RESERVOIR BED(S) CONDITIONS is "Highly Favorable for
Potential Reservoirs" [threshold 0.20]
     (4) and the RESERVOIR BED(S) POTENTIAL is "Highly favorable for a
 successful play" [threshold 0.20]
     (5) and the TIMING (T) GEOLOGIC INDICATORS FOR TIMING is "HIGHLY
FAVORABLE" [threshold 0.20]
     (6) and the MIGRATION (FROM SOURCE BEDS TO RESERVOIR BEDS)  (M) G
EOLOGIC INDICATORS FOR MIGRATION is "HIGHLY FAVORABLE" [threshold 0.20
]
 THEN ----------------------------
     (1)      PLAY PROBABILITY is "Suggested to be between 80 and 100
percent favorable or present" [certainty 1.00]

RULE #17 priority 50 -  0 0 0 0 0 0 0 0 0 ▲ ▲ ▲ ▲ ▲ ▲COMSPEC=C:\COMMAN
D.COM
 IF ------------------------------
     (1)      the SOURCE BED(S) CONDITIONS is "Favorable for HCs Poten
tial" [threshold 0.20]
     (2) and the SOURCE BED(S) POTENTIAL is "Favorable for a potential
 play" [threshold 0.20]
     (3) and the RESERVOIR BED(S) CONDITIONS is "Favorable for Potenti
al Reservoirs" [threshold 0.20]
     (4) and the RESERVOIR BED(S) POTENTIAL is "Favorable for a Succes
sful Play" [threshold 0.20]
     (5) and the TIMING (T) GEOLOGIC INDICATORS FOR TIMING is FAVORABL
E [threshold 0.20]
     (6) and the MIGRATION (FROM SOURCE BEDS TO RESERVOIR BEDS)  (M) G
EOLOGIC INDICATORS FOR MIGRATION is FAVORABLE [threshold 0.20]
 THEN ----------------------------
     (1)      PLAY PROBABILITY is "Suggested to be between 30 and 79.9
9 percent favorable or present" [certainty 1.00]
```

Appendix 2—Continued.

```
RULE #18 priority 50 - Unfavorable or unknown play conditions
 IF ------------------------------
     (1)      the SOURCE BED(S) CONDITIONS is "Unfavorable for HCs Pot
ential or HCs Potential is Unknown" [threshold 0.20]
     (2) and the SOURCE BED(S) POTENTIAL is "Unfavorable for a potenti
al play, or very risky, or source potential unknown" [threshold 0.20]
     (3) and the RESERVOIR BED(S) CONDITIONS is "Unfavorable for Poten
tial Reservoirs or Reservoir Conditions Unknown" [threshold 0.20]
     (4) and the RESERVOIR BED(S) POTENTIAL is "Unfavorable for a succ
essful play" [threshold 0.20]
     (5) and the TIMING (T) GEOLOGIC INDICATORS FOR TIMING is UNFAVORA
BLE [threshold 0.20]
     (6) or  the TIMING (T) GEOLOGIC INDICATORS FOR TIMING is Unknown
[threshold 0.20]
     (7) and the MIGRATION (FROM SOURCE BEDS TO RESERVOIR BEDS)  (M) G
EOLOGIC INDICATORS FOR MIGRATION is UNFAVORABLE [threshold 0.20]
     (8) or  the MIGRATION (FROM SOURCE BEDS TO RESERVOIR BEDS)  (M) G
EOLOGIC INDICATORS FOR MIGRATION is Unknown [threshold 0.20]
 THEN ----------------------------
     (1)      PLAY PROBABILITY is "Suggested to be between 1.00 and 29
.99 percent favorable or present" [certainty 1.00]

     * * *   R U L E S   * * *   of   C:\MAHOGANY\PLAYAN.KB       * *
*
```

Appendix 3. Printout of goal-structures illustrating 15 goals in the Object-Attribute format for play-specific and prospect-specific evaluatins based on the rules shown in appendix 2, taken directly from the GEOPLAY-MAHOGANY expert-system program.

```
     * * *   G O A L S   * * *   of   C:\MAHOGANY\PLAYAN.KB       * *
*

POTENTIAL RESERVOIR BED(S) AVERAGE TOTAL THICKNESS OF RESERVOIR BED(S)
 IN PLAY  (priority 60)

POTENTIAL RESERVOIR BED(S) PROBABLE AREAL EXTENT OF RESERVOIR BED(S) I
N PLAY  (priority 60)

POTENTIAL RESERVOIR BED(S) AVERAGE EFFECTIVE POSOSITY OF RESERVOIR BED
(S) IN PLAY  (priority 60)

POTENTIAL RESERVOIR BED(S) AVERAGE DEPTH TO RESERVOIR BED(S) IN PLAY
(priority 60)

PROBABLE SOURCE BEDS TOTAL ORGANIC CARBON IN SOURCE BEDS  (priority 60
)

PROBABLE SOURCE BEDS AVERAGE TOTAL THICKNESS OF SOURCE BEDS  (priority
 60)

PROBABLE SOURCE BEDS AREAL EXTENT OF SOURCE BEDS  (priority 60)

PROBABLE SOURCE BEDS AVERAGE DEPTH TO SOURCE BEDS  (priority 60)

PLAY PROBABILITY  (priority 50)

RESERVOIR BED(S) POTENTIAL  (priority 50)

SOURCE BED(S) POTENTIAL  (priority 50)

PROBABLE SOURCE BEDS GEOLOGIC AGE OF SOURCE BEDS  (priority 50)

RESERVOIR BED(S) CONDITIONS  (priority 50)

SOURCE BED(S) CONDITIONS  (priority 50)

PLAY Property  (priority 50)

     * * *   G O A L S   * * *   of   C:\MAHOGANY\PLAYAN.KB       * *
*
```

Appendix 4. Printout of an example of the Conclusions arrived at by GEOPLAY using the Attribute-Values illustrated in table 1 as defined for a highly favorable play, taken directly from the GEOPLAY-MAHOGANY expert-system program

```
SOURCE BED(S) CONDITIONS    is Highly Favorable for HCs Potential   [ce
rtainty 1.00]
SOURCE BED(S) POTENTIAL    is Highly favorable for a successful play
[certainty 1.00]
RESERVOIR BED(S) CONDITIONS    is Highly Favorable for Potential Reser
voirs  [certainty 1.00]
RESERVOIR BED(S) POTENTIAL    is Highly favorable for a successful pla
y  [certainty 1.00]
PLAY PROBABILITY    is Suggested to be between 80 and 100 percent favo
rable or present  [certainty 1.00]
PLAY Property    is Highly Favorable with Good Direct Evidence of HCs
 [certainty 1.00]

     * * * * * * * * * *  C O N C L U S I O N S  * * * * * * * * * *

the POTENTIAL RESERVOIR BED(S) AVERAGE TOTAL THICKNESS OF RESERVOIR BE
D(S) IN PLAY
   is 400  [certainty 1.00]

the POTENTIAL RESERVOIR BED(S) PROBABLE AREAL EXTENT OF RESERVOIR BED(
S) IN PLAY
   is 2000  [certainty 1.00]

the POTENTIAL RESERVOIR BED(S) AVERAGE EFFECTIVE POSOSITY OF RESERVOIR
 BED(S) IN PLAY
   is 11  [certainty 1.00]

the POTENTIAL RESERVOIR BED(S) AVERAGE DEPTH TO RESERVOIR BED(S) IN PL
AY
   is 6000  [certainty 1.00]

the PROBABLE SOURCE BEDS TOTAL ORGANIC CARBON IN SOURCE BEDS
     (no values)

the PROBABLE SOURCE BEDS AVERAGE TOTAL THICKNESS OF SOURCE BEDS
   is 400  [certainty 1.00]

the PROBABLE SOURCE BEDS AREAL EXTENT OF SOURCE BEDS
   is 789  [certainty 1.00]

the PROBABLE SOURCE BEDS AVERAGE DEPTH TO SOURCE BEDS
   is 9000  [certainty 1.00]

the PLAY PROBABILITY
   is Suggested to be between 80 and 100 percent favorable or present
 [certainty 1.00]

the RESERVOIR BED(S) POTENTIAL
   is Highly favorable for a successful play  [certainty 1.00]

the SOURCE BED(S) POTENTIAL
   is Highly favorable for a successful play  [certainty 1.00]

the PROBABLE SOURCE BEDS GEOLOGIC AGE OF SOURCE BEDS
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Appendix 4—Continued.

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   is MIDDLE THRU LOWER CRETACEOUS  [certainty 1.00]

the RESERVOIR BED(S) CONDITIONS
   is Highly Favorable for Potential Reservoirs  [certainty 1.00]

the SOURCE BED(S) CONDITIONS
   is Highly Favorable for HCs Potential  [certainty 1.00]

the PLAY Property
   is Highly Favorable with Good Direct Evidence of HCs  [certainty 1.
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SELECTED SERIES OF U.S. GEOLOGICAL SURVEY PUBLICATIONS

Periodicals

Earthquakes & Volcanoes (issued bimonthly).
Preliminary Determination of Epicenters (issued monthly).

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Professional Papers are mainly comprehensive scientific reports of wide and lasting interest and importance to professional scientists and engineers. Included are reports on the results of resource studies and of topographic, hydrologic, and geologic investigations. They also include collections of related papers addressing different aspects of a single scientific topic.

Bulletins contain significant data and interpretations that are of lasting scientific interest but are generally more limited in scope or geographic coverage than Professional Papers. They include the results of resource studies and of geologic and topographic investigations; as well as collections of short papers related to a specific topic.

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Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are reproduced on request unlike formal USGS publications, and they are also available for public inspection at depositories indicated in USGS catalogs.

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Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7 1/2-minute quadrangle photogeologic maps on planimetric bases which show geology as interpreted from aerial photographs. The series also includes maps of Mars and the Moon.

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