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INTELLIGENT COMPUTING SYSTEM FOR RESERVOIR ANALYSIS AND RISK ASSESSMENT OF THE RED RIVER FORMATION

Topical Report
October 2001

By:
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ABSTRACT

Integrated software has been written that comprises the tool kit for the Intelligent Computing System (ICS). The software tools in ICS are for evaluating reservoir and hydrocarbon potential from various seismic, geologic and engineering data sets. The ICS tools provide a means for logical and consistent reservoir characterization. The tools can be broadly characterized as 1) clustering tools, 2) neural solvers, 3) multiple-linear regression, 4) entrapment-potential calculator and 5) combining tools. A flexible approach can be used with the ICS tools. They can be used separately or in a series to make predictions about a desired reservoir objective. The tools in ICS are primarily designed to correlate relationships between seismic information and data obtained from wells; however, it is possible to work with well data alone.

EXECUTIVE SUMMARY

This report contains descriptions of software tools for aiding companies and individuals in their efforts to extract the most information from geophysical, geological and engineering data in the pursuit of oil exploration and development. The primary objective of this project is to construct software tools for an integrated system of reservoir characterization and risk assessment. Nine software tools and one utility comprise the "Intelligent Computing System" or ICS tool kit. These tools were written in MATLAB™. MATLAB is an integrated programming and visualization environment that uses a proprietary interpreted language designed for easy experimental development of scientific and engineering software. These tools were developed and tested using seismic, geologic and well data from the Red River Play in Bowman County, North Dakota and Harding County, South Dakota. The geologic setting for the Red River Formation is shallow-shelf carbonate at a depth from 8000 to 10,000 ft. It is thought that the ICS tools can be used in many geological settings.

Accompanying this report is a CD-ROM with all the necessary script files for execution of the ICS tools under the MATLAB platform. The necessary components are MATLAB, Neural Net Toolbox and Fuzzy Logic Toolbox. Also included on the CD-ROM are data files that can be used to demonstrate the functionality of each tool or utility. In addition, there are example data files to be used with the tutorial section of this report.

Currently, there are seven ICS tools that have been successfully compiled to Windows executable programs. Three ICS tools use MATLAB Neural Network or Fuzzy Logic Toolboxes. The current MATLAB compiler does not support creation of stand-alone executable programs from scripts that have calls to routines from these Toolboxes. The ICS tools that utilize the MATLAB neural network or fuzzy logic toolboxes will be re-written in an alternate language and compiled if a new release of the MATLAB compiler still does not support these Toolboxes.

There are three budget periods for this project. The ICS tools developed during budget period 1 are considered to be preliminary or beta versions. Software refinements will be made in the next budget period. Predictions of reservoir potential in the Red River Formation at predetermined sites will be made with the ICS tools at the conclusions of budget period 1. Testing and validation of the ICS reservoir predictions will follow in budget period 2. This will involve drilling new wells or re-completing existing wells through open-hole horizontal laterals at ICS selected locations.

The report that follows describes in detail the logic and mechanics of running each ICS tool and utility. Practice files are provided to allow testing. A full description is given for the creation of input files. The tutorial section provides a template using ICS tools to achieve several reservoir characterization objectives and to assess reservoir potential.

Intelligent Computing System for Reservoir Characterization and Risk Assessment

INTRODUCTION

The Intelligent Computing System (ICS) is a set of software tools to aid exploration and development for oil and gas. It has been designed and tested with data from the Red River Formation, Williston Basin. However, the ICS tools and approaches for addressing reservoir characterization problems should be applicable in many hydrocarbon provinces.

The ICS tools are implemented in MATLAB™. MATLAB is an integrated programming and visualization environment that uses a proprietary interpreted language designed for easy experimental development of scientific and engineering software. MATLAB runs on UNIX or Microsoft Windows platforms, and is distributed by

The Math Works, Inc.
3 Apple Hill Drive
Natick, MA 01760-2098
http://www.mathworks.com

All ICS code development was done using version 5.3 of MATLAB running on Microsoft Windows NT. Elements of the MATLAB Neural Network Toolbox and Fuzzy Logic Toolbox were used, respectively, for those ICS components that involve artificial neural networks (ANN) or fuzzy logic algorithms.

The ICS tools and utilities that are delivered with this report are MATLAB native code (.m files). Using the MATLAB native code files requires that the user purchase the appropriate MATLAB products. This option provides the ability to modify the ICS source code. A full description of MATLAB products and pricing can be found by browsing the MATLAB web site. We are currently compiling the MATLAB code as Microsoft Windows executables (.exe files). **The Windows executable files can be run, without the purchase of additional software, on any suitable Windows platform, but cannot be modified by the user.**

The software tools in ICS are for evaluating various data sets from seismic, geologic and engineering sources. The objective of these tools is to provide a means for logical and consistent reservoir characterization. These tools can be broadly characterized as 1) clustering tools, 2) neural solvers, 3) multiple-linear regression, 4) entrapment-potential calculator and 5) combining tools. The tool kit has been tested on seismic and well data from six 3D seismic surveys and with well data that are located outside the seismic survey boundaries.

In the most general way, the user of these software tools will characterize the common physical parameters that cause a sedimentary layer to be a good or poor oil reservoir. Seismic information will be transformed to those physical parameters. The pseudophysical parameters will then be used to predict the reservoir potential for a sedimentary layer or unit.

Tools are not available in ICS for extraction of seismic time or waveform attributes from a seismic data file as delivered by the processing provider. It is expected that users have the ability to pick and extract relevant seismic information using seismic interpretation software. The data files imported and exported by ICS routines are in simple ASCII comma-separated-variable format.

Approach and Methodology

A generic approach for using ICS would follow the reservoir characterization items listed below.

Depositional setting
Structure and growth history
Seismic pseudo-reservoir parameters
Fluid saturation
Structure and stratigraphic entrapment
Combining and weighting characterization parameters

The tools in ICS are primarily designed to correlate relationships between seismic information and data obtained from wells. It is possible to work with well data alone. Likewise, there may be special circumstances where seismic data could be used without well data. A generalized approach to reservoir characterization with ICS is shown in Figure 1. A "Z" map is a representation of reservoir potential or "goodness", either in relative ranking or scaled with some values that correspond to production.

Figure 1. ICS Data and Logic flow.

DATA →	**TOOLS →**	**INTERMEDIATE OBJECTIVES →**	**COMBINE →**	**"Z" MAP**
Formation Tops	Clustering	Deposition	Manual Weight	
Log Analysis	Neural Solver	Structure	Neural Solver	
Production	Linear Regression	Growth History	Fuzzy Rules	
Flow Tests		Storage		
Seismic Time		Transmissibility		
Seismic Intervals		Fluid Saturation		
Seismic Attributes		Entrapment		
Seismic Models				

Depositional setting

Evaluation of depositional setting involves identifying the correspondence of rock-type parameters with the environment in which the sediments were deposited. Rock-type parameters can be assessed from well logs and cores. Environmental setting can be inferred from interval thickness between marker beds within or near the zone of interest.

In some cases the reservoir layer of interest might be seismically invisible but an interval, postulated to describe the environmental setting, may have seismic expression. The tools in ICS can help provide a correlation between depositional setting and rock type.

Structure and growth history

The importance of present-day structure for entrapment of hydrocarbons in many reservoirs is obvious. In addition, the growth history of the structure will have a bearing on the migration of hydrocarbons into the structure or compartmentalization of the reservoir. ICS tools can be used to assess the correlation of structural growth with known areas of production.

Seismic pseudo-reservoir parameters

Variation in reservoir thickness and porosity can produce variation in seismic response. Seismic attributes such as amplitude and interval time can be correlated with thickness and porosity-thickness in some reservoirs. In those conditions, the results can be used to predict the nature and extent of the reservoir. With ICS tools, any reservoir attribute can be experimentally compared to multiple seismic attributes. ICS will attempt a correlation and ranking of seismic attributes with the reservoir parameters provided. When using a neural solver, the limit of seismic attributes that can be evaluated at one time is constrained by the number of control wells.

Fluid saturation

In some reservoirs and under certain conditions, a higher saturation of hydrocarbons can be indicated from frequency or AVO response of seismic data. Seismic modeling should be performed to determine if such attributes are applicable for the reservoir under evaluation. Analysis of these data can be viewed as a subset under seismic pseudo-reservoir parameters.

Structure and stratigraphic entrapment

The entrapment potential of a reservoir is comprised of structural and capillary components. A special ICS routine has been developed that can import depth and rock-type information to assess entrapment potential.

Combining and weighting characterization parameters

The potential for hydrocarbon entrapment and production from a reservoir is comprised of many factors. These include reservoir structure, reservoir size, vertical and lateral changes in reservoir quality, location relative to source rock and tectonic setting. Under certain conditions or for different formations, the importance or weight of the reservoir characterization parameters will vary. ICS allows users to subjectively combine and weight any characterization output. A neural solver can be used, when there are sufficient control wells, to objectively combine and weight characterization output. A fuzzy-logic routine is under development as means of objective combining and weighting.

Data Requirements

The structure of ICS is primarily designed to incorporate seismic information in a reservoir characterization process. This is not mandatory, however. The tools in ICS can work with well-log data as the sole source of geological input. The input data can be as simple or complete as is available or desired by the user. It must be stressed that characterization results will improve more significantly by adding dependent data (well information) than by adding more independent (seismic) data. Throughout the text that follows, there are references to dependent and independent data. Dependent data (or values) generally are items that are measured at wells. Dependent data are represented by a dependent variable in some function, $z = f(x,y)$ where z is the dependent variable. In this context, when we make predictions of reservoir phi-h from some seismic attributes, phi-h is represented by a dependent variable and is predicted by some function applied to the seismic attributes (independent variables).

A well data set would be comprised of items that represent reservoir storage, permeability, saturation, production and structure. The most common source of reservoir storage and saturation is from well logs. Digitized log data can be interpreted for net thickness, porosity and saturation. Drill-stem test data are a good source for permeability. Core data are also a good source for permeability, but the number of cores is often too few to provide an adequate population distribution. Permeability or productivity can be estimated from advanced decline-curve analysis using type-curve techniques. However, stimulation, damage or pressure depletion can significantly affect results from these methods. Production volumes and phase ratios over a normalized time period should also be included in the data set. Structure and growth history information can be obtained from depths of important geologic markers from well logs.

Once collected, the data set is then organized in an ordinary spreadsheet with data in one row representing one well or location. The location of each well must be in the same coordinate system as the seismic data. The type of information in each column will be the same. A well-master database is now constructed.

A seismic database is assembled from exported files from the user's seismic interpretation software. Several seismic databases may be needed. One seismic database should have time picks at major geologic events. Another seismic database may have waveform and iso-time attributes over a narrow time window that is associated with the reservoir. The selection of appropriate attributes and time window should be determined from some synthetic seismic modeling exercises.

Geologic and Seismic Setting for ICS Development

Statement of Problem

Red River oil reservoirs in southwestern North Dakota and northwest South Dakota are relatively deep (8,000 to 10,000 feet below ground surface), which result in significant cost for exploration and development. Therefore, technology and methods of data analysis that assist decision makers in the selection of optimal drill-site locations and risk reduction have great value in petroleum exploration.

Subtle changes in structure and stratigraphic controls are thought to cause entrapment of hydrocarbons in reservoirs of the Red River formation. Early exploration models included deposition of Red River reservoirs over buried Precambrian topographic hills or structures. Exploration tools such as mapping seismic travel time between two strong reflectors (one shallow and one deep) has been used successfully to identify topography at Red River depth that fits the buried-hill model. Many of the small anticlinal features discovered in the Bowman-Harding area exhibit structural relief from 50 to 100 ft from a structural base encompassing an area of 0.5 to 1.0 square mile. As the region matured through drilling successes and failures, it has become clear that the buried-hill model is oversimplified, incomplete and inadequate for a modern-day explorationist in a restrictive economic environment.

Modern seismic methods of processing and 3D acquisition can help operators improve recovery of hydrocarbons from existing reservoirs by targeting areas of thick porosity development and identifying subtle basement faults or lineaments. The number of geologic, geophysical, and engineering variables pertinent to the occurrence of hydrocarbons in the Red River formation have increased dramatically as 3D seismic data are manipulated in more detail. Effectively resolving issues of entrapment of commercial quantities of oil in reservoirs of the Red River involves a complex understanding of geological depositional processes and tectonic growth from the time of deposition (450 million years ago) of the Red River Formation through present-day.

There are several evaluations that are completed by scientists and engineers, either conscientiously or sub-conscientiously, that assist exploration managers in determining whether a location is prospective for drilling. In a geological framework, these are:

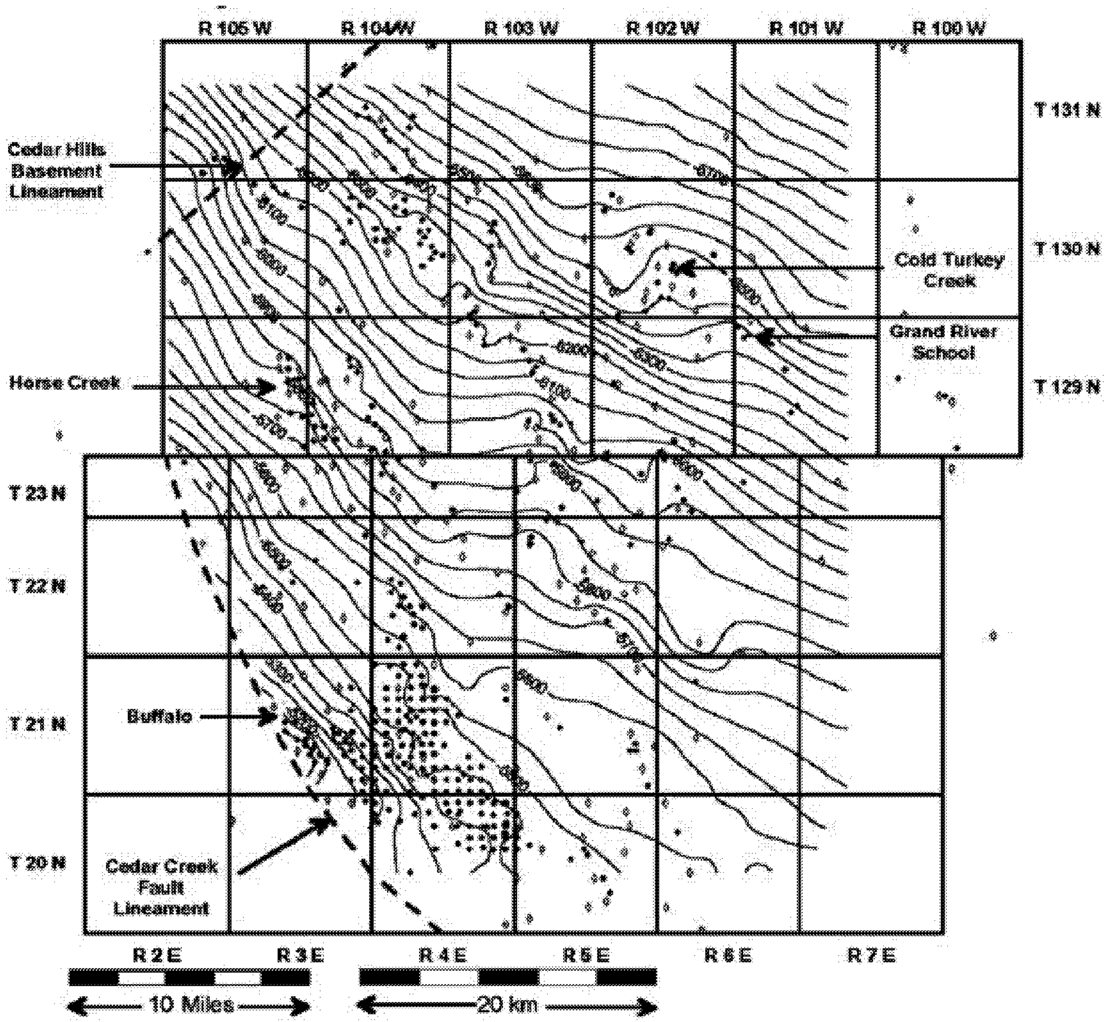
1) the setting in which the reservoir sediments were deposited and affects on reservoir quality,
2) chemical alteration or weathering that may affect reservoir quality after burial,
3) affects of burial and thermal history on maturation of source rock,
4) movement (upheaval or subsidence) of potential reservoir layers after burial,
5) identification of a viable source rock,
6) position of potential reservoir layers with respect to oil migration flow paths from hydrocarbon source rock,
7) entrapment of oil during expulsion and post oil migration, and
8) volume of oil contained by the reservoir trap.

The Intelligent Computing System consists of a set of tools that can analyze a large volume of multi-disciplinary data. The objective of these tools is to provide a means for logical and consistent reservoir characterization.

Geologic Setting

The Red River formation of Bowman County, North Dakota and Harding County, South Dakota can be characterized as a continuous sequence of carbonate rocks that are Ordovician age and range in thickness from 500 to 550 feet. Carbonates of the Red River formation conformably overly marine shale of the Winnipeg formation, and are overlain by marine shale and carbonates of the Stony Mountain formation. The predominant dip direction of the Red River formation in Bowman and Harding counties is northeast. The rate of dip ranges from approximately 50 to 150 feet/mile (Figure 2).

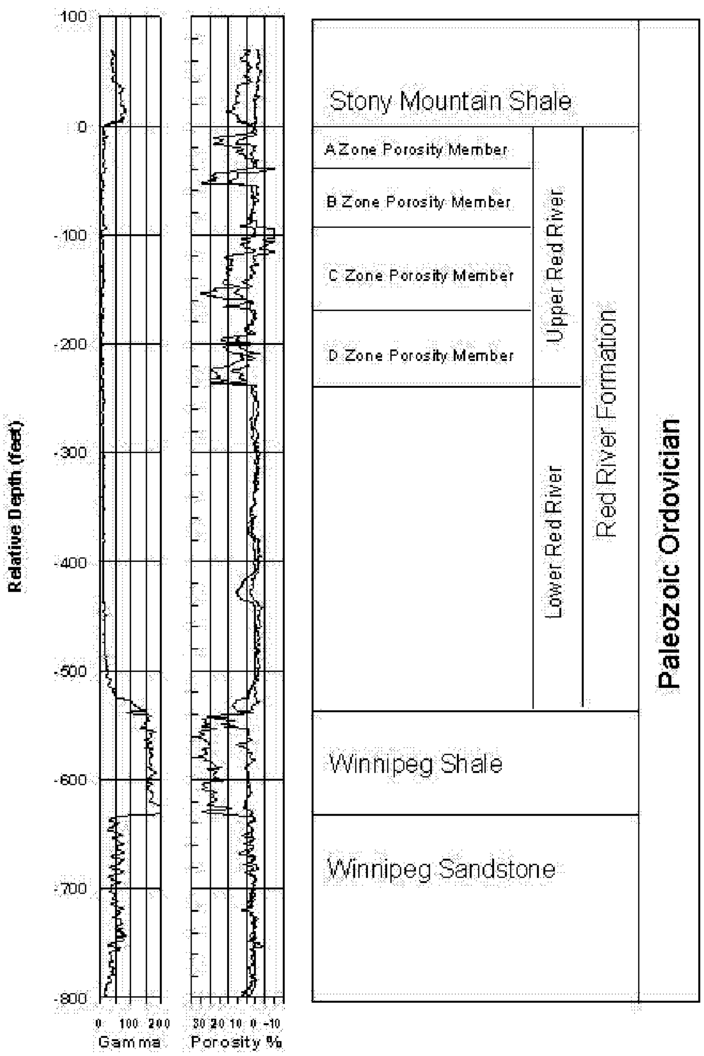
Figure 2. Structure map of the Red River Formation over a portion of the Bowman Red River Play.



The Red River formation in Bowman and Harding counties is informally divided into two members, an upper and lower unit based on the occurrence and absence of economic quantities of hydrocarbons. The sequence of carbonate rocks in the lower member (lowermost 250 feet) of the Red River formation were deposited in a relatively deep-water, open shelf, marine environment. Wells penetrating to the base of the Red River section have not encountered porosity in the lower member. In contrast, carbonate rocks in the upper member (uppermost 250 feet) of the Red River formation were deposited in a relatively shallow marine to evaporite sabkha setting. Carbonate rocks in this interval are more variable in lithology and rock texture, and intervals of porosity are commonly observed.

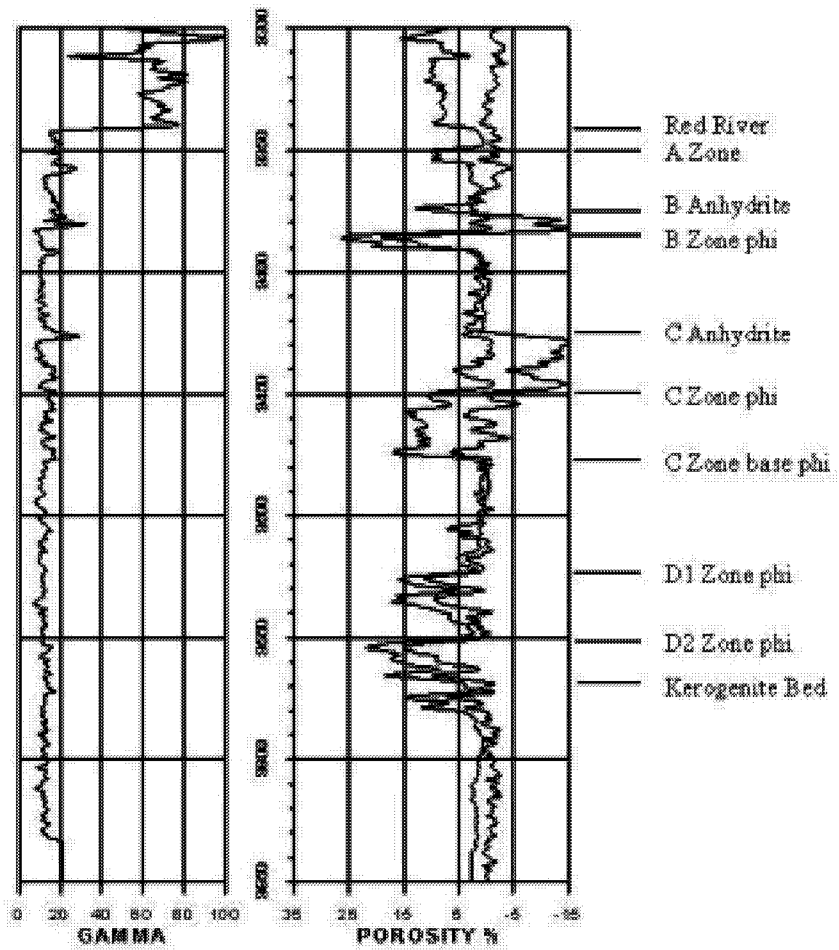
Oil production in Bowman and Harding counties occurs in the upper member of the Red River formation. In this interval, four zones of porosity are identified that may store commercial quantities of oil. In descending order, the four zones of porosity are the A, B, C, and D (Figure 3).

Figure 3. Stratigraphic section of the Red River Formation.



The four zones of porosity represent at least three cycles of carbonate sedimentation. A cycle of Red River carbonate sedimentation consists of four depositional units that reflect variations in sedimentation and biological activity due to increases in the concentrations of water salinity and a postulated corresponding change in water depth (Figure 4).

Figure 4. Type log of the Upper Red River Formation.



In ascending order, these units are (1) a permeable to impermeable, mottled, sometimes dolomitic (where permeable), bioturbated and fossiliferous wackestone, (2) a porous, non-fossiliferous, laminated, fine-grained, dolomitic mudstone, (3) nodular (at the base) to laminated (near the top) anhydrite that is occasionally interbedded with dolomitic mudstone, (4) a thin argillaceous carbonate that often corresponds to a "hot" gamma-ray signature on open-hole logs. In addition, thin but relatively continuous layers (1 to 2 feet in thickness) of black, organic-rich packstone that contain relatively high concentrations of total organic carbon (TOC) are commonly observed in contact with extensively dolomitized mudstone in the D porosity zone, and possibly the C zone. These thin organic rich layers are also observed in other portions of the Williston Basin and are thought to represent periods of basin stagnation, severe restriction, and euxinic (low oxygen) bottom conditions. In thermally mature segments of the basin, these layers are considered a source of Red River oil.

Oil entrapment in the Red River formation in Bowman and Harding counties generally occurs by complicated combinations of porosity pinchout, lateral variations in pore-throat size, low-relief structural closure, and fault displacement. Traps dominated by structure typically exhibit structural closure in the range of 50 to 100 feet. Stratigraphically controlled traps are commonly associated with a structural flexure that exhibits very little spill-point closure. Good reservoir conditions with high oil saturation generally prevail on the basin-ward side (east-northeast) of the structural flexure while low permeable carbonates generally occupying the updip margin of the flexure. Porosity in the A and C zones exhibit very limited lateral extent and effective thickness, and is only marginally oil productive in the Bowman and Harding county area. Reservoir development in the B and D zones is significantly more widespread, thus, significant oil reserves have been found in these two zones. The B zone ranges in thickness from less than 5 feet to as much as 15 feet, and exhibits relatively widespread porosity development throughout the regional. Oil reserves in the B zone are commonly trapped by a combination of structural and stratigraphic influences across a relatively widespread structural platform. Due to its continuity both in thickness and lateral extent, the Red River B zone has been a primary target during the drilling and completion of wells through open-hole horizontal laterals. In contrast, porosity in the D zone may range in thickness from 0 to more than 40 feet. In addition, D zone reservoirs are generally limited in their aerial extent. Most D zone reservoirs in Bowman and Harding counties range is size from less than 200 acres to 600 acres. Due to abrupt changes in thickness and limitations on reservoir aerial extent, D zone reservoirs can be identified from amplitude changes in the Red River formation measured from 3D seismic data.

Seismic Setting

Seismic records from the Bowman Red River play are good to excellent. The seismic data used for ICS development are from six 3D surveys acquired with dynamite and recorded at 110-ft spacing. All surveys were processed with same parameters and by the same company.

The reflector from Red River Formation occurs at approximately 1850 milliseconds where the Red River depth is about 9300 feet (Figure 5). On seismic records, the Upper Red River consists of peak-trough-peak-trough sequence that covers approximately 80 milliseconds. Synthetic models and well-seismic correlation show that amplitude variation in OrrT1 and OrrP2 in conjunction with interval time OrrT1z to Owiz are good predictors for Upper Red River reservoir development (Figure 6).

Figure 5. Seismic cross-section from the Bowman Red River Play.

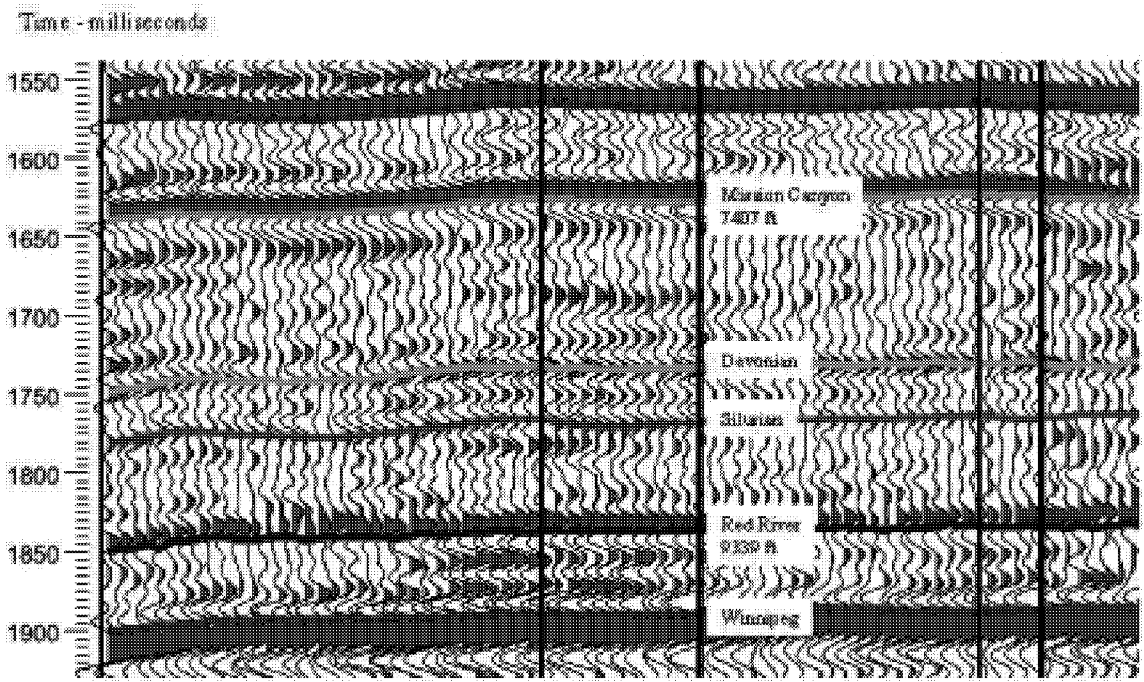
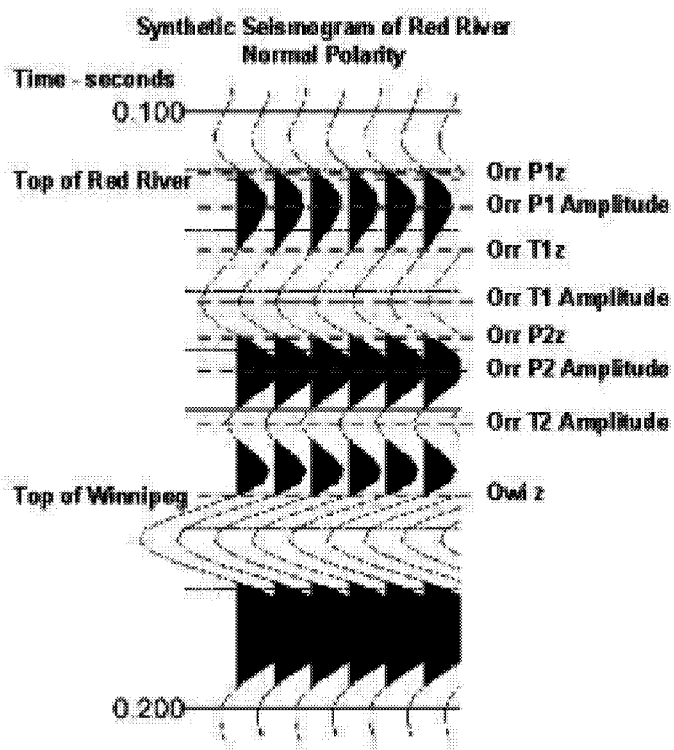


Figure 6. An example of a synthetic seismogram across the Upper Red River.

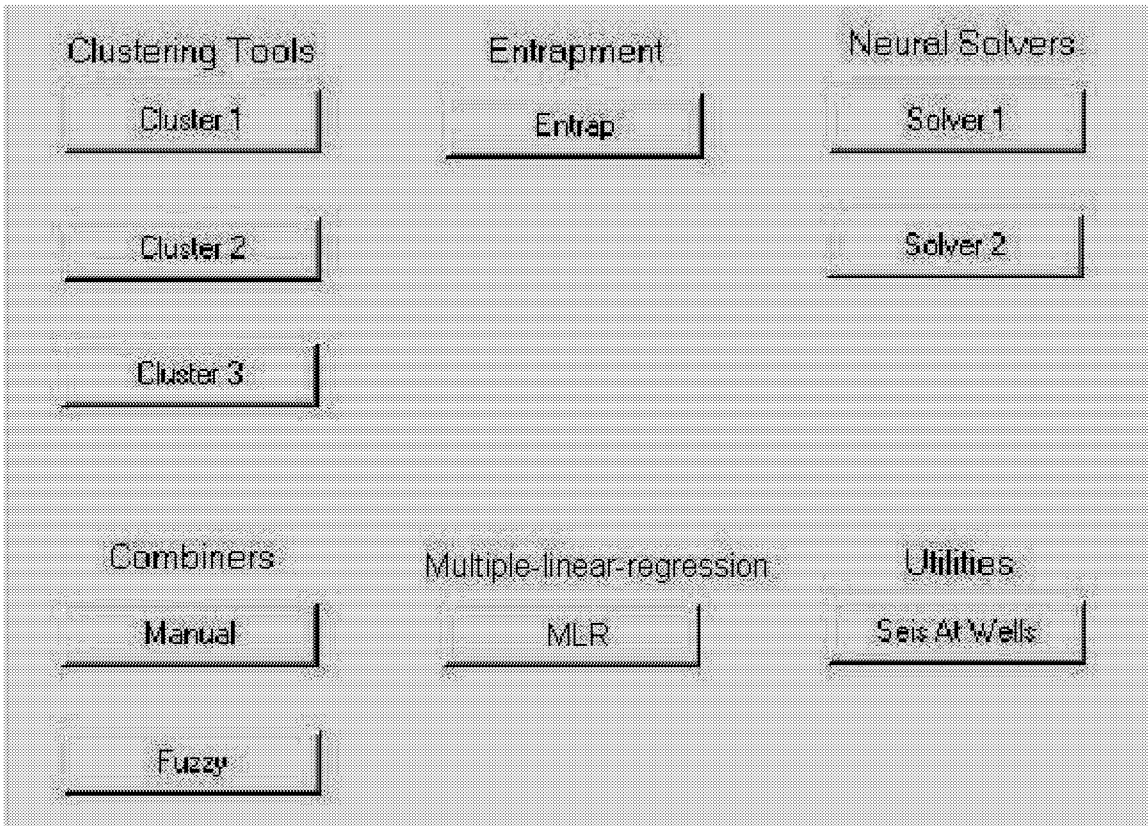


TOOLS and UTILITIES

ICS Front Page

All tools and utilities can be executed from a simple window that is presented after starting ICS. The first window that is presented after starting ICS is shown in Figure 7.

Figure 7. Front-page window ICS for access to all tools and utilities.



Simply press the appropriate button to start the tool or utility.

If ICS is run under the MATLAB shell, start MATLAB and type ICS at the command prompt followed by enter. The path to the directory which contains the ICS code needs to be permanently set in MATLAB. To do this, select File/Set Path from the main MATLAB window menu. A dialog will open. Select the Add Folder button in this dialog. A second dialog opens from which you select the folder that contains the code. Select OK from the second dialog and Close from the first. The path will now appear in the path list in the first dialog.

TOOLS and UTILITIES

Seismic at Wells

"Seismic at Wells" is a utility used to obtain values of 3D seismic parameters at specific well locations. Two comma-separated-variable (csv) files are required as input. One defines well locations with three data columns: x, y, and a numeric well identifier (such as API). The second input file contains the 3D seismic data. It may have any number of columns, but the first two are assumed to be x and y. The output file columns are x, y, and well identifier, followed by columns 2…n from the input seismic data file.

The output file will contain one row of data for each well location that falls within the convex hull of the seismic data points. An error message will be displayed if none of the well locations qualifies. The values for the parameters at each well location are obtained by averaging data from the three closest input data points.

After the two input files are read, the map displays the seismic data points as gray dots, and the output wells as red dots.

Shown in Figure 8 is an example file containing wells locations as viewed with spreadsheet software.

Figure 8. An example of a file with well locations.

east	north	API
1212611	154710	3301100198
1214184	150850	3301100258
1214039	147068	3301100259
1212821	149427	3301100262
1212031	153869	3301100305
1213827	150045	3301100311
1207014	152537	3301100339
1215767	142373	3301100343
1212374	144767	3301100432
1212474	145067	3301100488
1211646	144209	3301100915

The well file contains only three columns. The first two are x-y coordinates. The third column is a well identifier.

Shown in Figure 9 is an example of a file containing seismic data as viewed with spreadsheet software.

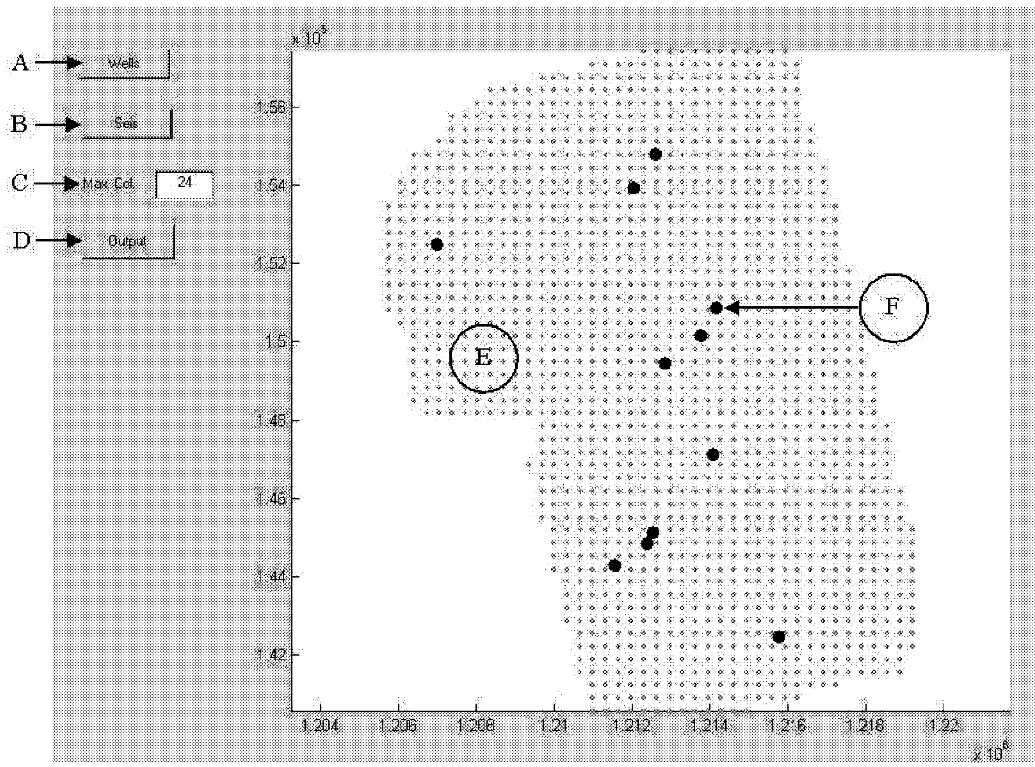
Figure 9. An example of a file that contains seismic data to be captured at well locations.

x	y	ke-mmc_norm	Kn-Mmc_norm	Kgh-mmc_norm	Mmc-T1z_norm	T1z-Owi_norm
1207727	148819	1.0107	1.0010	1.0034	1.0079	1.0221
1206414	148488	1.0077	0.9971	1.0022	1.0220	1.0042
1209040	148488	1.0103	1.0051	1.0081	0.9945	1.0138
1206414	148819	1.0097	0.9991	1.0041	1.0137	0.9985
1206742	148488	1.0051	0.9953	1.0002	1.0301	1.0191
1207070	149482	1.0136	1.0037	1.0063	0.9984	0.9967
1208055	148819	1.0099	1.0053	1.0081	0.9984	1.0208
1210025	144847	1.0084	0.9980	0.9972	0.9897	1.0274
1211338	145840	1.0071	0.9994	0.9973	0.9930	1.0162
1207727	148488	1.0077	1.0013	1.0040	1.0061	1.0355
1206742	148157	1.0030	0.9943	0.9985	1.0341	1.0198

There is no limit to the number of data columns in the seismic file. The first two columns are coordinates. Items such as line, trace and shot-point identifiers should be excluded from the file.

Shown in Figure 10 is a screen capture of the work window for the "Seismic at Wells" utility.

Figure 10. Work window for Seismic at Wells utility and navigation key.



Key to work window for "Seismic at Wells" utility.

A. Load file containing well locations.
B. Load file containing seismic data.
C. Set maximum column of data to be included. No data after column 24 will be included in this example.
D. Export a new file with well locations and extracted seismic information.
E. Locations of seismic traces.
F. Locations of wells.

After pressing "Output" button "D", a file is created as shown in Figure 11.

Figure 11. Example of output file from Seismic at Wells utility.

x	y	API	ke-mmc_norm	Kn-Mmc_norm	Kgh-mmc_norm	Mmc-T1z_norm	T1z-Owi_norm
1212611	154710	3301100198	0.99435	0.99755	0.99877	0.96832	0.98190
1214184	150850	3301100258	0.99597	1.00078	1.00072	0.97606	0.93612
1214039	147068	3301100259	0.99157	0.99286	0.99259	0.98564	1.00310
1212821	149427	3301100262	0.99769	1.00059	1.00046	0.99006	0.97297
1212031	153869	3301100305	0.99680	0.99645	0.99684	0.96979	0.99849
1213827	150045	3301100311	0.99617	0.99950	0.99853	0.98445	0.93024
1207014	152537	3301100339	1.00401	1.00179	1.00653	1.00281	0.96395
1215767	142373	3301100343	0.99637	0.99191	0.98641	0.98592	1.01018
1212374	144767	3301100432	1.00303	1.00078	0.99549	0.98460	1.00728
1212474	145067	3301100488	1.00012	0.99963	0.99440	0.98812	0.99969
1211646	144209	3301100915	1.00247	0.99705	0.98876	0.98749	1.00726

TOOLS and UTILITIES

Land Grid and Wells

ICS tools that include map displays feature a button labeled "Grid/Wells." This button implements a feature that allows user-supplied land grid and well spots to be overlaid on the map. This discussion provides a guide to help users build files that are needed by the "Grid/Wells" feature. If running ICS from MATLAB, the path to the directory which contains the ICS code needs to be permanently set in MATLAB. To do this, select File/Set Path from the main MATLAB window menu. A dialog will open. Select the Add Folder button in this dialog. A second dialog opens from which you select the folder that contains the code. Select OK from the second dialog and Close from the first. The path will now appear in the path list in the first dialog. When the "Grid/Wells" button is selected, the software attempts to find, in the directory set as described above, three files with the names shown below.

secs.txt
twps.txt
wells.txt

These are ASCII files that contain, one per line, the full paths to one or more data files describing, respectively, section boundaries and labels, township boundaries and labels, and well locations. The section file(s) are drawn first, in black, followed by the township files in blue and the well spots in black.

The well location files are standard ICS .csv files having x and y coordinates in the first two data columns. The section and township data files are ASCII files that describe labels and polyline boundaries. These files may contain any number of label and/or polyline boundary definitions.

A label is defined by two lines of data:

L, *label*
x, y

where *label* represents the label text, and *x*, *y* the coordinates of the center of the text.

A polyline boundary is defined by n + 1 lines of data:

P, *n*
x1, *y1*
x2, *y2*
…
xn, *yn*

where *n* gives the number of nodes in the polyline, defined by *xn*, *yn*.

For example, the following file fragment defines the label and boundary of township 21N 3E.

```
L, 21N 3E
1171026, 57015
P, 5
1187771, 72418
1187553, 67169
1182277, 67388
1182461, 72660
1187771, 72418
```

Note that the coordinates used in these files, and the coordinates used in all ICS .csv files, are quadrant I Cartesian coordinates, not latitude/longitude.

Example files are provided under the directory \grid_wells\.

TOOLS and UTILITIES

Overview of Clustering Tools

There are three clustering tools in ICS. The Cluster 1 routine calculates two to four clusters (user-selected option) using all combinations of differences from the independent data columns. Examples of independent data for this case would be seismic time picks. Cluster 2 calculates two to four clusters on the independent data as imported. Examples of independent data for this case would be seismic amplitudes. Examples of dependent data for Cluster 1and Cluster 2 tools would be well or reservoir parameters. The Cluster 3 tool computes from two to ten clusters of the independent data without relationships to any well data. These clusters could be viewed as natural or intrinsic clusters.

The ICS cluster tools perform clustering using a method called fuzzy c-means clustering. This technique is described in

> Bezdek, J. C., *Pattern Recognition with Fuzzy Objective Function Algorithms*, Plenum Press, New York, 1981.

The implementation is provided by the "fcm" command of the MATLAB Fuzzy Logic Toolbox. A full description of MATLAB products and documentation can be found at the MATLAB web site, http://www.mathworks.com.

The great utility of the clustering tool is to import a potentially large number of independent data (such as seismic amplitude) and quickly assess which are most related to the dependent data (such as porosity-thickness). The tool then can produce a cluster-pattern map of those most-related independent data or any user selected data contained in the imported file (correlation and ranking is provided as output). The clustering tool is very robust as it works well in cases where the dependent data (well control) population is small. In addition to producing a cluster map, an output file can be generated that contains grid location (x, y), cluster rank and cluster mean-value from the dependent data. This file can be imported for use in other ICS tools or external mapping software.

Cluster 1 Tool

The Cluster 1 Tool produces clusters using differences of the independent data columns (intervals). Organize the data for clustering with Cluster 1 in a spreadsheet as shown in Figure 12. The first two columns are reserved for coordinates. In this example we have used a state-plane system. The second column is a numeric identifier for wells or seismic traces. The cells in column 3 can be blank, but some identifier is required if the user wishes to track cluster output by well or seismic trace. Columns four and five are reserved for well information (dependent data). In this example we have chosen depths at two geological horizons. Other common examples of dependent data for columns 4 and 5 would be 1) phi-h and h, 2) phi-h and shale volume, 3) phi-h and kh, and 4) net h and gross h. If only one dependent value is desired, duplicate the data in columns 4 and 5. It is desirable to have six or more dependent data (wells) for good results. The subsequent columns are independent data. In this example, the independent data are seismic time at selected geologic horizons. Each cell for independent data must be filled. There is no limit to the number of independent data columns, but a practical limit for independent data columns is seven, as this will produce 21 intervals for clustering

Figure 12. An example of a file used by the Cluster 1 Tool.

x	y	Well	Orr Depth	B Zn Depth	Ke_time	Kgh_time	Kmo_time	Mk_time	Mmc_time	Dtf_time	Orr_time
1254737	158993	1	-6500	-6543	712	1053	1172	1612	1670	1775	1873
1258348	159293	2	-6454	-6499	711	1056	1170	1594	1658	1764	1863
1257953	158110	3	-6401	-6443	711	1051	1169	1594	1658	1763	1858
1258116	158314	4	-6404	-6447	711	1051	1171	1594	1658	1762	1856
1258315	158463	5	-6405	-6448	711	1053	1171	1594	1657	1761	1856
1258702	158574	6	-6413	-6456	713	1055	1173	1593	1658	1762	1857
1259280	158704	7	-6437	-6480	715	1057	1171	1595	1660	1764	1862
1259006	157371	8	-6433	-6475	713	1054	1171	1599	1660	1767	1861
1257814	154290	9	-6496	-6537	712	1054	1169	1601	1664	1771	1874
1251925	148805				722	1064	1174	1595	1665	1775	1881
1251925	149132				724	1064	1174	1596	1666	1775	1881
1251925	149459				723	1064	1175	1598	1667	1776	1881
1251925	149785				726	1059	1174	1612	1667	1775	1881
1251925	150112				727	1059	1175	1604	1670	1776	1882
1251925	150439				719	1059	1177	1604	1671	1776	1882
1251925	150765				717	1059	1178	1604	1672	1776	1881
1251925	151092				717	1057	1174	1605	1672	1776	1881
1251925	151419				720	1059	1174	1606	1669	1777	1880
1251925	151745				723	1061	1173	1605	1669	1774	1879
1251925	152072				720	1062	1169	1605	1669	1771	1877
1251925	152399				716	1061	1171	1602	1670	1773	1878
1251925	152725				715	1060	1170	1601	1667	1772	1879
1251925	153052				714	1060	1170	1603	1664	1773	1877
1251925	153379				717	1055	1172	1606	1666	1774	1875
1251925	153705				717	1054	1170	1606	1668	1775	1875
1251925	154032				714	1056	1170	1603	1668	1775	1876
1251925	154359				713	1056	1168	1600	1666	1776	1877
1251925	154685				715	1055	1171	1599	1665	1775	1877
1251925	155012				716	1054	1170	1600	1666	1774	1877
1251625	155339				717	1053	1168	1600	1665	1774	1876
1251925	155339				717	1053	1168	1600	1665	1774	1876
1251925	155665				715	1054	1169	1600	1666	1775	1877
1251925	155992				712	1055	1169	1601	1666	1775	1877

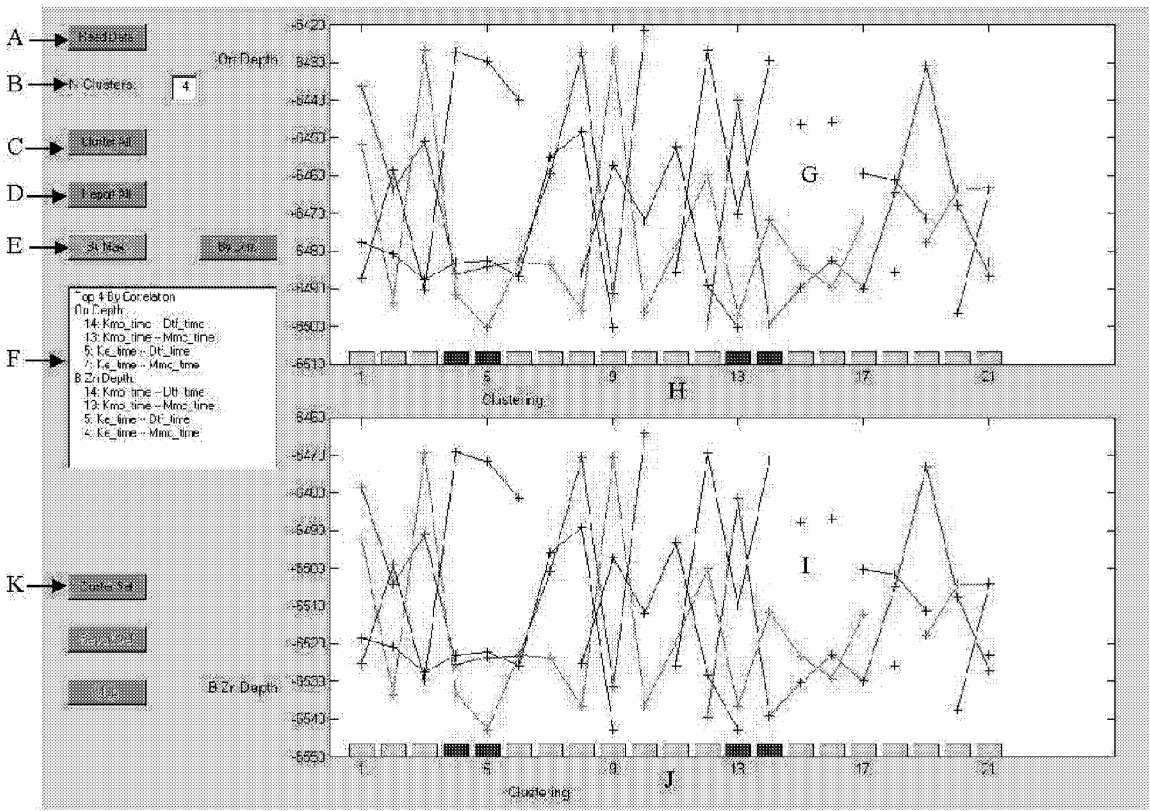
Export the spreadsheet as a comma-separated-variable (csv) file as shown. All files imported into ICS routines must be in comma-separated-variable (csv) format. An example of a comma-separated-variable file is shown in Figure 13.

Figure 13. An example of comma-separated-variable file as viewed with a text editor.

```
x,y,Well,Orr Depth,B Zn Depth,Ke_time,Kgh_time,Kmo_time,Mk_time,Mmc_time,Dtf_time,Orr_time,
1254737,158993,1,-6500,-6543,712,1053,1172,1612,1670,1775,1873,1933
1258348,159293,2,-6454,-6499,711,1056,1170,1594,1658,1764,1863,1917
1257953,158110,3,-6401,-6443,711,1051,1169,1594,1658,1763,1858,1907
1258116,158314,4,-6404,-6447,711,1051,1171,1594,1658,1762,1856,1908
1258315,158463,5,-6405,-6448,711,1053,1171,1594,1657,1761,1856,1909
1258702,158574,6,-6413,-6456,713,1055,1173,1593,1658,1762,1857,1910
1259280,158704,7,-6437,-6480,715,1057,1171,1595,1660,1764,1862,1915
1259006,157371,8,-6433,-6475,713,1054,1171,1599,1660,1767,1861,1917
1257814,154290,9,-6496,-6537,712,1054,1169,1601,1664,1771,1874,1928
1253880,156077,10,-6485,-6525,710,1051,1169,1600,1663,1768,1865,1923
1253711,156637,11,-6490,-6530,712,1052,1167,1598,1663,1769,1868,1925
1253676,157227,12,-6489,-6529,714,1052,1168,1605,1665,1771,1869,1925
1253674,157422,13,-6493,-6533,714,1051,1168,1607,1666,1771,1868,1925
1253675,157457,14,-6494,-6534,714,1051,1168,1607,1666,1771,1868,1925
1253662,158426,15,-6489,-6529,714,1055,1176,1608,1668,1775,1870,1927
1253645,158616,16,-6494,-6534,714,1056,1176,1609,1669,1776,1870,1928
1253572,158894,17,-6503,-6541,714,1057,1174,1610,1670,1776,1871,1930
1253603,158801,18,-6503,-6541,714,1057,1174,1610,1670,1776,1871,1929
1253502,159032,19,-6505,-6543,716,1058,1174,1611,1671,1777,1872,1931
1253050,159452,20,-6516,-6554,720,1058,1176,1613,1673,1780,1876,1935
1254615,155311,21,-6472,-6514,711,1048,1169,1597,1660,1764,1865,1919
1255263,151907,22,-6455,-6494,711,1055,1169,1605,1663,1770,1869,1921
1257096,151448,23,-6436,-6476,716,1055,1172,1600,1661,1767,1867,1919
1256972,151226,24,-6434,-6474,716,1055,1172,1600,1661,1768,1867,1920
1256930,151043,25,-6438,-6478,716,1055,1172,1601,1661,1769,1868,1921
1256883,150688,26,-6444,-6484,718,1056,1172,1602,1663,1770,1870,1923
1256883,150564,27,-6448,-6488,717,1056,1172,1601,1664,1771,1871,1924
1256817,150039,28,-6463,-6503,717,1059,1175,1605,1666,1774,1875,1929
1256797,149908,29,-6467,-6507,716,1059,1176,1605,1666,1774,1876,1930
1256747,149687,30,-6473,-6513,716,1058,1176,1605,1666,1774,1877,1932
1256699,149474,31,-6477,-6517,717,1057,1175,1606,1668,1775,1879,1935
1256614,149113,32,-6483,-6523,717,1059,1174,1606,1670,1774,1882,1935
1251925,148805,,,,722,1064,1174,1595,1665,1775,1881,1931
1251925,149132,,,,724,1064,1174,1596,1666,1775,1881,1932
1251925,149459,,,,723,1064,1175,1598,1667,1776,1881,1931
1251925,149785,,,,726,1059,1174,1612,1667,1775,1881,1932
1251925,150112,,,,727,1059,1175,1604,1670,1776,1882,1932
1251925,150439,,,,719,1059,1177,1604,1671,1776,1882,1933
1251925,150765,,,,717,1059,1178,1604,1672,1776,1881,1933
```

After execution of the command or button to call the Cluster 1 tool, a work window is presented as shown in Figure 14.

Figure 14. An example of the first work window and navigation key for Cluster 1.



Key to first work window for Cluster 1.

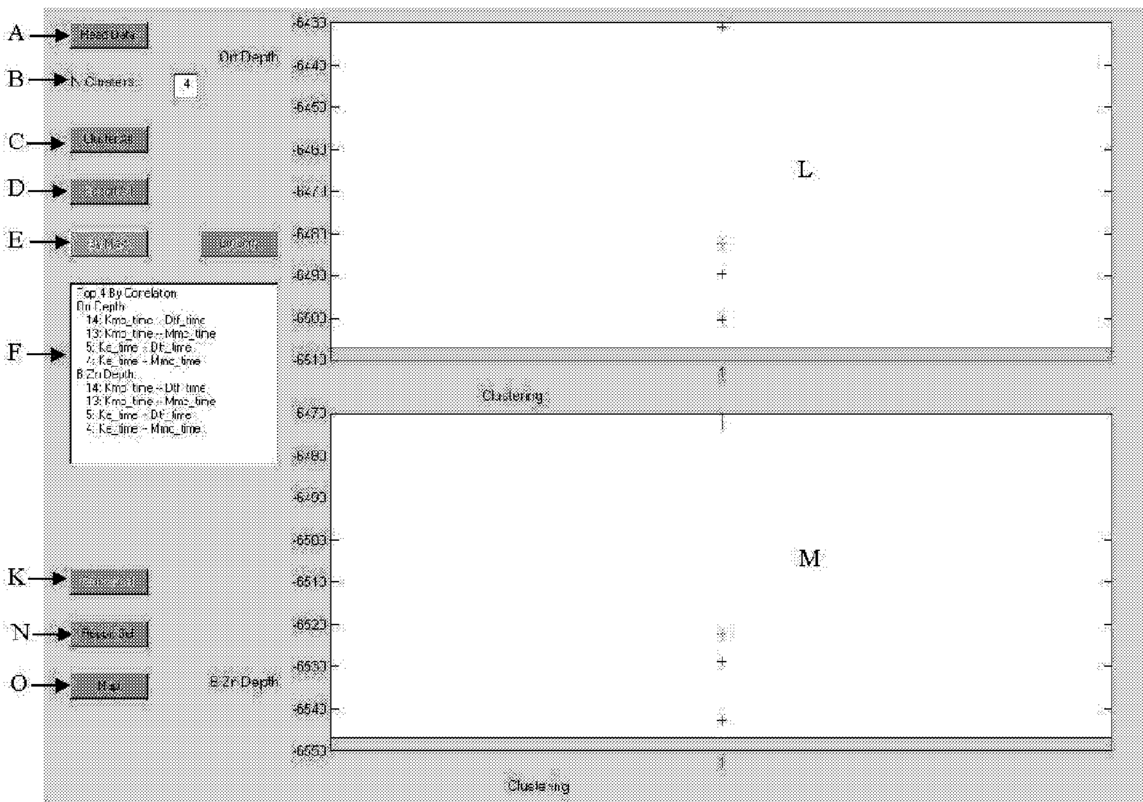
A. Button for importing data file.
B. Input box to change number of clusters from 2 to 4.
C. Button to create all clusters.
D. Button to write report for all clusters, (optional).
E. Default buttons for selecting most significant cluster groups. “By Max” selects the top 4 clusters with the maximum spread. “By Corr” selects the top 4 by correlation coefficient.
F. Text window displays top 4 ranking of independent data according to which default cluster button (E) was pressed.
G. A graphical display of cluster means for dependent data column 4. The number of possible clusters is N*(N-1)/2.
H. Colored tabs correspond to the default selections that result from “ By Max” or “By Corr.” These selections can be modified by a left-mouse click.
I. A graphical display of cluster means for dependent data column 5.
J. Colored tabs correspond to the default selections. These selections can be modified by a left-mouse click.

K. Button to make final clusters from selected tabs (H and J).

Step 1. Load input file by pressing button "A."
Step 2. Set number of clusters (2-4) in input box "B."
Step 3. Press button "C" to create all possible clusters.
Step 4. Create an output file that describes all clusters by pressing button "D", optional. View example output file "cluster1_example_report_all.dat" with a text editor.
Step 5. Select cluster method for ranking by pressing button "E."
Step 6. If desired, edit default cluster selections by clicking tabs "H" or "J."
Step 7. Press button "K" and create clusters from selected data.

After pressing button "K" (cluster selections) the work window changes and displays the clusters by their mean value as shown in Figure 15.

Figure 15. Second work window and navigation key for Cluster 1.



Key to second work window for Cluster 1.

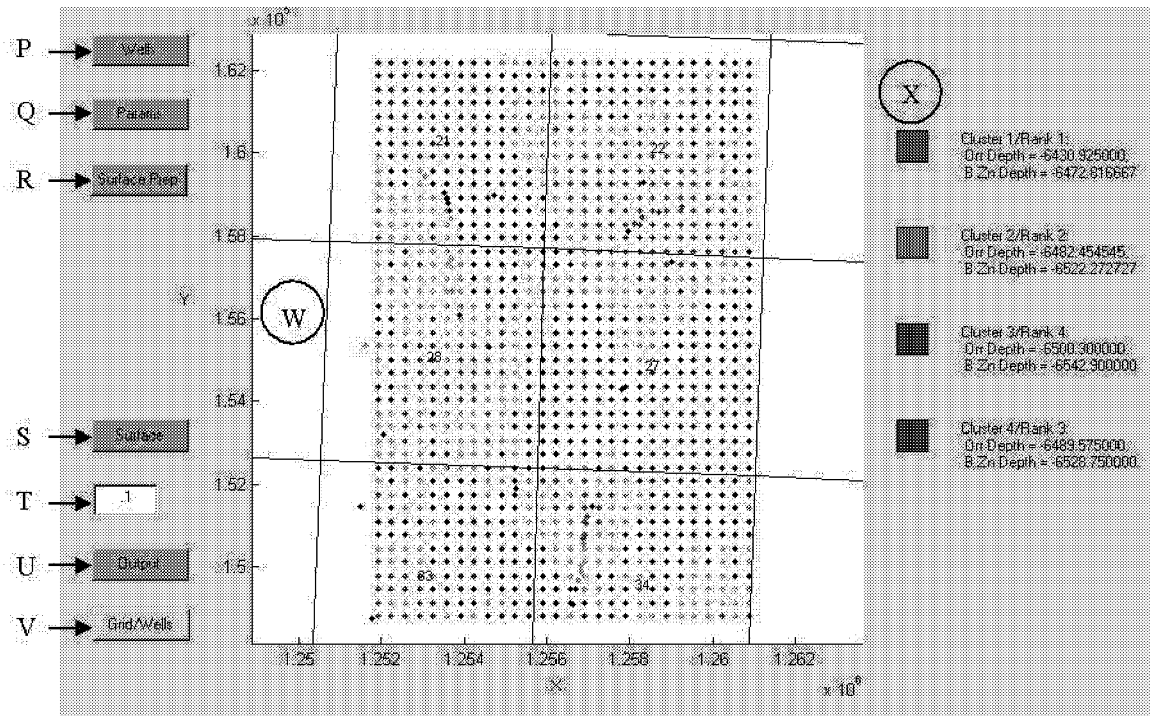
L. A graphical display of clusters for dependent data from column 4. An evenly spaced separation of clusters is desirable.
M. A graphical display of clusters for dependent data from column 5.

N. Button to write a report that describes the final cluster groups, optional.
O. Button to create map of cluster groups.

Step 8. Create an output file that describes all clusters by pressing button "N", optional. View example output file "cluster1_report1_dump.dat" with a text editor.
Step 9. Create map and go to next work window by pressing button "O."

After pressing button "O" (map) the work window changes and displays an empty map window as shown in Figure 16.

Figure 16. An example of the third work window and navigation key for Cluster 1.



Key to third work window for Cluster 1.

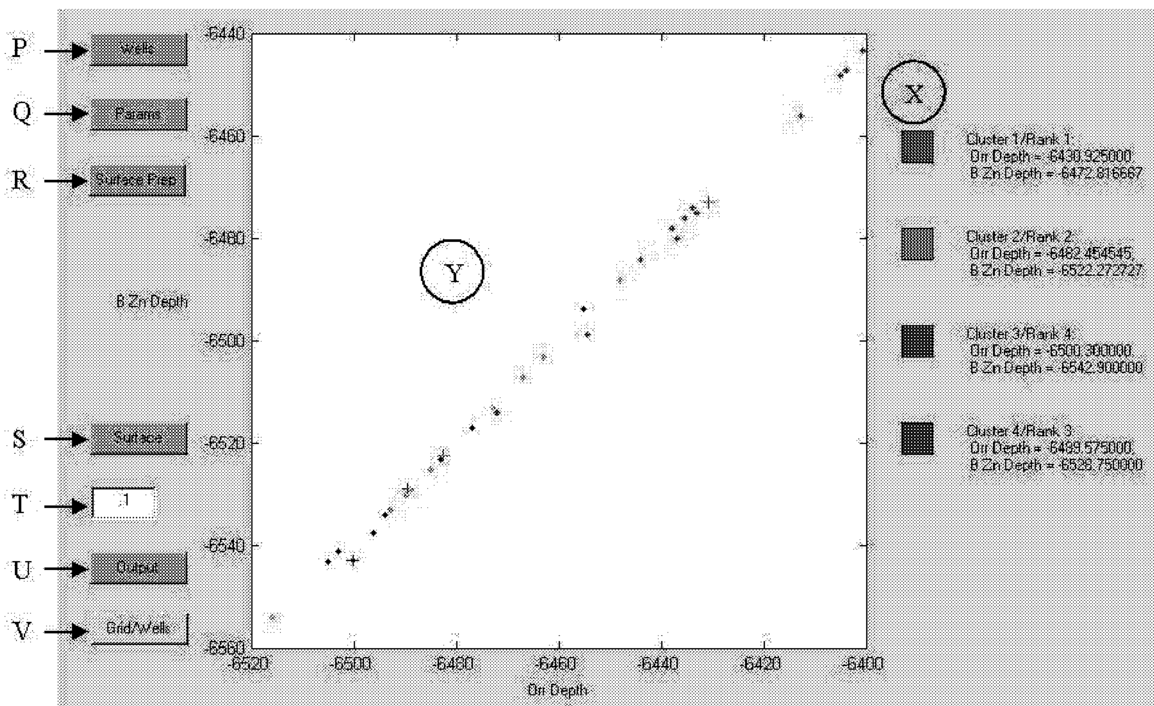
P. Button will display the points at each data location. Each location will be colored according to cluster assignment.
Q. Button will display a plot of the dependent data and colored coded to match the cluster assignment.
R. Button will begin grid operations for the final cluster map.
S. Button will produce final cluster map.
T. Window displays minimum correlation for painting final cluster map.
U. Button will produce an output file.
V. Button will overlay land grid, if special file is available
W. Map is displayed in this area.

X. Color code for cluster assignments is shown in this area. Ranking is based on dependent data in column 4.

Step 10. Press button "P" to display the points at each data location, optional.
Step 11. Press button "Q" to display a plot of the dependent data, optional
Step 11. Press button "R" to begin grid operations for the final cluster map.
Step 12. Press button "S" to display cluster map.
Step 13. Change correlation coefficient in box "T", optional. If desired, change value to 0.1 to remove white areas (low correlation areas).
Step 14. Press button "S" again to display the map after changes in box "T."
Step 15. Press button "V" to overlay land grid, optional
Step 16. Press button "U" to create an output file with cluster assignment, rank, cluster value 1 and cluster value 2. View output file "cluster1_rank_dump.csv" with a text editor.

After pressing button "Q", the work window changes to display the dependent data and cluster means as shown in Figure 17.

Figure 17. A plot of dependent data and cluster means from third work window for Cluster 1.

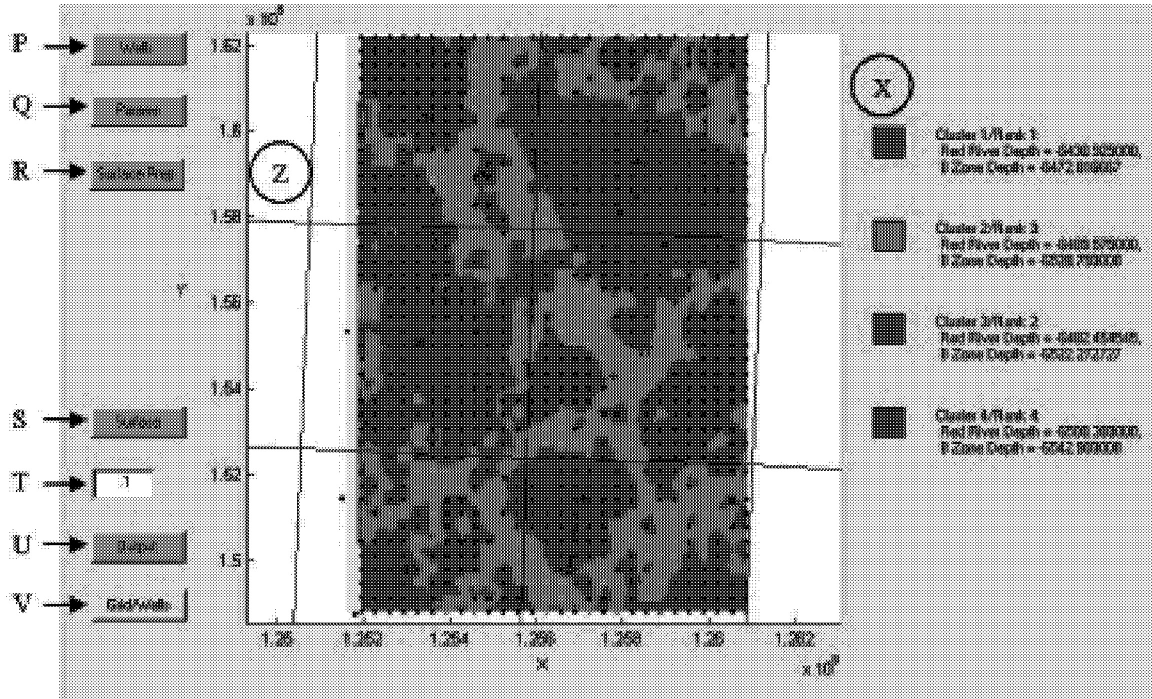


Key to third work window for Cluster 1.

Y. A plot of the dependent data from columns 4 and 5 is displayed with cluster means after pressing "Params" button "Q."

After pressing button "S", the final cluster map is displayed as shown in Figure 18.

Figure 18. An example of the final cluster map and navigation key from third work window for Cluster 1.



Key to third work window for Cluster 1.

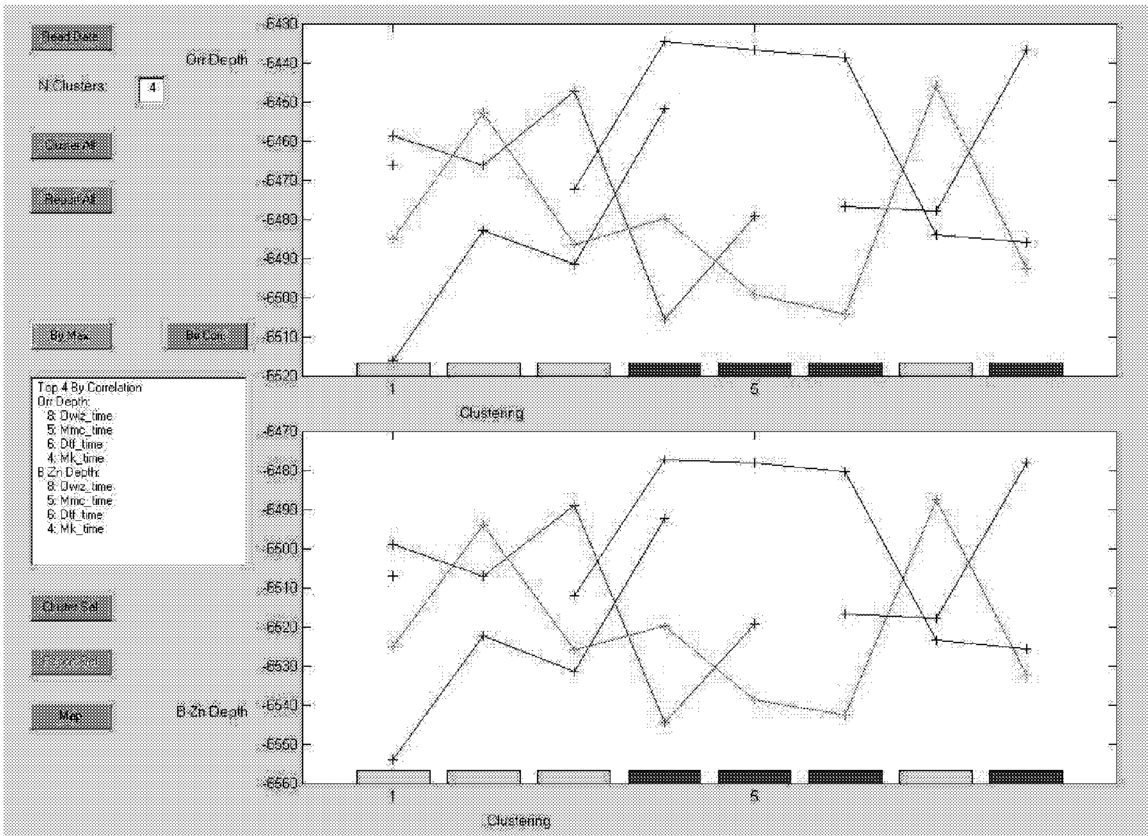
Z. Color fill is applied after the "Surface" button "S" is pressed.

If a cluster is produced without any correlation to the dependent data (there are no wells or control in the areas comprising this cluster), a comment for the cluster will be "NaN." This means that the well population (dependent control) is too small for the number of clusters set in box "B." If this occurs, it is suggested to start over and reduce the number of clusters. Passing output from the cluster map to the Entrapment routine, where a cluster mean has no value, will produce undesirable results.

Cluster 2 Tool

The Cluster 2 routine works the same as Cluster 1 except that the independent data are used as imported. That is, differences or intervals are not computed. The same file can be used for both Cluster 1 and Cluster 2. When the Cluster 2 routine is called from a command line or button a work window is displayed. This work window functions the same as for Cluster 1 and is shown in Figure 19.

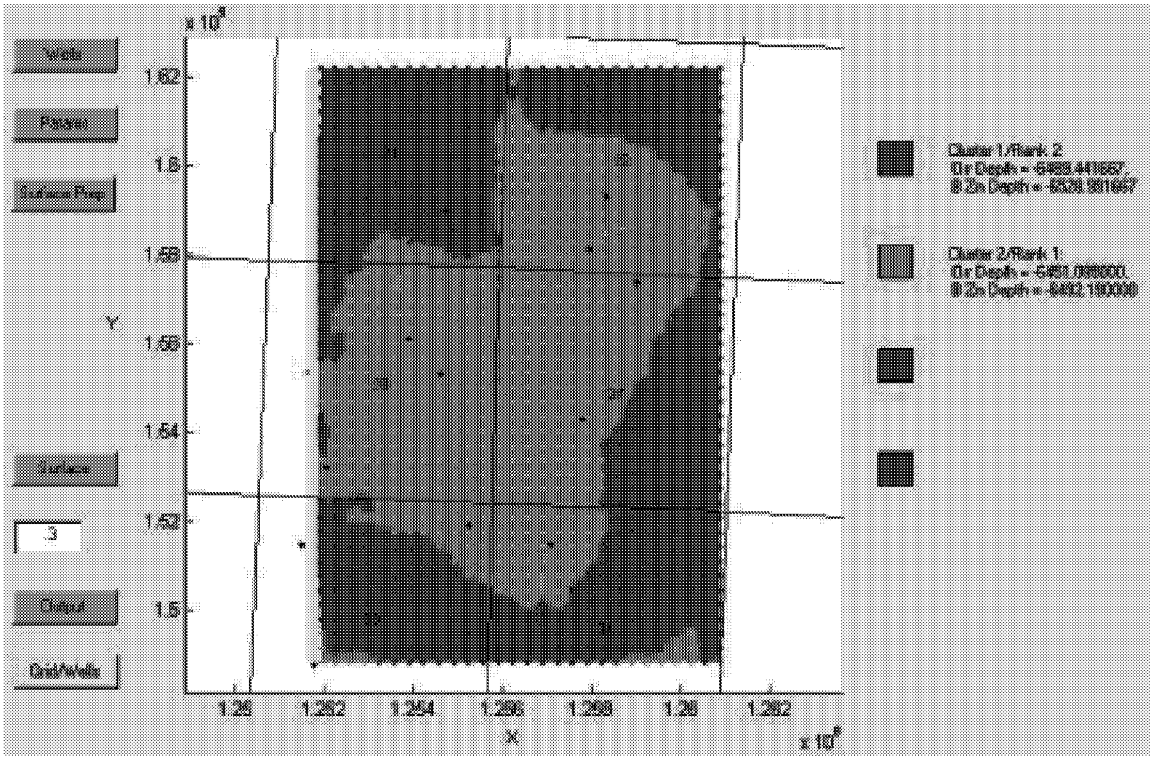
Figure 19. An example of the first work window for Cluster 2.



The number of possible clusters equals the number of independent data columns after column 5.

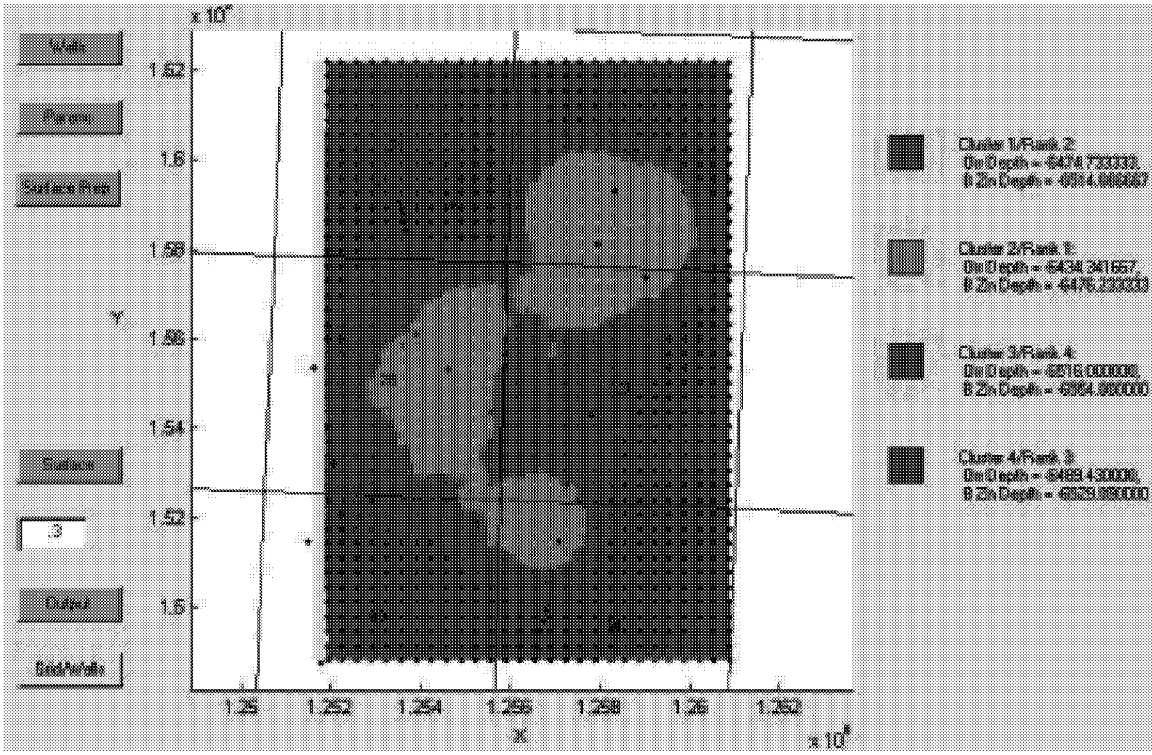
An example of a cluster map from the Cluster 2 Tool, where the number of clusters is 2, is shown in Figure 20.

Figure 20. A cluster map from Cluster 2 after selecting only two clusters.



An example of a cluster map from the Cluster 2 Tool, where the number of clusters is 4, is shown in Figure 21.

Figure 21. A cluster map from Cluster 2 after selecting four clusters.



Cluster 3 Tool

The Cluster 3 routine is similar to Cluster 1 and 2. The routine uses a different file format. This format is the same as described previously for Cluster 1 and 2 except there are no columns for dependent data (wells). Cluster 3 produces intrinsic or natural clusters of the independent data. It is especially useful where there is limited control. Cluster 3 should also be used for comparison with results from either Cluster 1 or 2.

An example of a data file to be processed by the Cluster 3 Tool is shown in Figure 22.

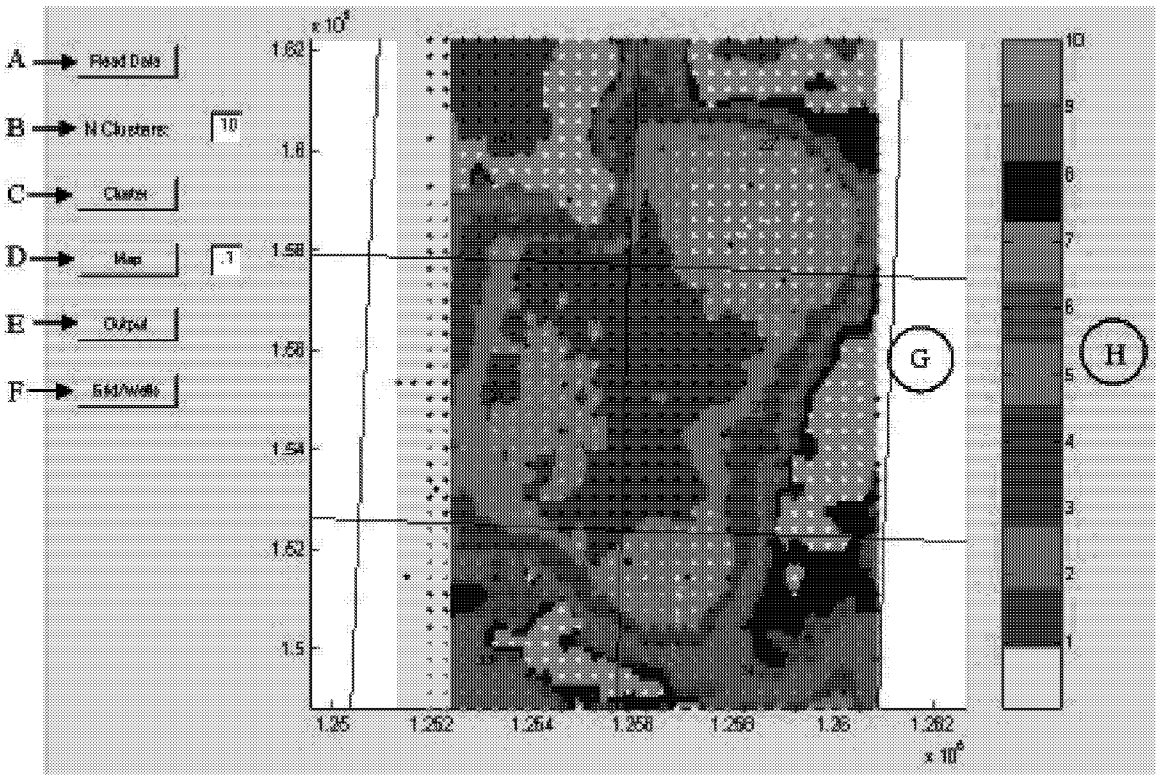
Figure 22. An example of a data file for Cluster 3.

x	y	Ke_time	Kgh_time	Kmo_time	Mk_time	Mmc_time	Dtf_time	Orr_time	Owiz_time	Ke-kgh	Ke-Kmo	Ke-Mk	Ke-Mmc	Ke-Dtf	Ke-Orr	Ke-Owi
1251925	148805	722	1064	1174	1595	1665	1775	1881	1931	342	452	873	943	1053	1159	1209
1251925	149132	724	1064	1174	1596	1666	1775	1881	1932	340	451	872	942	1051	1157	1209
1251925	149459	723	1064	1175	1598	1667	1776	1881	1931	342	452	875	944	1054	1158	1209
1251925	149785	726	1059	1174	1612	1667	1775	1881	1932	333	447	886	941	1049	1155	1206
1251925	150112	727	1059	1175	1604	1670	1776	1882	1932	333	449	877	943	1049	1155	1205
1251925	150439	719	1059	1177	1604	1671	1776	1882	1933	340	458	885	952	1057	1163	1214
1251925	150765	717	1059	1178	1604	1672	1776	1881	1933	342	461	887	955	1059	1164	1215
1251925	151092	717	1057	1174	1605	1672	1776	1881	1933	341	457	888	955	1060	1164	1216
1251925	151419	720	1059	1174	1606	1669	1777	1880	1932	339	454	886	949	1057	1159	1211
1251925	151745	723	1061	1173	1605	1669	1774	1879	1930	338	450	882	946	1051	1156	1207
1251925	152072	720	1062	1169	1605	1669	1771	1877	1930	342	450	885	949	1051	1158	1210
1251925	152399	716	1061	1171	1602	1670	1773	1878	1931	346	456	887	954	1057	1163	1215
1251925	152725	715	1060	1170	1601	1667	1772	1879	1929	346	455	886	952	1057	1164	1214
1251925	153052	714	1060	1170	1603	1664	1773	1877	1928	345	456	889	950	1059	1162	1214
1251925	153379	717	1055	1172	1606	1666	1774	1875	1928	338	455	889	949	1057	1158	1211
1251925	153705	717	1054	1170	1606	1668	1775	1875	1929	337	453	889	951	1058	1158	1212
1251925	154032	714	1056	1170	1603	1668	1775	1876	1931	343	456	889	954	1061	1163	1217
1251925	154359	713	1056	1168	1600	1666	1776	1877	1931	343	455	887	953	1063	1164	1218
1251925	154685	715	1055	1171	1599	1665	1775	1877	1932	341	457	884	950	1061	1163	1217
1251925	155012	716	1054	1170	1600	1666	1774	1877	1932	338	453	884	950	1058	1160	1215
1251325	155339	717	1053	1168	1600	1665	1774	1876	1931	336	451	883	948	1057	1159	1215
1251625	155339	717	1053	1168	1600	1665	1774	1876	1931	336	451	883	948	1057	1159	1215
1251925	155339	717	1053	1168	1600	1665	1774	1876	1931	336	451	883	948	1057	1159	1215
1251925	155665	715	1054	1169	1600	1666	1775	1877	1932	340	455	885	952	1060	1162	1218
1251925	155992	712	1055	1169	1601	1666	1775	1877	1932	343	457	888	954	1063	1165	1219
1251925	156319	714	1055	1169	1601	1666	1775	1878	1933	341	455	887	952	1061	1163	1218
1251925	156645	716	1056	1170	1602	1666	1775	1876	1933	340	454	886	950	1059	1160	1217
1251925	156972	717	1059	1172	1606	1667	1773	1874	1933	342	455	889	950	1056	1157	1216
1251925	157298	717	1060	1171	1608	1668	1773	1875	1933	343	454	891	951	1056	1158	1216
1251925	157625	716	1062	1174	1609	1670	1773	1877	1933	345	458	892	953	1056	1161	1216
1251925	157952	717	1061	1180	1610	1671	1773	1877	1933	344	463	893	954	1056	1161	1216
1251925	158278	718	1062	1175	1611	1672	1775	1876	1933	343	457	892	953	1057	1158	1214
1251925	158605	721	1062	1175	1614	1670	1777	1875	1933	341	454	893	949	1056	1153	1212
1251925	158932	722	1063	1174	1614	1671	1778	1874	1934	340	452	892	949	1056	1152	1212
1251925	159258	720	1063	1177	1611	1673	1780	1877	1935	342	456	891	953	1059	1156	1215
1251925	159585	720	1064	1180	1611	1675	1782	1880	1936	344	459	891	954	1062	1160	1216
1251925	159912	723	1063	1178	1611	1675	1784	1882	1937	340	455	888	952	1061	1159	1214
1251925	160238	724	1059	1175	1610	1674	1786	1883	1938	335	451	885	950	1062	1159	1213
1251925	160565	724	1059	1176	1609	1675	1788	1887	1939	335	452	885	951	1064	1163	1215
1251925	160892	724	1058	1176	1610	1676	1791	1889	1940	334	452	886	952	1067	1165	1216
1251925	161218	724	1057	1177	1611	1677	1792	1890	1941	333	453	887	954	1068	1166	1217

The independent data in this file are seismic time and intervals.

When the Cluster 3 routine is called from a command line or button, a work window is displayed. This work window is shown in Figure 23.

Figure 23. The work window for Cluster 3 and navigation key.



Key to work window for Cluster 3.

A. Button is pressed to read data file.
B. Set number of cluster, from 2 to 10.
C. Create clusters.
D. Create the cluster map.
E. Export a report file (optional).
F. Overlay land grid (optional).
G. Cluster map is displayed in the work area.
H. Color codes for the cluster groups are displayed. The colors and order are arbitrary.

Step 1. Import data file, button "A".
Step 2. Set the number of clusters, input box "B."
Step 3. Create clusters, button "C".
Step 4. Press the "Map" button D after setting correlation coefficient in the window box. Setting the coefficient to 0.1 will remove all white areas. White areas represent correlation less than specified in window box.

Step 5. Overlay the land grid by pressing button "F." A land grid and well spots can be overlain on the map if a special land grid file is available.

Step 6. Export a report, button "E", with cluster assignments at x-y locations in a 120 by 120 grid.

The cluster-tool demonstrations in this section used seismic-time data from a 3D survey in Bowman Co., ND. Files containing these data are located under the directory \tools_cluster\cluster_data\. These files can be imported into a spreadsheet for viewing and used with the appropriate cluster tool. The cluster results from these files demonstrate one use of clustering, evaluation of reservoir structure and growth history. Output and report files from the cluster tool examples can be found under the directory \tools_cluster\cluster_output\.

TOOLS and UTILITIES

Entrapment Tool

A reservoir-entrapment tool evaluates components of structure and rock quality for entrapment potential. The tool can produce several map views of the imported data and a map of entrapment potential in pressure units. The entrapment tool uses a depth file from seismic time conversion or grid output from a mapping package, possibly using only well control. A second source of data is imported that is related to rock quality or stratigraphic information. The source of this file is output from Cluster 1 or Cluster 2 tools. An output file can be created from the Entrapment tool for use in other ICS routines.

The entrapment routine uses two files. The first file contains sub-sea depth information. The format uses the first two columns as x-y coordinates. The third column is ignored, so could be padded with any numeric value. The fourth column contains the depth data. Several ICS tools can generate the depth information, if using seismic data, or the file can be generated externally. The second input file is a rank file produced by the ICS Cluster 1 or Cluster 2 routines. The rank file is intended to represent a range of reservoir quality. A rank of 1 is best while a rank of 4 is poor.

An example of a depth file as used by the Entrapment Tool is shown in Figure 24.

Figure 24. An example of a depth file for the Entrapment routine.

x	y	Not Used	avg depth
1207727	148819	0	-6505
1206414	148488	0	-6493
1209040	148488	0	-6513
1206414	148819	0	-6496
1206742	148488	0	-6495
1207070	149482	0	-6504
1208055	148819	0	-6504
1210025	144847	0	-6490
1211338	145840	0	-6487
1207727	148488	0	-6501
1206742	148157	0	-6492
1207070	148157	0	-6493
1207398	148819	0	-6507

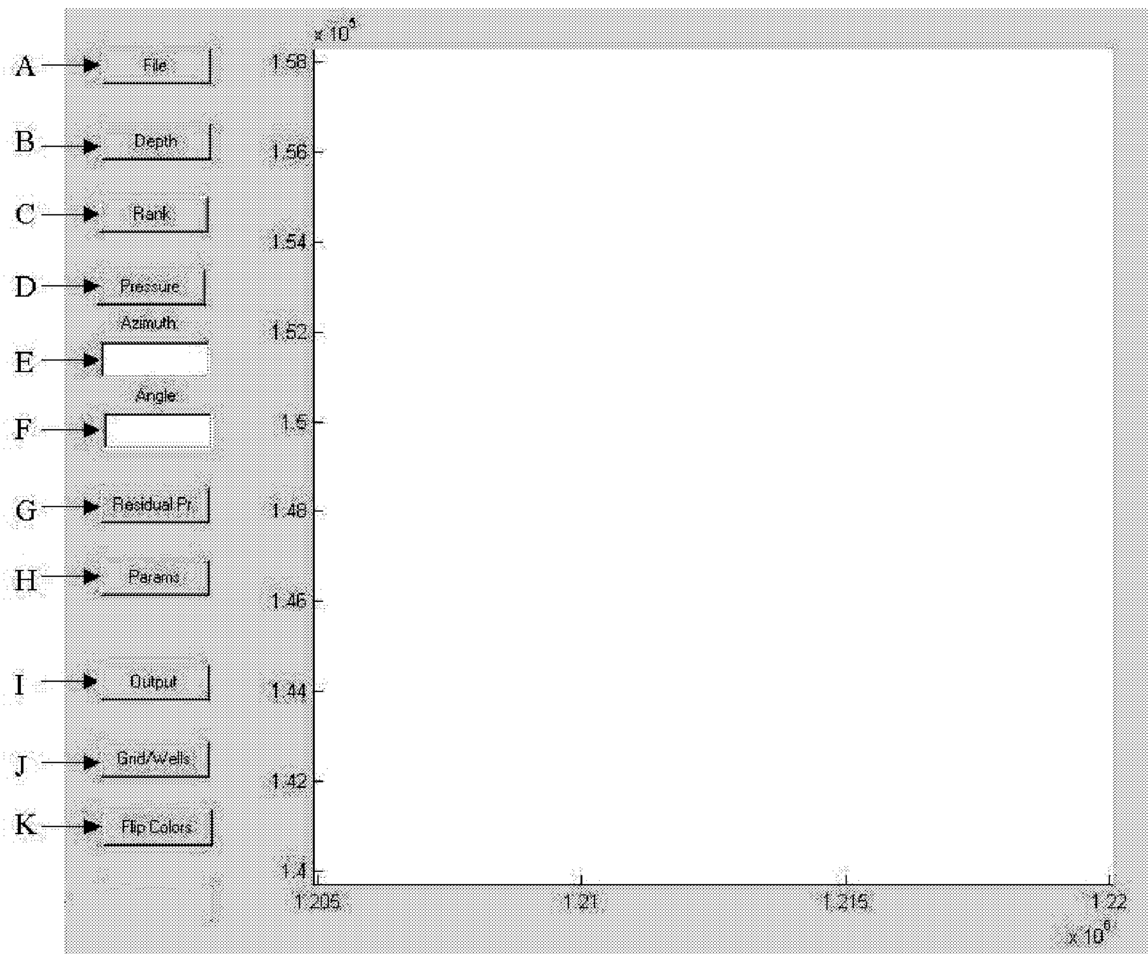
An example of a rank file as used by the Entrapment Tool is shown in Figure 25.

Figure 25. An example of a rank file for the Entrapment routine.

x	y	cluster	rank	mean 1	mean 2
1205030	140303	0	0	NaN	NaN
1205742	153501	0	0	NaN	NaN
1205742	153787	1	4	220.9	0.652
1205742	153644	2	1	229.4	4.683
1205979	150058	3	3	226.0	5.729
1205979	150345	4	2	228.3	5.830

After starting the entrapment routine, a work window is presented as shown in Figure 26

Figure 26. An example of the first work window for the Entrapment Tool with navigation key.



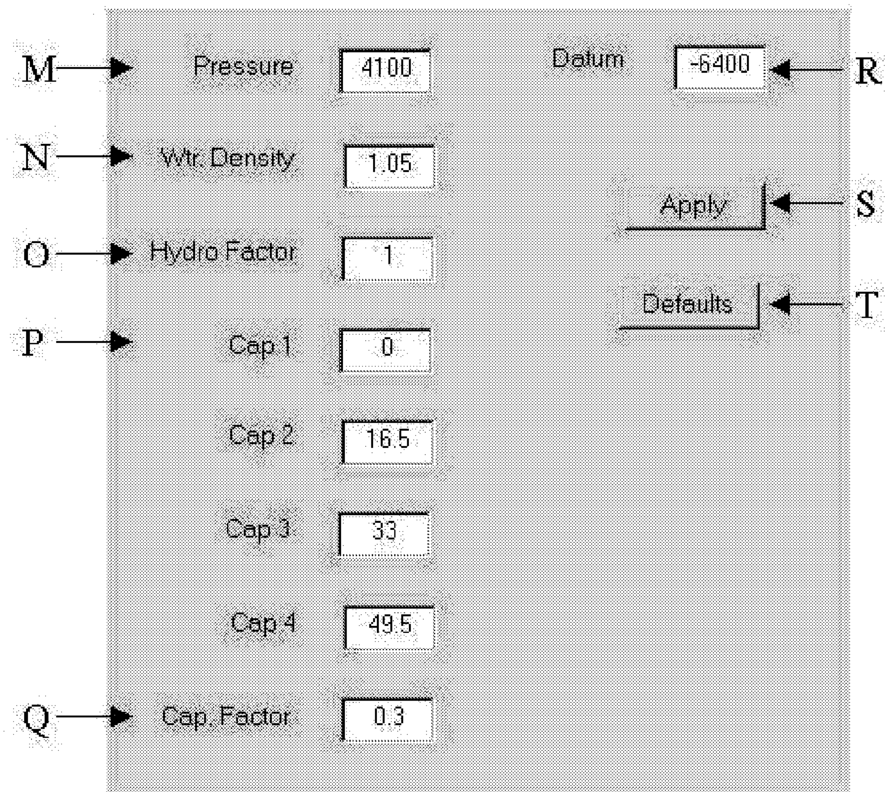
Key for the first work window of the Entrapment routine.

A. Import depth and rank files.
B. Display depth file in map view.
C. Display rank file in map view.
D. Display computed reservoir pressure based on parameter settings.
E. Azimuth of pressure trend.
F. Angle of pressure trend.
G. Display computed residual pressure from trend surface.
H. Open a second window for pressure and capillary parameters.
I. Export a file for the current map.
J. Overlay land grid and well locations from a special file.
K. Invert color-bar scheme.

Step 1. Import files by pressing button "A."
Step 2. Press the "Params" button "H" after importing data the files.

After pressing the "Params" button "H", a new window is presented as shown in Figure 27.

Figure 27. An example of the parameter window from the Entrapment Tool with navigation key.



Key to the parameters window from the Entrapment Tool.

M. Reservoir pressure in PSI units
N. Water density, gm/cc.
O. Leave "Hydro Factor" set at 1.
P. Table for capillary pressures.
Q. Factor applied to capillary pressure table.
R. Datum for reservoir pressure in feet.
S. Apply new parameters.
T. Revert to default settings.

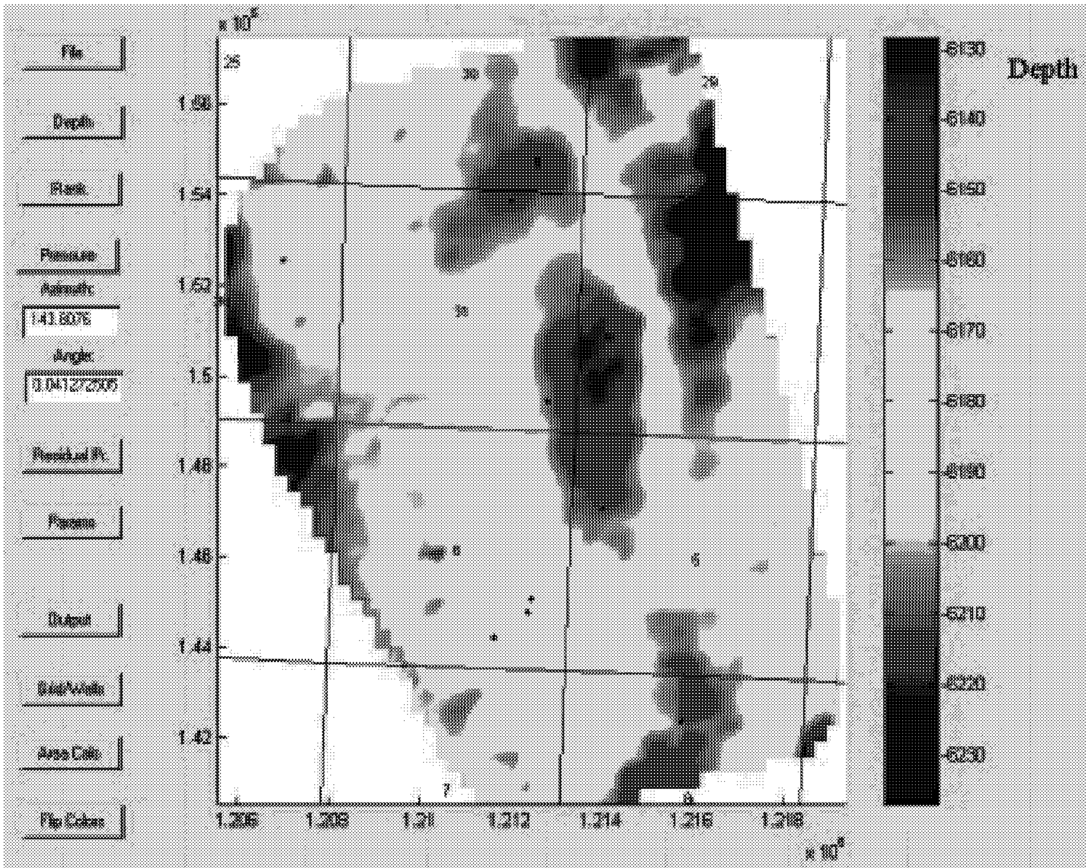
Step 3. Change parameters in boxes as appropriate for the reservoir. In general use, the capillary pressure table will be unchanged. Adjusting the capillary factor "Q" will provide means to adjust rock-quality or stratigraphic effects on entrapment.

Step 4. Press "Apply" button "S."

After completing and applying changes from the parameter window, return to the main work window.

Step 5. Press the "Depth" button "B", and display the map file in map view as shown in Figure 28.

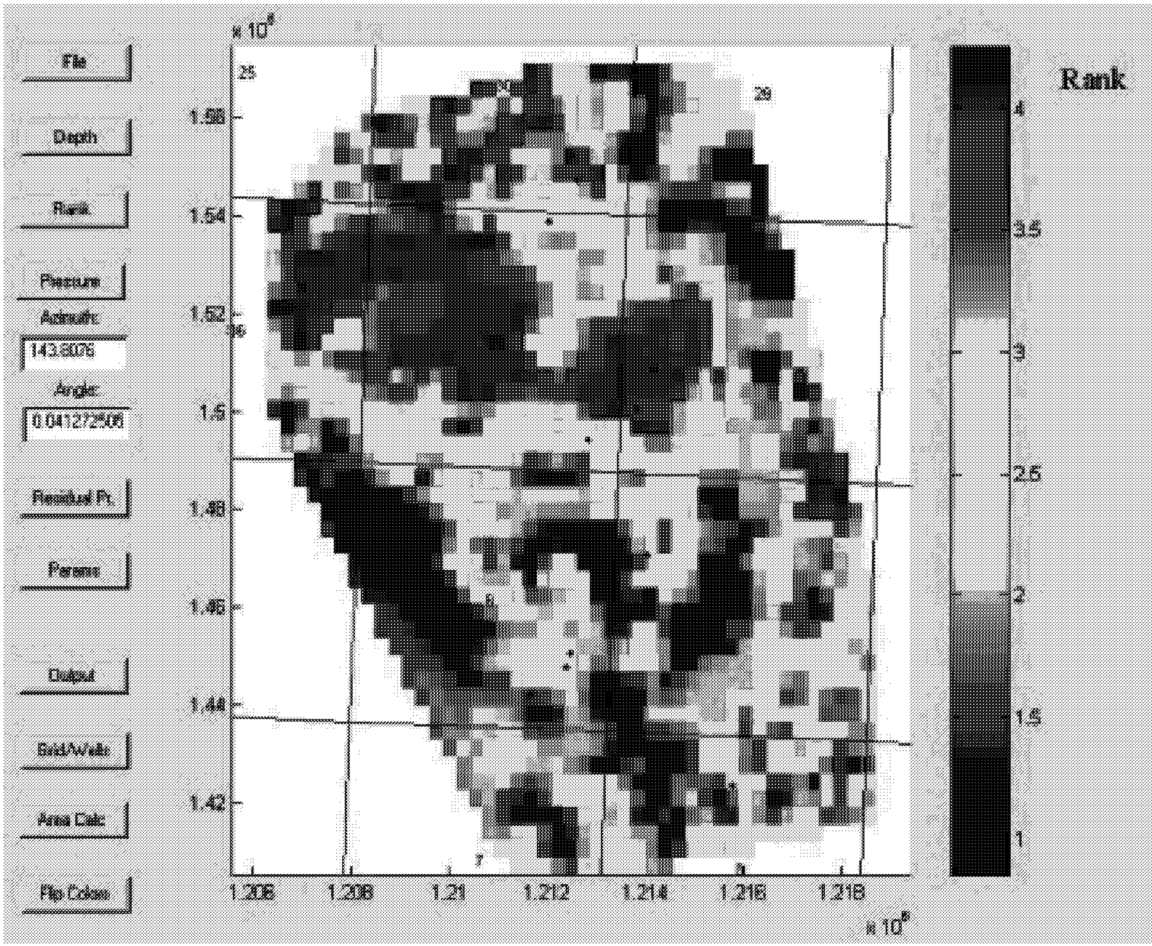
Figure 28. An example display of the depth file from the Entrapment Tool.



The depth file can be displayed at any time after the depth and rank files are imported.

Step 6. Press the "Rank" button "C", and display the rank file in map view as shown in Figure 29.

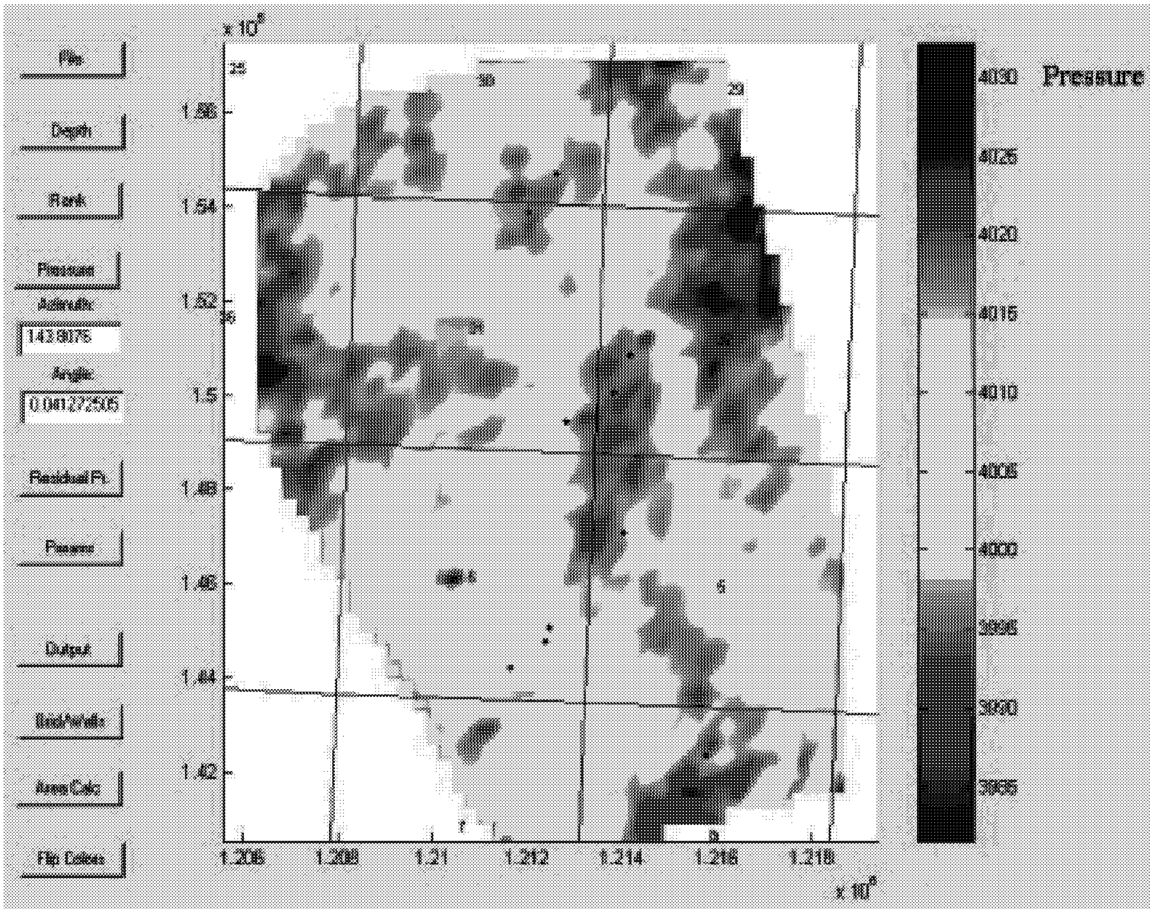
Figure 29. An example of the rank file from the Entrapment Tool.



The rank file map can be made at any time after the depth and rank files are imported. A rank file should describe reservoir quality. The rank file is created with the Cluster 1 tool or Cluster 2 tool. A rank of 1 is considered good. A rank of 2 is considered somewhat good. A rank of 3 is considered somewhat poor. A rank of 4 is considered poor.

Step 7. Press the "Pressure" button "D", and display the computed reservoir pressure based on the parameter settings as shown in Figure 30.

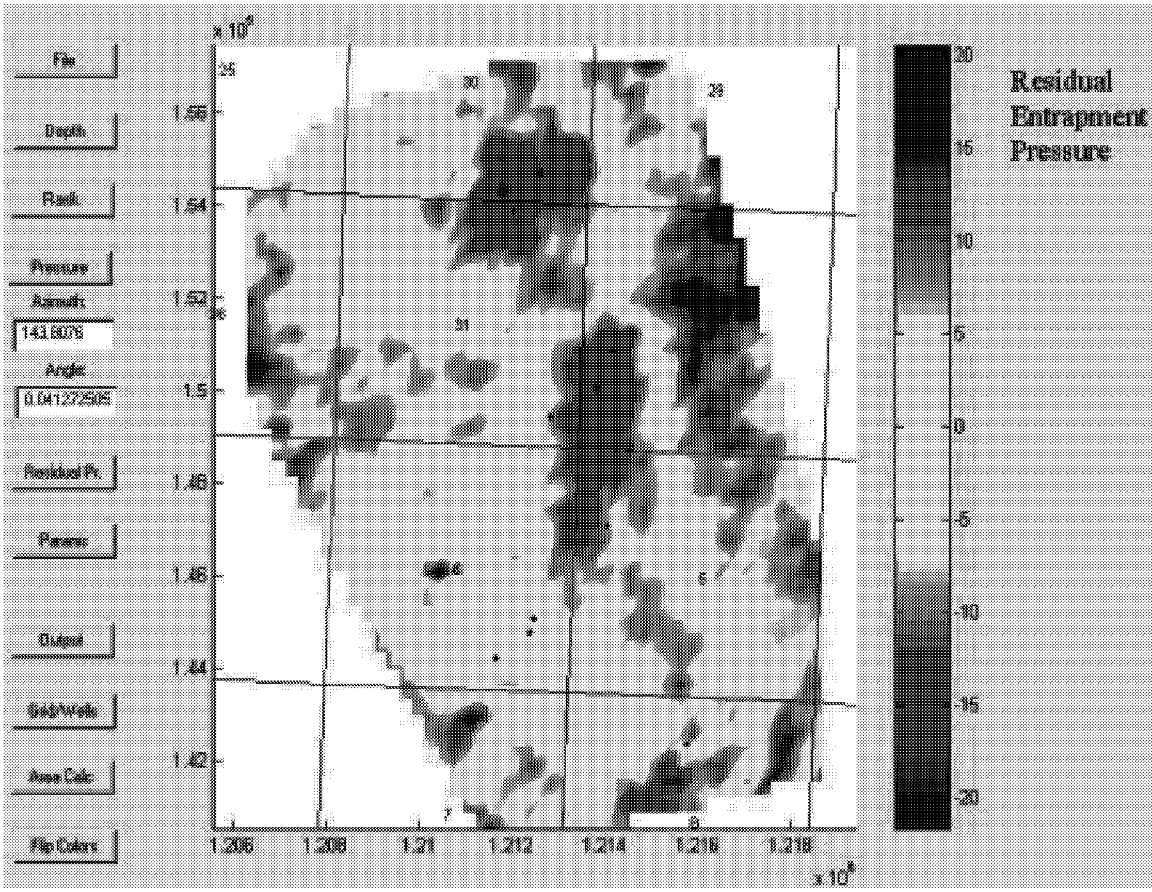
Figure 30. An example of calculated pressure from the Entrapment Tool.



The pressure map should be displayed after setting the values in the parameters window. After a display of the pressure map, the computed azimuth and angle of the pressure-trend surface are shown in boxes "E" and F."

Step 8. Press the "Residual Pressure" button "G", and display the computed reservoir pressure based on the parameter settings as shown in Figure 31.

Figure 31. An example of residual pressure from the Entrapment Tool.



The residual pressure map is the entrapment potential map. It is a combination of structural and capillary entrapment. A more negative value will indicate a greater entrapment potential. A pressure of zero would imply an oil-water contact.

Step 9. Changing the azimuth and angle of the pressure-trend surface will tilt the entrapment map. Setting the capillary factor to 0 in the parameters window and re-computing the pressure map will allow a display of entrapment based only on structure. Changing the azimuth and angle of the pressure-trend surface will facilitate study of possible hydrodynamic effects.

Practice files for the Entrapment Tool are located under the directory \tools_entrap\input_files\.

TOOLS and UTILITIES

Multiple-linear Regression

The Multiple-Linear-Regression Tool can produce maps from classical correlation techniques of a linear best-fit equation using multiple independent data. At this time, the routine requires that the regression parameters and coefficients be obtained from some external statistics software. Microsoft Excel and other spreadsheet software provide regression analysis tools. If using Microsoft Excel, go to tools\ data analysis\ regression from the tool bar. The Multiple-Linear-Regression Tool can also be used to simply display a map view of data when a coefficient of one is applied to a single data column. Applications of this tool include comparison of results from clustering and neural tools and visual quality check of data. An output file can be created that may be imported into other ICS tools or other mapping software.

An example of an input file for use with the Multiple-Linear-Regression Tool is shown in Figure 32.

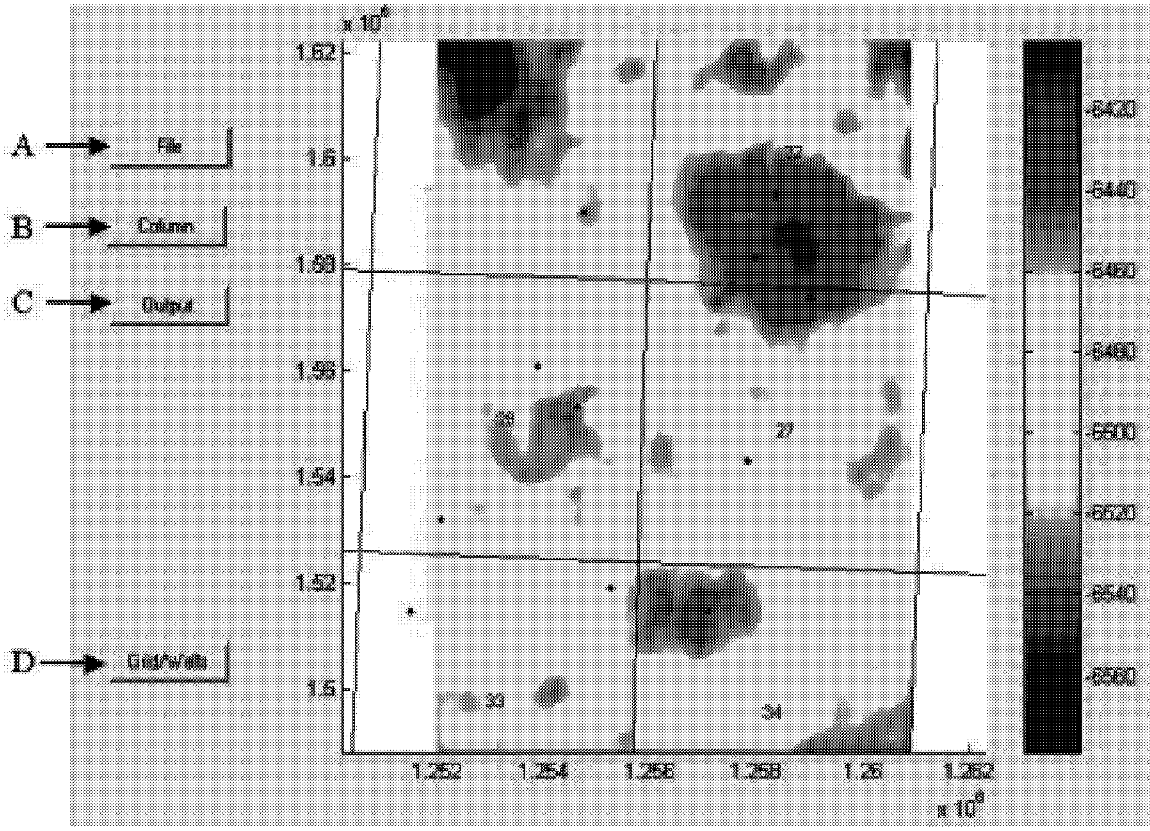
Figure 32. An example input file for the Multiple-Linear-Regression Tool.

x	y	Ke_time	Kgh_time	Kmo_time	Mk_time	Mmc_time	Dtf_time	Orr_time	Ke-kgh	Ke-Kmo
1251925	148805	722	1064	1174	1595	1665	1775	1881	342	452
1251925	149132	724	1064	1174	1596	1666	1775	1881	340	450
1251925	149459	723	1064	1175	1598	1667	1776	1881	341	452
1251925	149785	726	1059	1174	1612	1667	1775	1881	333	448
1251925	150112	727	1059	1175	1604	1670	1776	1882	332	448
1251925	150439	719	1059	1177	1604	1671	1776	1882	340	458
1251925	150765	717	1059	1178	1604	1672	1776	1881	342	461
1251925	151092	717	1057	1174	1605	1672	1776	1881	340	457
1251925	151419	720	1059	1174	1606	1669	1777	1880	339	454
1251925	151745	723	1061	1173	1605	1669	1774	1879	338	450
1251925	152072	720	1062	1169	1605	1669	1771	1877	342	449
1251925	152399	716	1061	1171	1602	1670	1773	1878	345	455
1251925	152725	715	1060	1170	1601	1667	1772	1879	345	455
1251925	153052	714	1060	1170	1603	1664	1773	1877	346	456
1251925	153379	717	1055	1172	1606	1666	1774	1875	338	455
1251925	153705	717	1054	1170	1606	1668	1775	1875	337	453
1251925	154032	714	1056	1170	1603	1668	1775	1876	342	456
1251925	154359	713	1056	1168	1600	1666	1776	1877	343	455
1251925	154685	715	1055	1171	1599	1665	1775	1877	340	456
1251925	155012	716	1054	1170	1600	1666	1774	1877	338	454
1251625	155339	717	1053	1168	1600	1665	1774	1876	336	451
1251925	155339	717	1053	1168	1600	1665	1774	1876	336	451
1251925	155665	715	1054	1169	1600	1666	1775	1877	339	454

The first two columns are reserved for x-y coordinates. The remaining columns are independent data. The first row is reserved for labels. Every cell must be filled

After calling the Multiple-Linear-regression Tool, a work window is presented as shown in Figure 33.

Figure 33. Work window for the Multiple-Linear-Regression Tool and navigation key.



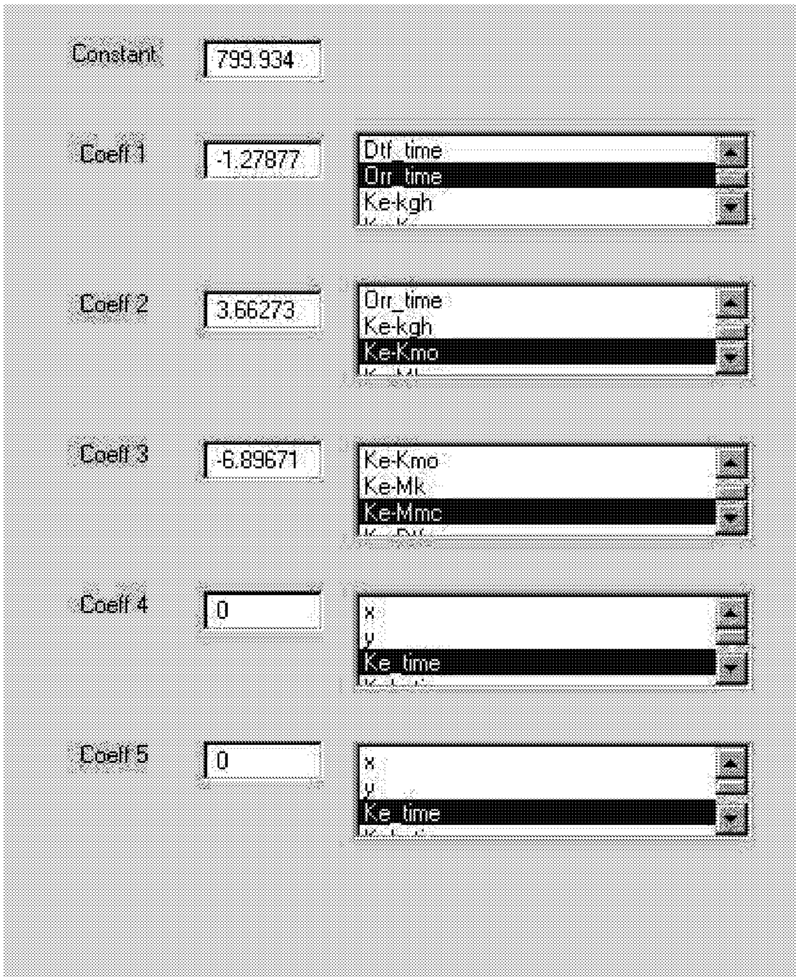
Key to work window for the MLR tool.

A. Import the data file.
B. Opens a second window for setting of regression coefficients to selected data columns.
C. Export an output file from the computed map.
D. Overlay a land grid with well locations.

Step 1. Import data by pressing button"A."
Step 2. Press button "B" and open the second window.

The second work window for the MLR tool is shown in Figure 34.

Figure 34. Second work window for the Multiple-Linear-Regression Tool.



Step 3. Enter regression coefficients for the appropriate data columns. Regression coefficients will come from a separate utility or statistics software. Close the second window and a map will be generated.

Step 4. Press button "D" to overlay a land grid and well locations.

Step 5. Press button "C" to write an output file from the map. The output will be for a grid size of 120 by 120 nodes.

Regression coefficients and constant are entered with the window boxes. Scroll through the data columns to select the appropriate independent data for each coefficient. A constant of 1 and coefficient of 1 will display the data column unaltered (other column coefficients set to 0). These parameters will produce a prediction of Red River depth for the "mlr_data_set_01.csv" file found under the directory \tools_mlr\mlr_data\.

TOOLS and UTILITIES

Overview of Neural Solvers

There are two versions of the neural solver. One version is useful for training from external data sources (other 3D surveys). The other version can use multiple independent data files but trains only from dependent data (well control) within the common area of the independent data. An output map is created. Optionally, an output file can be created that can be imported into other ICS tools or external mapping software.

At the present time, the architecture of the neural-solver routines is fairly simple. It is planned to test more complicated architectures in budget period 2 and assess whether they can provide better training and predictions. We will also attempt to determine what size training population would justify more complicated architecture.

Neural Solver 1

The purpose of this program is to predict a parameter, that is measured at a limited number of locations, over some x-y region by using an artificial neural network (ANN) to relate it to a set of 3D seismic attributes which are known at regular grid locations over the region. The ANN used in this program is a simple linear classifier (ADALINE) having one output. The number of inputs is determined by the principal-component analysis (PCA) output matrix. A list box allows the user to choose one of three training techniques: "trainwb" and "trainlm" use variations of Levenberg-Marquardt optimization, "trainscg" is a scaled conjugate gradient method. See the MATLAB "Neural Network Toolbox User's Guide" for details. A full description of MATLAB products and documentation can be found at the MATLAB web site, http://www.mathworks.com.

Data

There are advantages for using Neural Solver 1. A common problem for evaluating a 3D survey with any ANN is a limited well population for control. There are no hard rules, but it is generally recommended to have at least twice the number of well control as the number of independent seismic attributes. The training file for Neural Solver 1 can be constructed from control at other 3D surveys. In this manner, a larger training population can be utilized. **Caution must be exercised that the seismic data are normalized if this is attempted.** For example, when using amplitudes, the gain must be the same. Acquisition and processing parameters should also be the same.

A disadvantage to Neural Solver 1 is that the independent seismic attributes must be captured at the well locations in order to construct the training file. This can be done manually as the seismic survey is worked with seismic interpretation software or can be done by interpolation with the utility "Seismic at Wells."

Neural solver 1 requires two files. One file is the training file that contains the dependent data (well data). A training file is shown in Figure 35. The first two columns contain the coordinates. The third column contains a numeric well or location label. Columns 4 and 5 contain the dependent well data. In this example, formation depths are used. The independent data (seismic time) begin in column 6. Independent data columns must be less than dependent data rows.

Figure 35. An example of a training file for Neural Solver 1 as viewed with spreadsheet software.

x	y	Well	Orr Depth	B Zn Depth	Ke_time	Kgh_time	Kmo_time	Mk_time	Mmc_time	Dtf_time	Orr_time
1254737	158993	1	-6500	-6543	712	1053	1172	1612	1670	1775	1873
1258348	159293	2	-6454	-6499	711	1056	1170	1594	1658	1764	1863
1257953	158110	3	-6401	-6443	711	1051	1169	1594	1658	1763	1858
1258116	158314	4	-6404	-6447	711	1051	1171	1594	1658	1762	1856
1258315	158463	5	-6405	-6448	711	1053	1171	1594	1657	1761	1856
1258702	158574	6	-6413	-6456	713	1055	1173	1593	1658	1762	1857
1259280	158704	7	-6437	-6480	715	1057	1171	1595	1660	1764	1862
1259006	157371	8	-6433	-6475	713	1054	1171	1599	1660	1767	1861
1257814	154290	9	-6496	-6537	712	1054	1169	1601	1664	1771	1874
1253880	156077	10	-6485	-6525	710	1051	1169	1600	1663	1768	1865
1253711	156637	11	-6490	-6530	712	1052	1167	1598	1663	1769	1868
1253676	157227	12	-6489	-6529	714	1052	1168	1605	1665	1771	1869
1253674	157422	13	-6493	-6533	714	1051	1168	1607	1666	1771	1868
1253675	157457	14	-6494	-6534	714	1051	1168	1607	1666	1771	1868
1253662	158426	15	-6489	-6529	714	1055	1176	1608	1668	1775	1870
1253645	158616	16	-6494	-6534	714	1056	1176	1609	1669	1776	1870
1253572	158894	17	-6503	-6541	714	1057	1174	1610	1670	1776	1871
1253603	158801	18	-6503	-6541	714	1057	1174	1610	1670	1776	1871
1253502	159032	19	-6505	-6543	716	1058	1174	1611	1671	1777	1872
1253050	159452	20	-6516	-6554	720	1058	1176	1613	1673	1780	1876
1254615	155311	21	-6472	-6514	711	1048	1169	1597	1660	1764	1865
1255263	151907	22	-6455	-6494	711	1055	1169	1605	1663	1770	1869
1257096	151448	23	-6436	-6476	716	1055	1172	1600	1661	1767	1867
1256972	151226	24	-6434	-6474	716	1055	1172	1600	1661	1768	1867

The second file contains the data to be mapped. This map file is similar to the objective file except for the omission of the well label and well dependent data columns (columns 3 through 5 in Figure 35). An example of a map file for neural solver 1 is shown in Figure 36. The independent data columns are in the same order as in the training file.

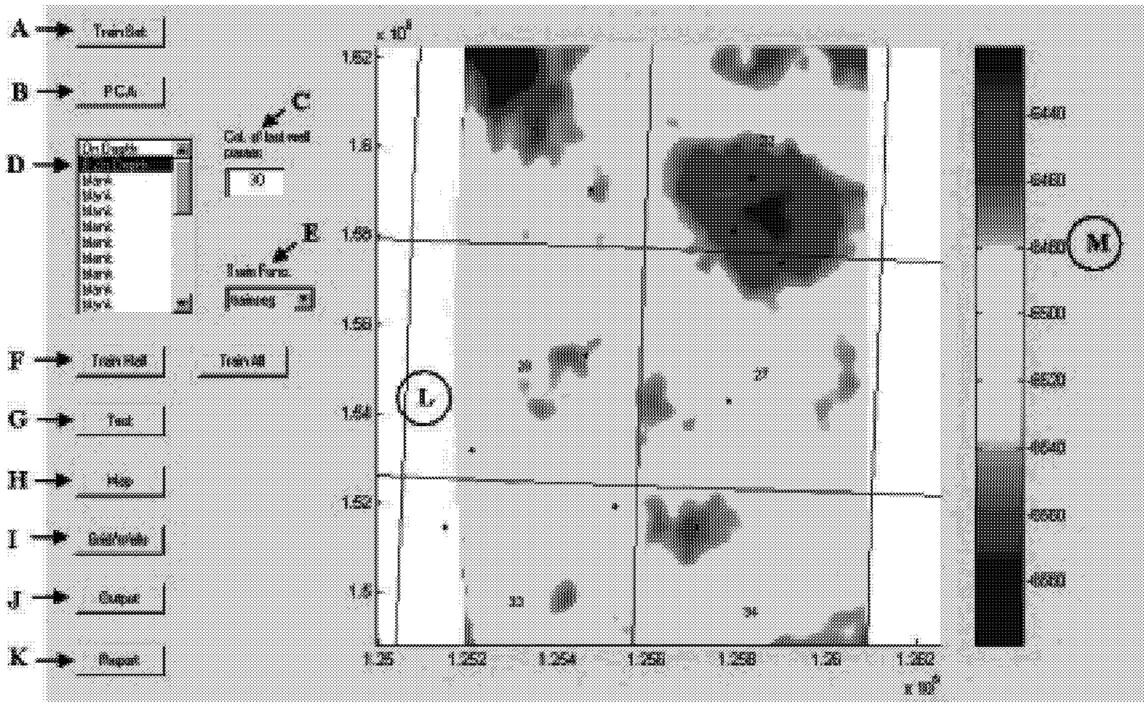
Figure 36. An example of a map file for Neural Solver 1 as viewed with spreadsheet software.

x	y	Ke_time	Kgh_time	Kmo_time	Mk_time	Mmc_time	Dtf_time	Orr_time
1251925	148805	722	1064	1174	1595	1665	1775	1881
1251925	149132	724	1064	1174	1596	1666	1775	1881
1251925	149459	723	1064	1175	1598	1667	1776	1881
1251925	149785	726	1059	1174	1612	1667	1775	1881
1251925	150112	727	1059	1175	1604	1670	1776	1882
1251925	150439	719	1059	1177	1604	1671	1776	1882
1251925	150765	717	1059	1178	1604	1672	1776	1881
1251925	151092	717	1057	1174	1605	1672	1776	1881
1251925	151419	720	1059	1174	1606	1669	1777	1880
1251925	151745	723	1061	1173	1605	1669	1774	1879
1251925	152072	720	1062	1169	1605	1669	1771	1877
1251925	152399	716	1061	1171	1602	1670	1773	1878
1251925	152725	715	1060	1170	1601	1667	1772	1879

The second file contains the data to be mapped. This map file is similar to the objective file. The independent seismic data items must be in the same order.

After calling the Neural Solver 1 routine, a work window is presented as shown in Figure 37.

Figure 37. Work window for Neural Solver 1 and navigation key.



Key to the work window for Neural Solver 1.

A. Load training data set.
B. Perform principal component analysis on training data set.
C. Set column for last well parameter before independent data columns.
D. Select objective column from training data set.
E. Select training function.
F. Train with all or half the training data.
G. Make correlation graph of training data set.
H. Make a map from training results by selecting file of independent data.
I. Overlay land grid and well locations.
J. Export a file from the prediction map.
K. Write a report of the PCA matrix and ANN weights.
L. Map display area.
M. Color bar and scale of map values.

Step 1. Import the training file by pressing "Train Set" button A.

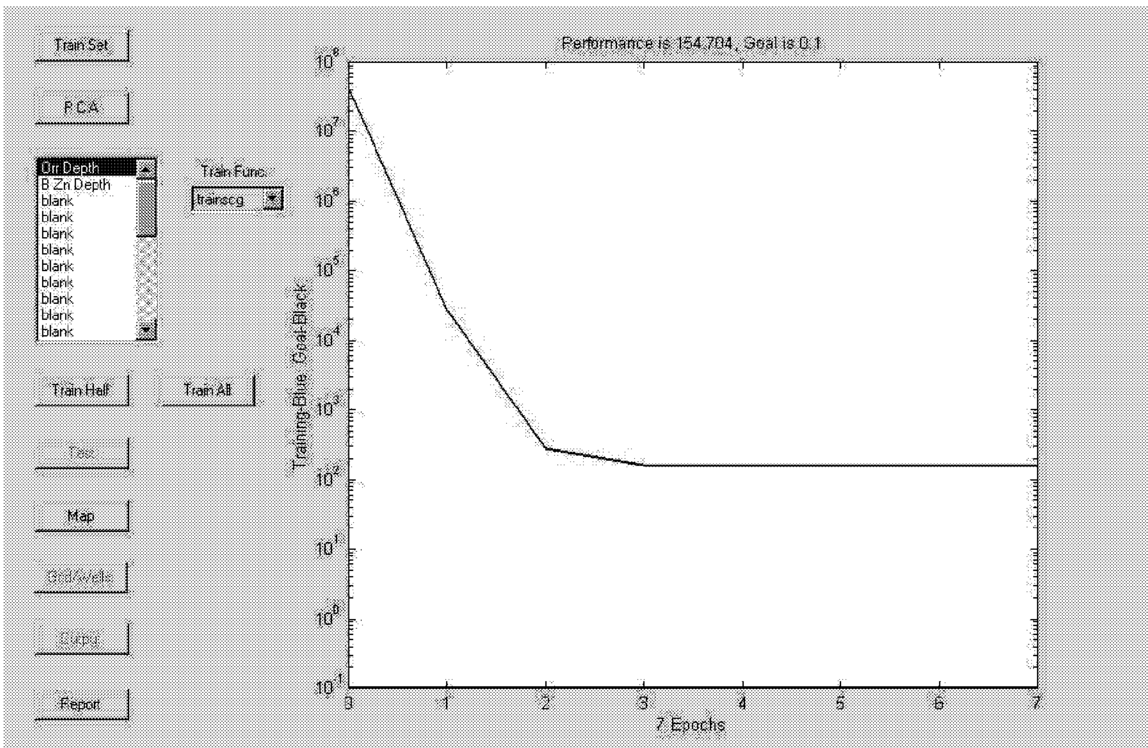
Step 2. Press "PCA" button B. A list of dependent data columns will be presented in the window. Select which data column is to be used for training.

Step 3. Select one of three training functions from window C.

Step 4. Select "Train Half" or "Train All." Acceptable training results would be indicated by similar convergence with both methods.

An example of successful training is shown in Figure 38.

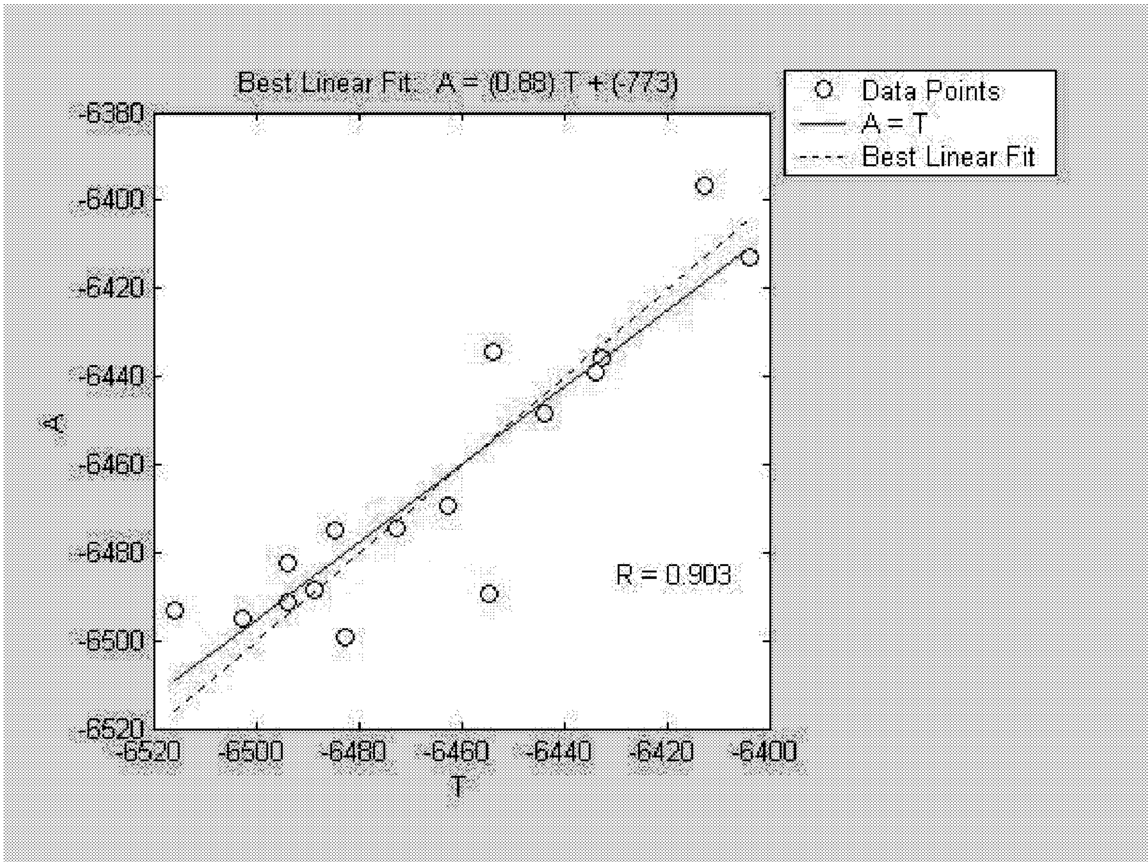
Figure 38. An example of successful training performance with Neural Solver 1



Step 5. Press “Test” button to display the correlation plot.

An example of plot displayed after pressing the “Test” button “G” is shown in Figure 39.

Figure 39. Display of training correlation between results and dependent data from Neural Solver 1.

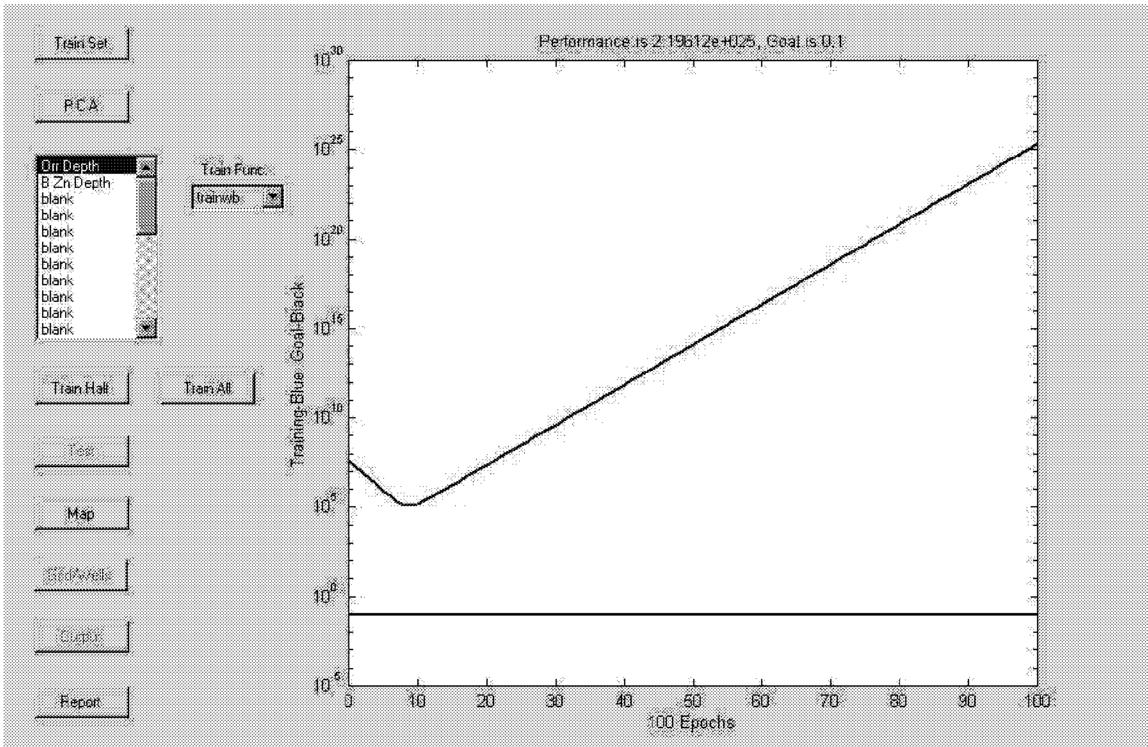


Although the training performance did not achieve the goal of 0.1, a reasonable correlation has been achieved if the “R” correlation coefficient is satisfactory.

Step 6. Press “Map” button to apply training and create a map from the independent data. The map will be displayed as in Figure 37.

If training is unsuccessful, the training performance graph will be similar to that shown in Figure 40.

Figure 40. An example of unsuccessful training performance with Neural Solver 1.



In some circumstances, training will not converge as shown in Figure 40. Try selecting a different training function in window box "E." If convergence cannot be achieved with any of the 3 training functions, the training population may be too small or there is insufficient relationship between the dependent and independent data.

Step 7. Export a PCA report by pressing "Report" button "K", optional.

An example of a PCA report is shown in Figure 41.

Figure 41. An example of a PCA report from Neural Solver 1.

```
Training file: D:\_01_overview\tools-ann\input_files1\ann_predict_depth_train.csv
Training Columns:
   1: Ke time
   2: Kgh_time
   3: Kmo time
   4: Mk_time
   5: Mmc_time
   6: Dtf time
   7: Orr_time
   8: Ke-kgh
   9: Ke-Kmo
   10: Ke-Mk
   11: Ke-Mmc
   12: Ke-Dtf
   13: Ke-Orr
PCA matrix (dot each column with training column to get PC data vector):
    1:  0.17  0.56  0.14 -0.16
    2:  0.20  0.43 -0.32  0.17
    3:  0.22  0.32 -0.36 -0.40
    4:  0.35 -0.04  0.13 -0.21
    5:  0.36  0.00  0.10 -0.13
    6:  0.36  0.07  0.08 -0.08
    7:  0.32  0.19  0.11  0.37
    8:  0.07 -0.10 -0.60  0.43
    9:  0.07 -0.23 -0.58 -0.30
   10:  0.31 -0.31  0.09 -0.16
   11:  0.30 -0.36  0.02 -0.04
   12:  0.33 -0.26  0.01  0.01
   13:  0.31 -0.03  0.07  0.53
ANN Weights:
   -10.104548    5.873466    -6.614024    -3.287220
```

There are three sections to the report.

- List of the data columns from the input files which are used as input to the ANN.

- The transformation matrix obtained from PCA. If there are n data columns listed in the previous section, and PCA has reduced these to m columns, then this is an n by m matrix. Each row of input data is multiplied by this matrix to reduce it from n to m elements.

- The weights used by the ANN. The ANN output is the dot product of these weights with the PCA-reduced input data.

Step 8. Export an output file that contains the map information by pressing "Output" button "J."

The output file contains the map information in a grid with 120 by 120 nodes. An example of an output file is shown in Figure 42.

Figure 42. An example of a map output file from Neural Solver 1.

x	y	value
1252636	161860	-6563
1252558	161860	-6562
1252636	161973	-6562
1252558	161973	-6562
1252714	161748	-6561
1252714	161860	-6560
1252636	161748	-6560
1252558	162085	-6560
1252636	162085	-6559
1252558	162198	-6559
1252636	162198	-6559
1252480	162198	-6559
1252714	161973	-6559
1252480	161860	-6559

Practice files for the Neural Solver 1 Tool are located under the directory \tools_ann\input_files1\. Output files relating to the figures shown in this section are located under the directory \tools_ann\output1\.

TOOLS and UTILITIES

Neural Solver 2

The Neural Solver 2 routine is used to predict a parameter, that is measured at a limited number of locations over some x-y region, by using an ANN to relate it to a set of attributes which are known at regular grid locations.

In normal use, the predicted parameter is some measure of well "goodness", such as initial production, and the attributes are the outputs from one or more other ICS programs. All input data files are assumed to be comma-separated-variable files, with coordinates assigned in the first two columns. The first row is reserved for column labels. There are no other assumptions about the content of the files. The user specifies training data by selecting them from list boxes. An over lap of the data files is computed. Grid operations are then applied to the data within the common area.

The ANN used in this program is a simple linear classifier (ADALINE) having one output. The number of inputs is by user-selection of data columns. The input data are normalized, but no PCA is done. The MATLAB default training function is used.

Data

Neural solver 2 can import multiple files containing independent data. The Neural Solver 2 routine is intended to import the output from other ICS tools that have been used to predict reservoir parameters such as porosity-thickness, growth-history and entrapment pressure. Data columns within each file can be selected as desired by the user. One file contains locations and well data. The file that contains well data is the "objective" file. Objectives that are contained in this file will represent reservoir "goodness." Quantities from production history such as initial 24-month production, oil-cut and estimated ultimate recovery are examples of "goodness." When the Neural Solver 2 routine is utilized with these types of data, the output will be a "Z" map that has been objectively weighted and ranked according to the data selected from the objective file. An example of using the Neural Solver 2 Tool in this manner is presented in the tutorial section.

There are some advantages for using Neural Solver 2. Separate files of independent data can be imported. These files are located in a common directory reserved for the study. The coordinates of the independent data files need not match, but there must be some common area. There is no need to capture the independent data at the location of the dependent data (wells). Interpolating the independent data at well locations is done by the program.

There are also some disadvantages for using Neural Solver 2. If the dependent data (wells) population is small, successful training may not be possible. Although there are no hard rules, the dependent data population should be more than twice the number of independent items (3 independent items with 6 wells). Another disadvantage is that there is only one option for training.

An example of a training objective file for neural solver 2 is shown in Figure 43. The first row is reserved for labels. The first two columns contain x-y coordinates. The third column contains a numeric well label. The dependent data are in the following columns. There is no limit to the number of dependent data columns. The objective file shown in Figure 43 contains sub-sea depths to the Red River Formation and Red River B zone reservoir at measured locations in a 3D seismic survey. In this case, the Neural Solver 2 routine is not used to created a "Z" map of reservoir "goodness." The example files that follow demonstrate, using depth as the objective, the procedure for working with the Neural Solver 2 Tool.

Figure 43. An example of an objective training file for Neural Solver 2 as viewed with spreadsheet software.

x	y	Well	Orr Depth	B Zn Depth
1254737	158993	1	-6500	-6543
1258348	159293	2	-6454	-6499
1257953	158110	3	-6401	-6443
1258116	158314	4	-6404	-6447
1258315	158463	5	-6405	-6448
1258702	158574	6	-6413	-6456
1259280	158704	7	-6437	-6480
1259006	157371	8	-6433	-6475
1257814	154290	9	-6496	-6537
1253880	156077	10	-6485	-6525
1253711	156637	11	-6490	-6530
1253676	157227	12	-6489	-6529
1253674	157422	13	-6493	-6533
1253675	157457	14	-6494	-6534
1253662	158426	15	-6489	-6529
1253645	158616	16	-6494	-6534
1253572	158894	17	-6503	-6541
1253603	158801	18	-6503	-6541
1253502	159032	19	-6505	-6543
1253050	159452	20	-6516	-6554
1254615	155311	21	-6472	-6514
1255263	151907	22	-6455	-6494
1257096	151448	23	-6436	-6476
1256972	151226	24	-6434	-6474
1256930	151043	25	-6438	-6478
1256883	150688	26	-6444	-6484
1256883	150564	27	-6448	-6488
1256817	150039	28	-6463	-6503
1256797	149908	29	-6467	-6507
1256747	149687	30	-6473	-6513
1256699	149474	31	-6477	-6517
1256614	149113	32	-6483	-6523

Shown in Figure 44, is an example of seismic times at important geologic horizons that have been exported from seismic interpretation software.

Figure 44. An example of an input file for Neural Solver 2 that contains independent data as viewed with spreadsheet software.

x	y	Ke_time	Kgh_time	Kmo_time	Mk_time	Mmc_time	Dtf_time	Orr_time
1251925	148805	722	1064	1174	1595	1665	1775	1881
1251925	149132	724	1064	1174	1596	1666	1775	1881
1251925	149459	723	1064	1175	1598	1667	1776	1881
1251925	149785	726	1059	1174	1612	1667	1775	1881
1251925	150112	727	1059	1175	1604	1670	1776	1882
1251925	150439	719	1059	1177	1604	1671	1776	1882
1251925	150765	717	1059	1178	1604	1672	1776	1881
1251925	151092	717	1057	1174	1605	1672	1776	1881
1251925	151419	720	1059	1174	1606	1669	1777	1880
1251925	151745	723	1061	1173	1605	1669	1774	1879
1251925	152072	720	1062	1169	1605	1669	1771	1877
1251925	152399	716	1061	1171	1602	1670	1773	1878
1251925	152725	715	1060	1170	1601	1667	1772	1879
1251925	153052	714	1060	1170	1603	1664	1773	1877
1251925	153379	717	1055	1172	1606	1666	1774	1875
1251925	153705	717	1054	1170	1606	1668	1775	1875
1251925	154032	714	1056	1170	1603	1668	1775	1876
1251925	154359	713	1056	1168	1600	1666	1776	1877
1251925	154685	715	1055	1171	1599	1665	1775	1877
1251925	155012	716	1054	1170	1600	1666	1774	1877
1251625	155339	717	1053	1168	1600	1665	1774	1876
1251925	155339	717	1053	1168	1600	1665	1774	1876

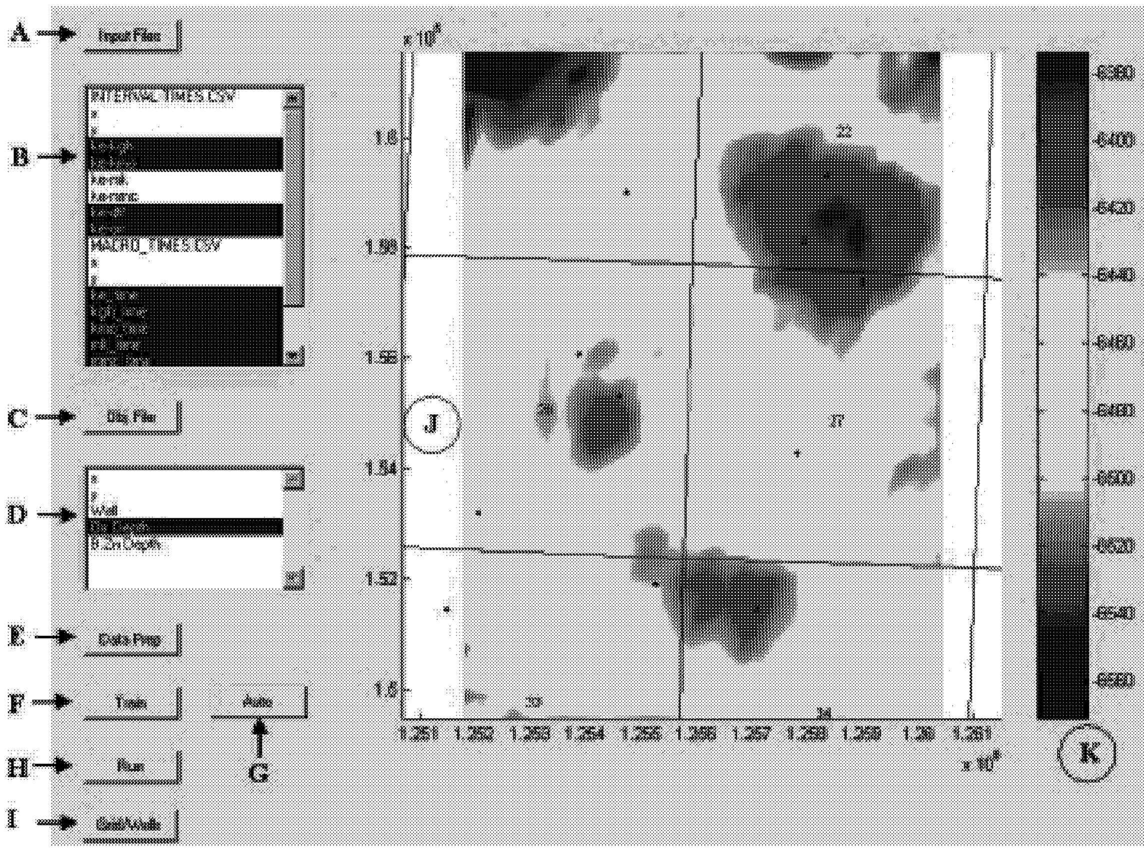
An example of an exported file that contains seismic interval-times is shown in Figure 45. This file is created by seismic interpretation software.

Figure 45. An example of a second input file for Neural Solver 2 that contains different independent data as viewed with spreadsheet software.

x	y	Ke-kgh	Ke-Kmo	Ke-Mk	Ke-Mmc	Ke-Dtf	Ke-Orr
1251925	148805	342	452	873	943	1053	1159
1251925	149132	340	450	872	942	1051	1157
1251925	149459	341	452	875	944	1053	1158
1251925	149785	333	448	886	941	1049	1155
1251925	150112	332	448	877	943	1049	1155
1251925	150439	340	458	885	952	1057	1163
1251925	150765	342	461	887	955	1059	1164
1251925	151092	340	457	888	955	1059	1164
1251925	151419	339	454	886	949	1057	1160
1251925	151745	338	450	882	946	1051	1156
1251925	152072	342	449	885	949	1051	1157
1251925	152399	345	455	886	954	1057	1162
1251925	152725	345	455	886	952	1057	1164
1251925	153052	346	456	889	950	1059	1163
1251925	153379	338	455	889	949	1057	1158
1251925	153705	337	453	889	951	1058	1158
1251925	154032	342	456	889	954	1061	1162
1251925	154359	343	455	887	953	1063	1164
1251925	154685	340	456	884	950	1060	1162
1251925	155012	338	454	884	950	1058	1161
1251625	155339	336	451	883	948	1057	1159

Upon execution of the command to start the Neural Solver 2 routine, a work window is presented as shown n Figure 46.

Figure 46. An example of the work window for Neural Solver 2 and navigation key.



Key to the work window for Neural Solver 2.

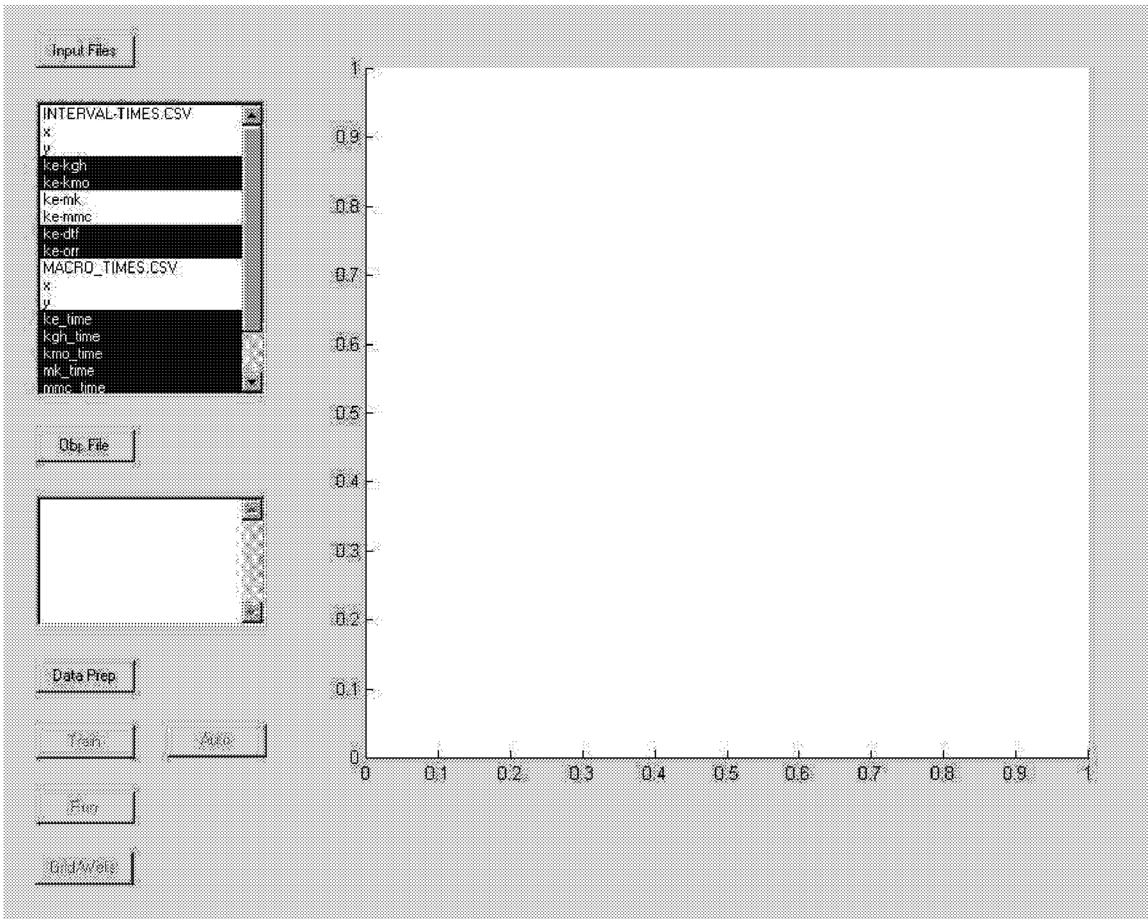
A. Select input files
B. List box displays files and data columns.
C. Select objective file for training.
D. List box displays the data columns contained in the objective file.
E. Prepare data after making selections from input files.
F. Train with highlighted objective item.
G. Special training and validation feature.
H. Training is applied and a map generated.
I. Land grid and well locations are overlain on map.
J. Map area.
K. Color bar and scale.

Step 1 Load input files by pressing “Input Files” button”A.” These files should exist in a separate work directory. All files with a csv extension will be read from the work directory.

Step 2. Select independent data to be processed from the list box “B.” Use a control left-click to toggle the selections. Do not select the file name or coordinates. The file name is shown with capital letters.

After the input files have been read and data columns selected, the work window for Neural Solver 2 will be similar to that shown in Figure 47.

Figure 47. The work window for Neural Solver 2 is shown after selecting directory with the input (independent data) files.

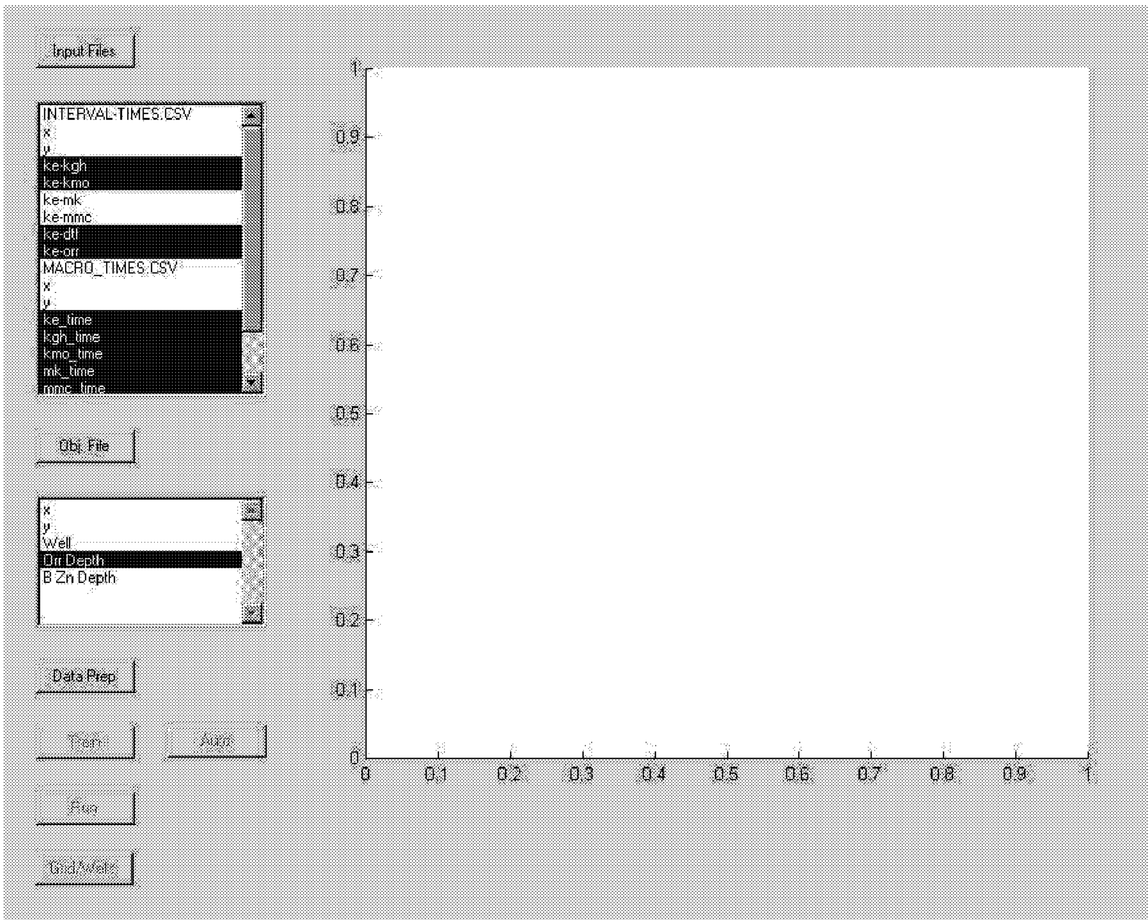


Step 3. Press "Objective File" button "C." This file should exist in a separate work directory that is different from the work directory for the input files.

Step 4. Press "Data Prepare" button "E." All selected data will be loaded. Intersecting area of the input files will be computed. The independent data (input files) will be interpolated and placed in a work matrix. Interpolated values for independent data will be captured at the well locations found in the objective file.

After the objective file is read and data column selected, the work window for Neural Solver 2 will be similar to that shown in Figure 48.

Figure 48. The work window for Neural Solver 2 is shown after selecting objective (dependent data) file.



Step 5. Select training objective from list box "D."

Step 6. Press "Train" button "F."

After pressing the "Train" button "F", a training performance graph is displayed as shown in Figure 49. The graph shown does not indicate convergence. The training has failed. If convergence does not occur, experiment with the input file selections from list box "B." Press "Data Prep" button again after new selections are made.

Figure 49. An example of unsuccessful training from Neural Solver 2

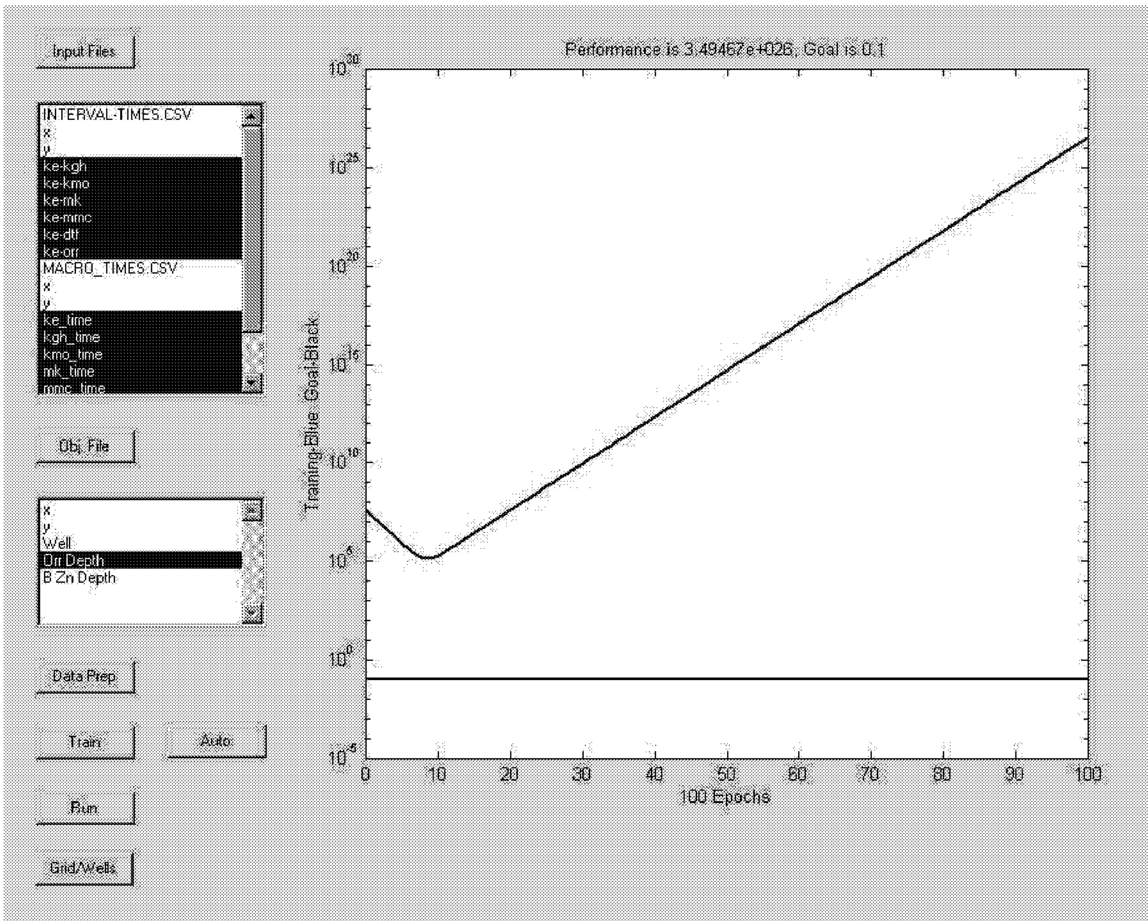
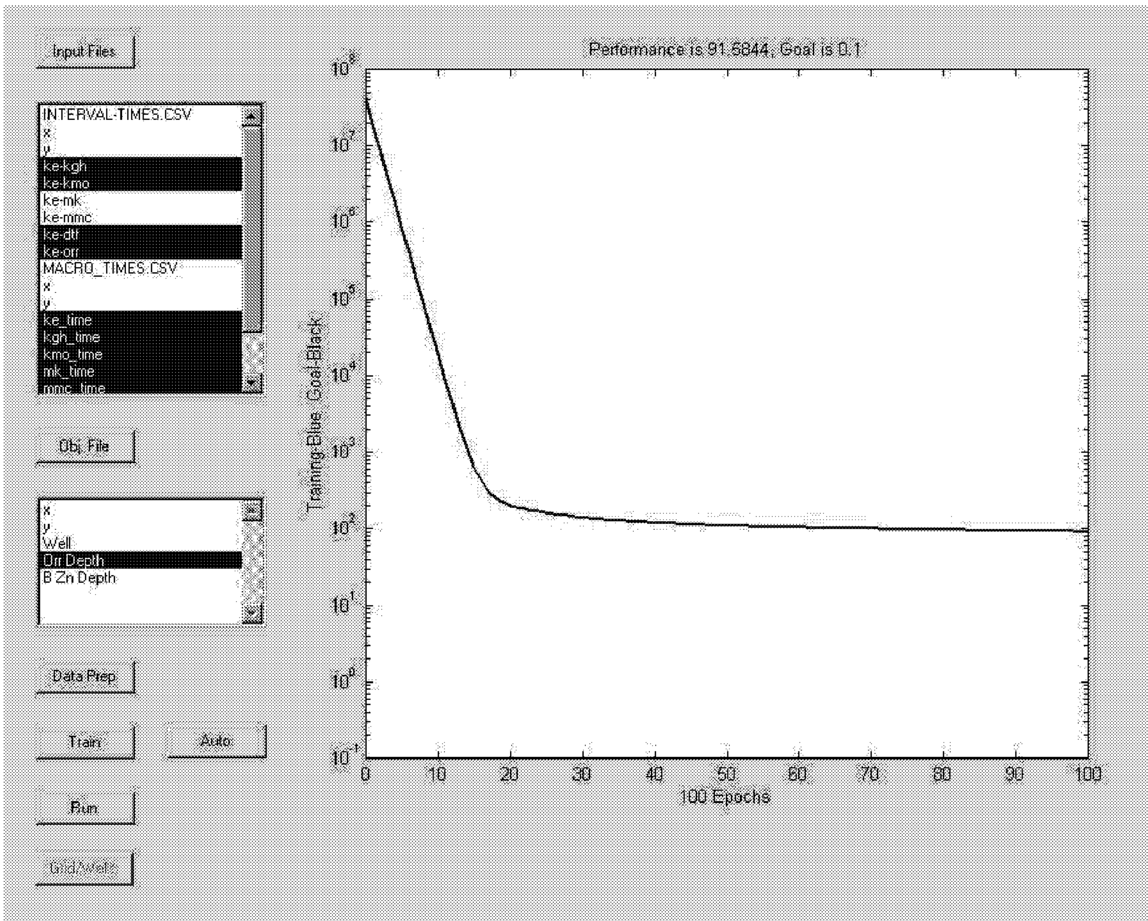


Figure 50 shows that convergence occurred after de-selection of "ke-mk" and "ke-mmc" from the independent data. It may be instructive to separately train with each independent data column and observe the training performance. In a final run, select only those independent data that produced the best performance.

Figure 50. An example of successful training from Neural Solver 2.



Step 7. Press "Run" button "H" to create a map of the training results applied to the independent data.

Step 8. Press "Grid/Wells" button "I" to over lay the land grid and well locations.

Step 9. Press the "Auto" button "G", optional.

The "Auto" option is a special feature that made that predicts parameters at each well (control point) from the remaining wells as training data. A report is generated that compares the measured values to the predicted values. An example of output from the "Auto" feature of the Neural Solver 2 Tool is shown in Figure 51.

Figure 51. An example of actual (a) and prediction (p) values from Neural Solver 2 for the dependent data in the objective file.

WELL	(a)Orr Depth	(p)Orr Depth	(a)B Zn Depth	(p)B Zn Depth
1	-6500	-6489	-6543	-6528
2	-6454	-6412	-6499	-6455
3	-6401	-6409	-6443	-6452
4	-6404	-6405	-6447	-6448
5	-6405	-6387	-6448	-6430
6	-6413	-6380	-6456	-6423
7	-6437	-6409	-6480	-6451
8	-6433	-6415	-6475	-6455
9	-6496	-6451	-6537	-6491
10	-6485	-6449	-6525	-6491
11	-6490	-6468	-6530	-6510
12	-6489	-6454	-6529	-6494
13	-6493	-6453	-6533	-6494
14	-6494	-6453	-6534	-6493
15	-6489	-6463	-6529	-6503
16	-6494	-6462	-6534	-6502
17	-6503	-6477	-6541	-6516
18	-6503	-6460	-6541	-6500
19	-6505	-6476	-6543	-6516
20	-6516	-6473	-6554	-6512
21	-6472	-6419	-6514	-6462
22	-6455	-6462	-6494	-6503
23	-6436	-6408	-6476	-6450
24	-6434	-6421	-6474	-6462
25	-6438	-6420	-6478	-6461
26	-6444	-6430	-6484	-6471
27	-6448	-6430	-6488	-6471
28	-6463	-6448	-6503	-6488
29	-6467	-6447	-6507	-6488
30	-6473	-6446	-6513	-6487
31	-6477	-6465	-6517	-6505
32	-6483	-6464	-6523	-6504

Practice files for the Neural Solver 2 Tool are located under the directory \tools_ann\input_files2\.

TOOLS and UTILITIES

Manual Combine

The Manual Combine Tool can produce a reservoir potential or "Z" map. Output can be arithmetically summed by supplying user-supplied weights to the data (up to seven data sources). Imported data could be output files for depositional setting and porosity development, structural growth, and entrapment potential. The Manual Combine Tool provides a subjective evaluation of reservoir potential as supplied by weights from the user in an arbitrary fashion or as an attempt to shift weights to match the user's knowledge of well performance. The combine tool could be also used to explore different weighting to approximate the results computed by the neural solver.

Data

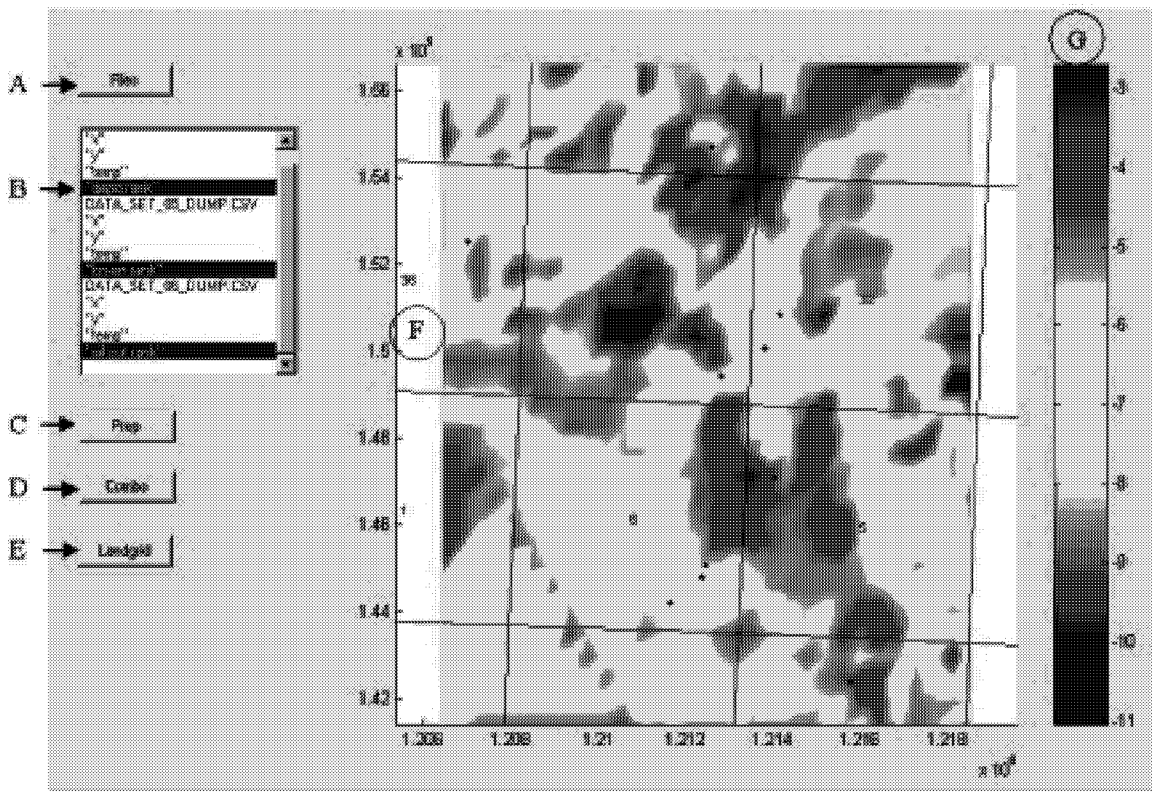
Input data for the Manual Combine Tool are created with the Cluster 1 or Cluster 2 routines. An example of an output file from Cluster 1 or 2 is shown is Figure 52. The rank column (4) from the cluster output is used to characterize reservoir "goodness." It is assumed that ranking order is the same for each input file; 1 is good and 4 is poor. Up to 7 input files can be imported at one time. The files must reside in a separate directory. The routine will attempt to read each file in the work directory that has a csv extension.

Figure 52. An example of a rank file produced by Cluster 1 or Cluster 2.

x	y	cluster	rank	mean 1	mean 2
1205030	140303	0	0	NaN	NaN
1205742	153787.4	1	4	221	0.65
1205505	151061.9	2	3	226	5.73
1205505	151205.3	3	2	228	5.83
1205505	153213.6	4	1	229	4.68

After executing the command for the Manual Combine Tool, a work window is presented as shown in Figure 53.

Figure 53. An example of the work window for Manual Combine and navigation key.



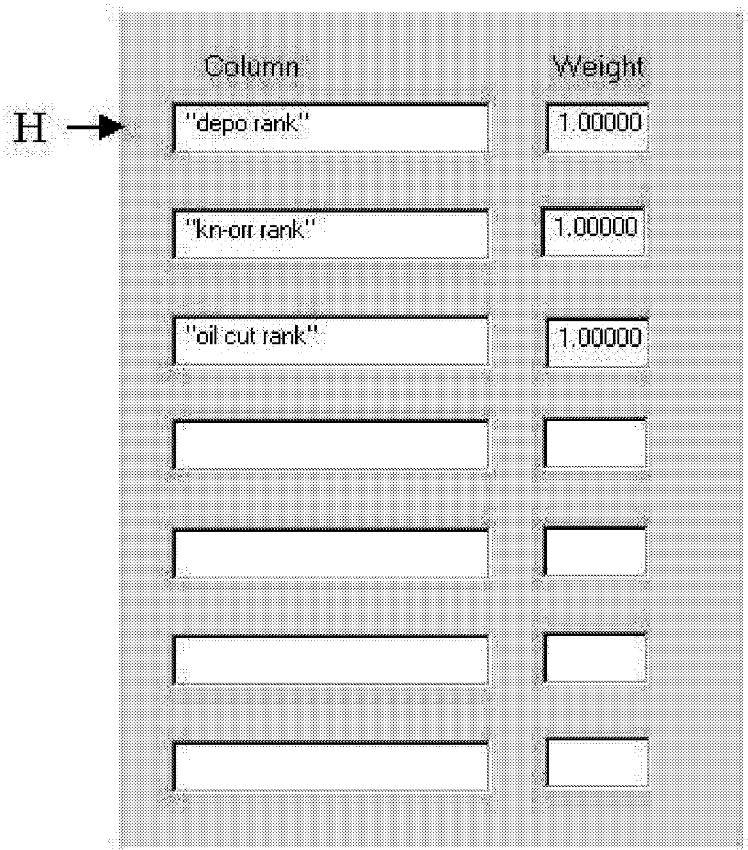
Key to work window for the Manual Combine Tool.

A. Load input files.
B. List box showing files and data columns.
C. Prepare button overlays and merges data.
D. Apply weights to selected data.
E. Overlay land grid and well locations, optional.
F. Map area.
G. Color bar and scale.

Step 1. Load input files by pressing "Files" Button "A."
Step 2. Select data columns from list box "B."
Step 3. Press "Prepare" button "C."
Step 4. Press "Combo" button "D." A second work window is presented.

After pressing the “Combo” button “D”, a new window is presented as shown in Figure 54. In general use, the weights will be from 0 to 1. Leaving all weights to a value of 1 will give each input file equal value.

Figure 54. An example of the second work window for the Manual Combine Tool and navigation key.



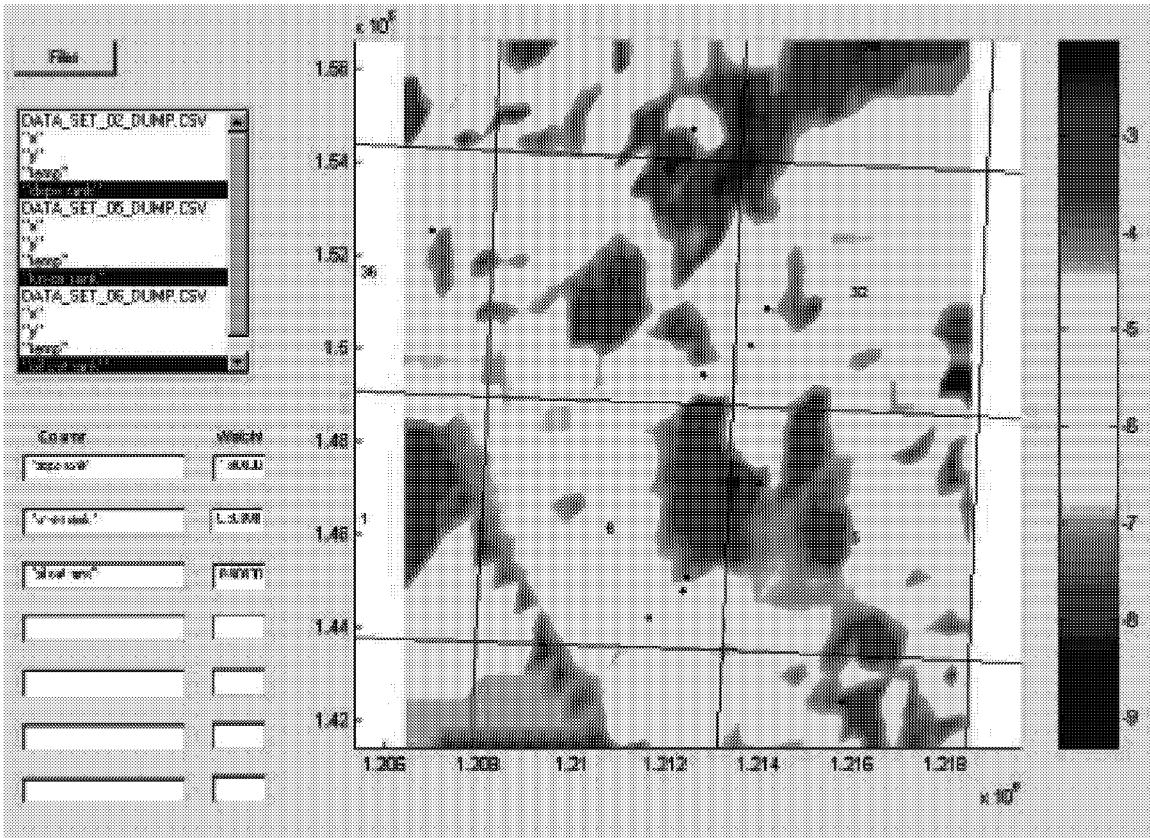
Key to second work window for Manual Combine Tool.

H. List box of selected data columns and weights to be applied.

Step 5. Change weights as desired. A zero will remove item from summation. Close the window and a new map will be created with the supplied weights.

A “Z” map is computed from the user-supplied weights and the selected data as shown in Figure 55.

Figure 55. An example from Manual Combine Tool with different weights applied to input data.



The areas with low values are good. Large values indicate poor ranking from selected data and weights. In this example there are 3 input files. Areas with a value of 3 represent regions where the 3 input files have a rank of 1 (best).

TOOLS and UTILITIES

Fuzzy Combine

The Fuzzy Combine Tool is a form of "expert system" used to consistently apply rules for characterization of reservoir potential. This tool relies for its operation on a fuzzy inference system (FIS) built with the MATLAB Fuzzy Editor. A MATLAB FIS is a single file (with extension .fis) which contains the definition of a complete fuzzy inference system, consisting of input variable membership functions, fuzzy rules, and output variable mapping functions. The FIS editor provides for the definition and editing of these components with a simple GUI. See the MATLAB Fuzzy Logic Toolbox User's Guide for details. This documentation can be found on the MATLAB web site.

The ICS Fuzzy Combine Tool is a control and display shell around the FIS, which allows the user to select data files for input to the FIS, and displays the FIS output in map form consistent with the other ICS tools.

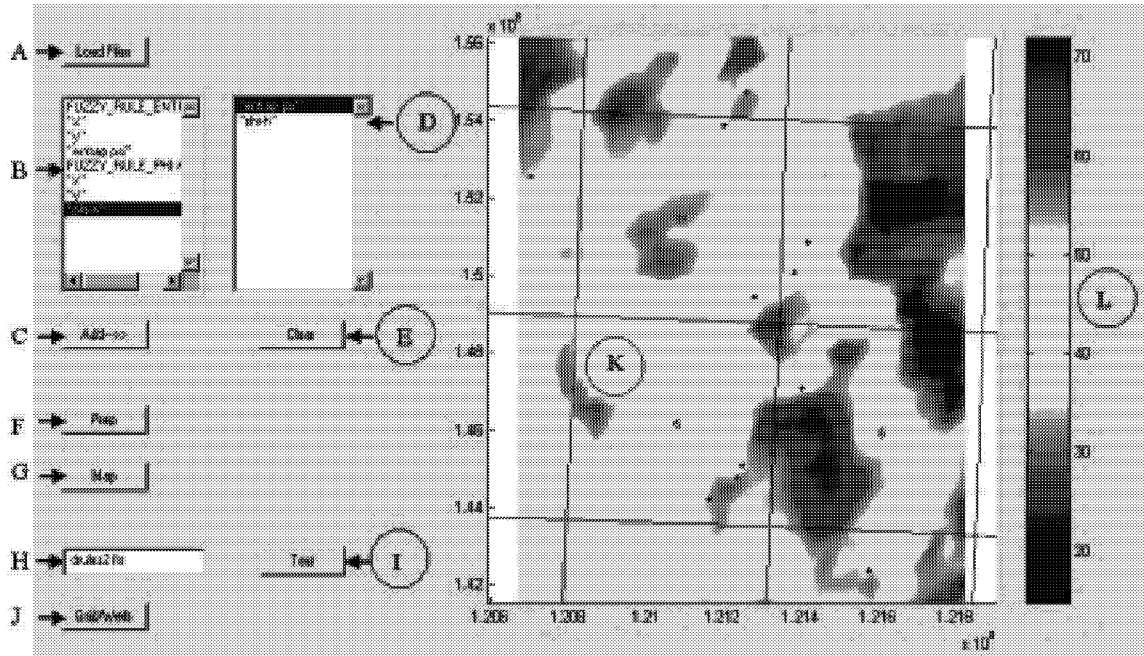
In general use, the user will define a FIS external to ICS. The FIS may have any number of inputs and rules, and should have one output. For use in ICS as a combine tool, the inputs are presumably data that are created by other ICS tools. The rules relate values of these reservoir characterization parameters to some overall measure of reservoir potential, which is the mapped output.

In its demonstration form supplied here, the tool applies rules to 2 reservoir parameters: entrapment pressure and porosity-thickness (phi-h) for a particular reservoir in the Upper Red River. The entrapment pressure is output from the Entrapment Tool, and the predictions of phi-h are made with a neural solver, cluster tool or multiple-linear regression tool. The 2-input FIS for this case is called drules2.fis. Demonstration files for the example shown in Figure 56 are located under the directory \tools_fuzzy\input_files\.

The Fuzzy Combine Tool is under development and is not ready for a tutorial example at this time. After further calibration and sophistication are incorporated in this tool, we plan to post an update and tutorial example on the project web site. It is anticipated that this will be accomplished in the first quarter of 2002.

Shown in Figure 56 is the work window and navigation key for the "Fuzzy Combine" tool.

Figure 56. Work window for Fuzzy Combine Tool and navigation key.

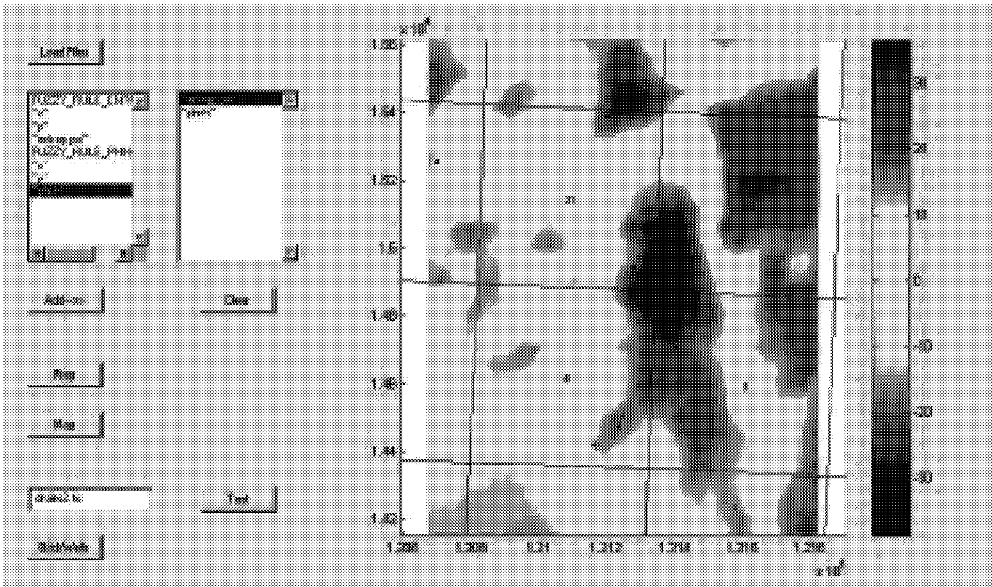


Navigation key for Fuzzy Combine Tool.

A. Load input files. Input files must reside in a separate directory.
B. Select one data column. Press "Add." Column name is copied to window "D." Repeat for second data column.
C. Copies column name selected from "B" to "D."
D. Window containing data for fuzzy rules. Entrapment is first, phi-h is second.
E. Clear button to start over with file selection.
F. Press "Prepare" button after data are selected. Overlay and grid operations begin.
G. Map is displayed of data item that is highlighted in window "D."
H. File name of fuzzy rules that apply to the data selected.
I. "Test" button applies fuzzy rules and creates a map in window "K."
J. Overlay land grid and well locations from a special file.
K. Map area.
L. Color bar and scale. Scale is from 0 to 100. A score of 100 is the best possible.

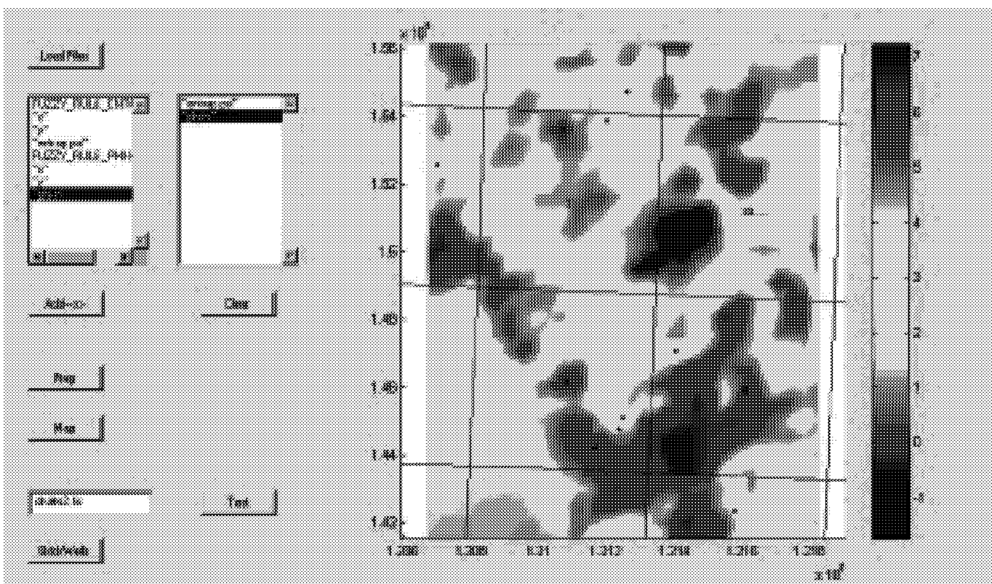
Shown in Figure 57 is an example of entrapment-pressure input as mapped by the "Fuzzy Combine" tool.

Figure 57. An example of entrapment-pressure input as mapped by the Fuzzy Combine Tool.



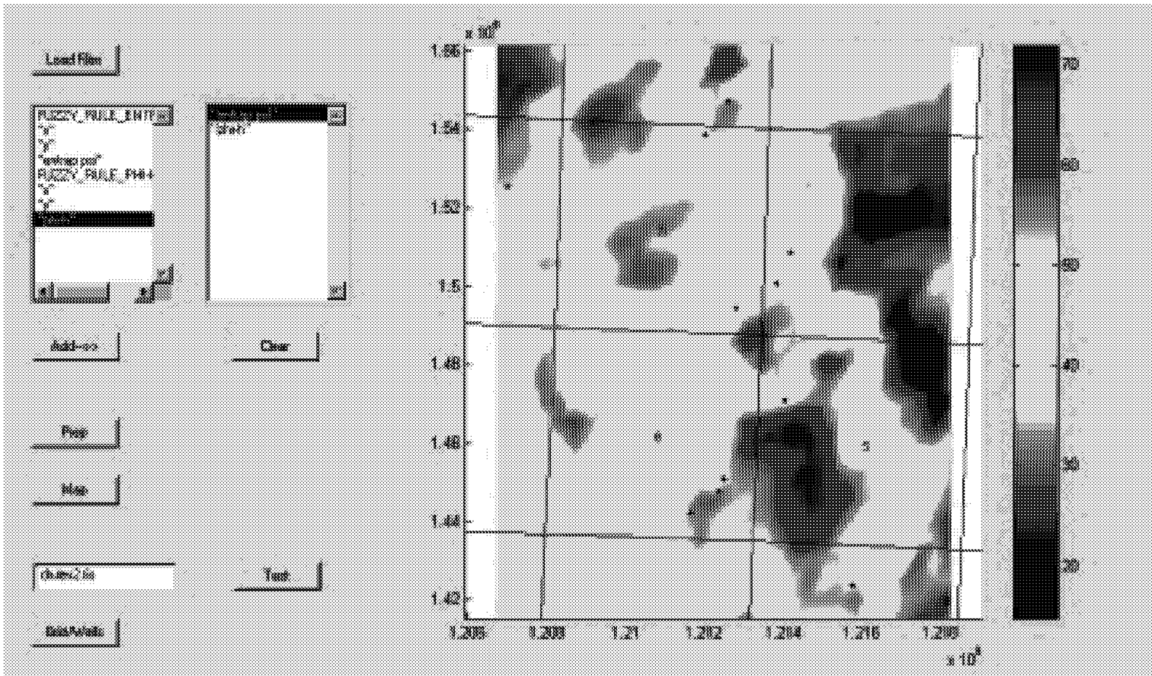
Shown in Figure 58 is an example of porosity-thickness input as mapped by the "Fuzzy Combine" tool.

Figure 58. An example of porosity-thickness input as mapped by the Fuzzy Combine Tool.



Shown in Figure 59 is an example of output from application of fuzzy rules with the "Fuzzy Combine" tool.

Figure 59.	Final output from application of rules with Fuzzy Combine Tool.



The score from application of the fuzzy rules (item box "H") is shown on the color bar. A score of 100 is the maximum "goodness." A score of "0" is the minimum "goodness."

TUTORIALS

Introduction

Software tools in ICS are for evaluating various data sets from seismic, geologic and engineering sources. The objective of these tools is to provide a means for logical and consistent reservoir characterization. These tools can be broadly characterized as 1) clustering tools, 2) neural solvers, 3) multiple-linear regression, 4) entrapment-potential calculator and 5) combining tools. A flexible approach can be used with the ICS tools. They can be used separately or in a series to make predictions about some objective.

The tools in ICS are primarily designed to correlate relationships between seismic information and data obtained from wells. It is possible to work with well data alone. Likewise, there may be special circumstances where seismic data could used without well data. A generalized approach to reservoir characterization with ICS is shown in Figure 60.

Figure 60. ICS Data and Logic flow.

DATA →	**TOOLS →**	**INTERMEDIATE OBJECTIVES →**	**COMBINE →**	**"Z" MAP**
Formation Tops	Clustering	Deposition	Manual Weight	Reservoir
Log Analysis	Neural Solver	Structure	Neural Solver	Potential
Production	Linear Regression	Growth History	Fuzzy Rules	
Flow Tests		Storage		
Seismic Time		Transmissibility		
Seismic Intervals		Fluid Saturation		
Seismic Attributes		Entrapment		
Seismic Models				

An example of data and approach for evaluation of depositional setting is shown in Figure 61.

Figure 61. Data and logic flow for depositional setting.

DEPENDENT DATA →	**INDEPENDENT DATA →**	**TOOLS→**	**OBJECTIVE →**	**OUTPUT**
Rock Quality	Micro Intervals	Clustering	Intervals	Rank- mean
Porosity	Formation-marker		Correlating	File and map
Permeability	Tops/Picks		To rock quality	
Facies	From well logs		Rock type or	
Shale Volume			Facies	

An example of data and approach for evaluation of structure and growth history is shown in Figure 62.

Figure 62. Data and logic flow for structure and growth history.

DEPENDENT DATA →	**INDEPENDENT DATA →**	**TOOLS →**	**OBJECTIVE →**	**OUTPUT**
Production	Macro Intervals	Clustering	Rank	Rank- mean
Oil volume	Formation-marker		Interval patterns	File and map
Production rate	Tops/Picks		With production	
Oil cut	From well logs		With depth	
Reservoir depth	From Seismic			
		Neural Solver	Transform	Production
			Interval patterns	Attribute
			To production	File and map
			Related values	

An example of data and approach for transformation of seismic attributes to reservoir attributes is shown in Figure 63.

Figure 63. Data and logic flow for seismic pseudo-reservoir attributes.

DEPENDENT DATA →	**INDEPENDENT DATA →**	**TOOLS →**	**OBJECTIVE →**	**OUTPUT**
Reservoir attributes	Seismic attributes	Clustering	Reservoir	Rank- mean
At wells	Amplitude		Attributes	File and map
Thickness	Frequency		At seismic	
Storage	Isochron		Traces	
Porosity				
Transmissibility		Neural Solver		Transformed
Permeability				Seismic
				Attributes
				File and map
		Multiple		Transformed
		Linear		Seismic
		Regression		Attributes
				File and map

An example of data and approach for transformation of seismic attributes to reservoir fluid saturation is shown in Figure 64.

Figure 64. Data and logic flow for fluid saturation.

DEPENDENT DATA →	**INDEPENDENT DATA →**	**TOOLS →**	**OBJECTIVE →**	**OUTPUT**
Reservoir attributes At wells Water saturation Oil cut Porosity	Special Seismic Attributes Frequency AVO	Clustering	Reservoir Attributes At seismic Traces Water saturation Oil cut	Rank- mean File and map
		Neural Solver		Transformed Seismic Attributes File and map

An example of data and approach for estimating entrapment potential for a reservoir is shown in Figure 65.

Figure 65. Data and logic flow for entrapment.

DEPENDENT DATA →	**INDEPENDENT DATA →**	**TOOLS →**	**OBJECTIVE →**	**OUTPUT**
Reservoir attributes At wells Water density Capillary properties Datum pressure	Reservoir depth Cluster rank file Porosity or permeability	Entrapment	Structure and Stratigraphic Potential	Entrapment Potential File and map

An example of data and approach for combining results from intermediate objectives is shown in Figure 66.

Figure 66. Data and logic flow for final objective.

DEPENDENT DATA →	**INDEPENDENT DATA →**	**TOOLS →**	**OBJECTIVE →**	**OUTPUT**
Reservoir attributes	Transformed	Manual combine	Subjective	Summation
At wells	Seismic attributes		Weights	For
Storage				Relative
Transmissibility	Storage			Goodness
Entrapment	Transmissibility			
Oil cut	Growth history			
Oil rate	Entrapment	Neural Solver	Objective	Direct
Ultimate recovery			Weights	Prediction
				From training
				Oil-cut
				Oil rate
				EUR
		Fuzzy rules	Objective	Consistent
			Weights	Rules For
				Relative
				Goodness

Data

Data should be collected and organized that are appropriate for intermediate objectives. Some suggested reservoir characterization items from well data are listed below.

A. A model for reservoir deposition and genesis should be developed. In general, the depositional setting can be inferred from various intervals within and near the reservoir objective. Appropriate data would include formation or marker-bed depths.

B. Most reservoirs have some component of structural trapping. Appropriate data would be the depth to the reservoir objective. In some instances, especially with seismic time, structure may be expressed as an interval from a shallow horizon to the reservoir objective.

C. Growth history describes the evolution of structure. Appropriate data would be important formation tops from surface to some formation or marker-bed below the reservoir objective. A suggested number of formation depths for this data set would be five or six.

D. Storage is porosity-thickness. The data will come from analysis of well logs. The data set will summarize gross thickness, net gross thickness and effective porosity-thickness for the reservoir objective.

E. Transmissibility is a property that describes flow capacity. Permeability-thickness or draw-down indices are possible parameters that describe flow capacity. Drill-stem tests, production-curve analysis and back-pressure tests are good sources for this characterization item.

F. Fluid saturation in the reservoir can be characterized from well-log analysis and production data.

The data should be entered into spreadsheets and organized in the manner shown in the following tables. The spreadsheets must be saved or exported in comma-separated-variable format. The first two columns are reserved for coordinates in any cartesian first quadrant format. The first row is reserved for data labels. Do not have more than one row of labels.

Construction of a database for dependent well information should be the first order of business. The file will contain numeric values of items that describe the quality of the reservoir as shown in Figure 67.

Figure 67. An example of a data file containing reservoir parameters from well information.

EAST FT	NORTH FT	WELL API No.	Storage PHI-H	DST Oil-cut Fraction	Transmissibility KH	BOPD Avg. 24 months	Oil-cut Avg. 24 months
1212611	154710	3301100198	1.770	0.600	8.51		
1214184	150850	3301100258		0.578	2.52		
1214039	147068	3301100259	0.908	1.000	10.31	112.5	0.601
1212821	149427	3301100262	1.349	0.983	33.49	60.3	0.736
1212031	153869	3301100305	0.990			74.3	0.937
1213827	150045	3301100311	1.130	0.938	85.70	79.8	0.981
1207014	152537	3301100339	1.569	0.088	0.29	0.0	0.088
1215767	142373	3301100343	1.734	0.949	19.47	14.3	0.415
1212374	144767	3301100432	1.248	0.082	2.63		
1212474	145067	3301100488	1.196	0.120	5.04		
1211646	144209	3301100915	0.929	0.470	15.10	42.0	0.500
1257953	158110	3301100195	0.918	0.938	24.06	141.9	0.980
1254615	155311	3301100200	1.485	1.000	121.17	118.6	0.688
1257096	151448	3301100208	1.824	1.000	329.83	162.8	0.983
1257814	154290	3301100254	1.511	0.071	63.38	0.0	0.000
1251775	148752	3301100297	1.117	0.660	67.55	32.5	0.764
1252062	153191	3301100356	1.817	0.005	170.62	0.0	0.000
1254737	158993	3301100423	1.977	0.217	199.63		
1251493	151452	3301100452	1.634	0.048	120.06	0.0	0.000
1255263	151907	3301100458	1.389	0.000	8.12	74.2	0.654
1259006	157371	3301100819	1.060	0.613	86.16	95.0	0.524
1258348	159293	3301100865	0.812	0.000	75.77	49.5	0.464
1253880	156077	3301100940					
1283178	124373	3301100182	0.691	0.620	26.28	52.7	0.944

It is recommended to construct a database of geologic tops related to depositional setting. These data are obtained from well logs. An example data file of geologic tops related to depositional setting is shown in Figure 68.

Figure 68. An example data file of geologic tops related to depositional setting.

EAST FT	NORTH FT	WELL API NO.	Red River Depth	A Zone Depth	B Zone Depth	C Zone Depth	D Zone Depth	Base Depth
1212611	154710	3301100198	-6216	-6225	-6256	-6306	-6398	-6443
1214184	150850	3301100258	-6217	-6226	-6255	-6303	-6385	-6434
1214039	147068	3301100259	-6189	-6198	-6225	-6271	-6363	-6411
1212821	149427	3301100262	-6202	-6213	-6241	-6284	-6380	-6427
1212031	153869	3301100305	-6218	-6227	-6258	-6305	-6398	-6445
1213827	150045	3301100311	-6186	-6194	-6222	-6267	-6366	-6400
1207014	152537	3301100339	-6250	-6259	-6290	-6336	-6429	-6476
1215767	142373	3301100343	-6204	-6214	-6243	-6293	-6387	-6435
1212374	144767	3301100432	-6179	-6188	-6217	-6265	-6359	-6407
1212474	145067	3301100488	-6189	-6199	-6229	-6277	-6369	-6418
1211646	144209	3301100915	-6192	-6202	-6231	-6277	-6370	-6418
1257953	158110	3301100195	-6401	-6407	-6443	-6487	-6586	-6623
1254615	155311	3301100200	-6472	-6481	-6514	-6558	-6652	-6699
1257096	151448	3301100208	-6436	-6442	-6476	-6522	-6616	-6662
1257814	154290	3301100254	-6496	-6505	-6537	-6588	-6683	-6734
1251775	148752	3301100297	-6446	-6455	-6488	-6533	-6627	-6675
1252062	153191	3301100356	-6475	-6482	-6517	-6565	-6660	-6709
1254737	158993	3301100423	-6500	-6509	-6543	-6594	-6690	-6740
1251493	151452	3301100452	-6465	-6473	-6508	-6555	-6653	-6701

For evaluation of structure and growth history, a database should be constructed from well logs that contains sub-sea depths to important geologic formations. An example data file of geologic tops related to structural growth is shown in Figure 69.

Figure 69. An example data file of geologic tops related to structural growth.

EAST FT	NORTH FT	WELL API NO.	Kn Depth	Kmo Depth	Km Depth	Mmc Depth	Si Depth	Orr Depth
1212611	154710	3301100198	-158	-1233	-3298	-4476	-5706	-6216
1214039	147068	3301100259	-128	-1234	-3281	-4442	-5677	-6189
1212821	149427	3301100262	-135	-1232	-3269	-4455	-5698	-6202
1212031	153869	3301100305	-152	-1233	-3301	-4478	-5714	-6218
1213827	150045	3301100311	-144	-1247	-3263	-4446	-5676	-6186
1207014	152537	3301100339	-130	-1236	-3352	-4487	-5723	-6250
1215767	142373	3301100343	-144	-1268	-3262	-4447	-5680	-6204
1212374	144767	3301100432	-127	-1246	-3252	-4426	-5662	-6179
1212474	145067	3301100488	-130	-1236	-3267	-4439	-5668	-6189
1211646	144209	3301100915	-140	-1249	-3262	-4440	-5672	-6192
1257953	158110	3301100195	-274	-1335	-3296	-4528	-5834	-6401
1254615	155311	3301100200	-275	-1347	-3325	-4558	-5868	-6472
1257096	151448	3301100208	-278	-1342	-3301	-4531	-5852	-6436
1257814	154290	3301100254	-287	-1349	-3319	-4567	-5895	-6496
1251775	148752	3301100297	-269	-1330	-3312	-4533	-5846	-6446
1252062	153191	3301100356	-276	-1339	-3305	-4557	-5864	-6475
1254737	158993	3301100423	-279	-1348	-3388	-4572	-5895	-6500
1251493	151452	3301100452	-270	-1325	-3312	-4546	-5859	-6465
1255263	151907	3301100458	-272	-1341	-3310	-4532	-5858	-6455
1259006	157371	3301100819	-272	-1334	-3308	-4539	-5852	-6433
1258348	159293	3301100865	-279	-1340	-3303	-4543	-5864	-6454

A database of seismic attributes that are (or could be) related to reservoir variation should be constructed from exported files from seismic interpretation software. Such a file is shown in Figure 70.

Figure 70. An example data file of seismic attributes related to the reservoir objective.

EAST FT	NORTH FT	P1max Amplitude	T1min Amplitude	P2max Amplitude	P1-Owiz msec	T1-Owiz msec	P2-Owiz msec
1216902	153434	6448	-2981	5018	64	57	37
1216455	152997	5203	-3072	4325	62	56	40
1216902	152997	6596	-2643	4337	63	57	38
1216455	153434	6003	-5684	6791	63	58	38
1216455	153872	5075	-5896	6688	65	57	39
1216455	154310	6344	-6037	7764	64	58	41
1216009	151683	7162	-7228	5456	63	56	38
1216902	152559	6827	-4617	6755	65	58	40
1216009	152997	6640	-4657	4144	65	59	40
1216902	152121	5004	-4457	6181	64	57	39
1216009	152121	6358	-8845	7009	66	59	38
1216455	151683	7173	-6478	4800	63	56	38
1216455	152121	4778	-9348	6518	64	57	39
1216009	152559	6987	-7869	5809	61	56	39
1216455	152559	5886	-7840	5346	63	57	40
1214668	157374	8032	-4073	7298	64	56	37
1216902	151683	5088	-2911	5653	62	55	36
1216009	153434	5240	-9732	6367	64	58	39
1216009	153872	6019	-6218	7329	64	58	39

For evaluation of structure and growth history, a database should be constructed from seismic that contains reflection time at important geologic formations. These data are exported files from seismic interpretation software. An example data file of seismic time picks related to structural growth is shown in Figure 71.

Figure 71. An example data file of seismic time picks at important geologic horizons.

EAST FT	NORTH FT	Ke msec	Kn msec	Kgh msec	Mmc msec	Orr msec	Owi msec
1207727	148819	635	854	984	1612	1803	1859
1206414	148488	636	855	983	1610	1803	1859
1209040	148488	636	852	982	1613	1801	1857
1206414	148819	636	856	984	1613	1804	1859
1206742	148488	636	854	982	1609	1803	1859
1207070	149482	637	856	987	1617	1805	1860
1208055	148819	637	852	983	1614	1802	1858
1210025	144847	637	857	988	1613	1800	1856
1211338	145840	637	854	987	1612	1799	1855
1207727	148488	637	853	984	1612	1802	1859
1206742	148157	637	854	983	1608	1803	1859
1207070	148157	638	854	983	1608	1803	1859
1207398	148819	638	855	985	1616	1804	1860
1207398	148157	638	853	984	1610	1803	1860
1208712	148819	638	853	983	1614	1802	1857
1209040	148157	638	852	982	1613	1799	1856
1210025	147164	638	853	984	1611	1800	1856
1210353	146171	638	852	983	1610	1799	1855
1210025	144516	638	855	990	1613	1800	1856
1205757	152792	638	855	983	1619	1807	1864
1208712	149482	638	854	985	1617	1804	1859
1207070	149150	638	855	985	1616	1805	1861

Getting Started

It is recommended to start with a 3D seismic data set and use the Cluster 3 tool. A simple seismic data set would consist of two-way travel time and interval time at major seismic reflectors or important geological horizons. Cluster 3 requires no well data as it produces natural or intrinsic clusters without correlation to any reservoir or physical property.

After producing cluster maps with time and interval time, proceed to experimenting, again with Cluster 3, with seismic attributes (such as amplitude) at the reservoir objective.

Next, create a file to use with the Cluster 1 tool. Start simple and use two-way travel time at major seismic reflectors as the independent data. Make a file of geologic intervals (corresponding to the seismic reflectors) from well logs (dependent data) that are available within the 3D seismic survey area. Merge the two files after the seismic two-way travel time has been supplied for the well locations. Create cluster maps for seismic two-way travel time and interval thickness from well logs. Observe which seismic time intervals correlate best with well-log interval thickness. Compare cluster maps from Cluster 1 to those produced by Cluster 3.

After becoming comfortable with Cluster 1, begin experimenting with the Cluster 2 tool. Make a dependent-data file of simple reservoir properties from the wells located within the 3D seismic survey. Include reservoir properties such as thickness, porosity-thickness and average porosity. Create an independent-data file from simple seismic information such as maximum peak and minimum trough amplitudes near the reservoir objective. Merge the two files after the seismic information has been supplied for the well locations. Create cluster maps for seismic information and reservoir properties from well logs. Observe which seismic attributes correlate best with reservoir properties. Compare cluster maps from Cluster 2 to those produced by Cluster 3.

Following a few sessions with the clustering tools, it is suggested to work with the Entrapment Tool. The Entrapment tool requires familiarity with output created by Cluster 1 and Cluster 2 tools.

The next step is to use the neural solvers. If the suggested steps described above are followed, the user should acquire a better understanding of the independent seismic data and relationships with the dependent well data. Successful use of the neural solvers, in most reservoir characterization problems, involves selecting or screening data that probably have a high correlation to the reservoir attribute or objective. This is especially necessary when the control or well population is small. It some cases, the well population may be too small for using neural solvers.

After using different techniques and data sets to make predictions for several reservoir characteristics, the user should develop a sense as to what factors are important and can be predicted for the reservoir. Once this is achieved, the user can combine these reservoir elements through application of three combining tools.

TUTORIALS

Example 1

In example 1, we will use data from a 3D seismic survey in Bowman County, North Dakota. The survey area has 9 wells for control. The example will emphasize clustering, as the clustering tools are robust and produce quick results with a small control population. We will make various cluster maps for depositional setting, porosity and structure. The output will be combined to produce a "Z" map or potential map. The practice files for example 1 are located under the directory \example_1\input_files\.

The first data set includes seismic attributes within the Upper Red River. A portion of this data file is shown in Figure 72

Figure 72. Portion of input data file 1 used in tutorial example 1.

east	north	P1amp_norm	T1amp_norm	P2amp_norm	T2amp_norm	P1max-Owiz_n	T1z-Owiz_norm	T1min-Owiz_nc	P2max-Owiz_n	T2min-Owiz_nc
1211646	144209	1.31120	-1.07060	1.15990	-0.40780	0.53910	0.52360	0.56370	0.53650	0.43150
1212474	145067	0.92050	-0.76770	0.70980	-0.27930	0.50350	0.45110	0.65560	0.59370	0.41790
1212374	144767	1.01780	-0.92930	0.80690	-0.32100	0.53460	0.50970	0.55100	0.52270	0.40470
1215767	142373	1.18840	-0.94600	0.79960	-0.23520	0.55440	0.53100	0.54830	0.33240	0.45990
1207014	152537	1.11600	-1.10620	0.81000	-0.02200	0.33260	0.28620	0.21850	0.34990	0.52990
1213827	150045	0.73520	-0.31820	0.59680	-0.21650	0.18330	0.09050	0.52450	0.56800	0.33370
1212031	153869	0.90270	-0.56280	0.86150	-0.20400	0.55940	0.49150	0.57730	0.49850	0.42030
1212821	149427	1.04380	-0.24690	0.49140	-0.10180	0.54140	0.34090	0.56100	0.35590	0.36430
1214039	147068	0.85860	-0.55220	0.65220	-0.07130	0.47180	0.48380	0.48260	0.40910	0.45650
1214184	150850	0.58930	-0.36430	0.62930	0.12660	0.38940	0.21150	0.33200	0.09840	0.24210
1212611	154710	0.76230	-0.63470	0.69910	-0.32530	0.41480	0.34250	0.44840	0.31220	0.37480
1208412	146869	1.24110	-0.53320	0.43900	-0.22670	0.57260	0.65670	0.72680	0.91660	1.00000
1208412	146431	0.84210	-0.30020	0.74640	-0.32580	0.59210	0.60990	0.61450	0.81390	1.00000
1208859	146869	0.87420	-0.76480	0.59090	0.07390	0.53090	0.71170	0.68650	0.96500	1.00000
1208859	146431	0.77810	-0.16070	0.65290	-0.51620	0.70520	0.70830	0.55980	0.86200	1.00000
1208412	147306	1.14520	-0.60710	0.79840	-0.11120	0.60970	0.70940	0.72350	0.86870	0.87720
1212880	145118	1.24240	-0.97770	0.79310	-0.57290	0.39450	0.55290	0.55790	0.66460	0.58480
1208859	145993	0.58930	-0.21920	0.98340	-0.70720	0.63910	0.62900	0.52500	0.71990	0.94050
1213774	147306	0.78400	-0.60040	0.51000	-0.18820	0.48110	0.50630	0.42490	0.47100	0.57090
1214668	147744	0.83830	-0.98010	0.74950	-0.28210	0.40330	0.42990	0.56820	0.46150	0.55720
1209305	145993	0.68860	-0.31420	0.79540	-0.67800	0.79690	0.90950	0.74740	0.87170	0.88500
1213327	147306	0.83280	-0.50590	0.83570	-0.31960	0.55460	0.50570	0.84560	0.87430	0.47060
1214221	146431	1.31390	-1.38410	1.10610	-0.66490	0.54810	0.54980	0.43240	0.36770	0.27250
1213774	146869	0.94250	-0.62930	0.90390	-0.10060	0.60300	0.62560	0.72570	0.60110	0.45580
1213327	146869	0.80850	-0.62840	0.76090	0.05200	0.60630	0.64260	0.76840	0.74650	0.69060
1213774	146431	1.05540	-0.93210	1.04020	-0.43610	0.52590	0.47470	0.40730	0.30980	0.31560
1209752	147306	1.03640	-1.01930	1.01190	-0.18770	0.54550	0.70120	0.66390	0.67560	0.68820
1209752	146431	0.85290	-0.16070	0.92570	-0.53450	0.76800	0.82190	0.90080	0.71990	0.60060
1210646	143805	1.15870	-0.89860	0.87970	-0.76390	0.58210	0.55300	0.56080	0.56710	0.43820
1211540	145118	1.16530	-0.92360	1.14060	-0.34310	0.55060	0.61490	0.50550	0.55450	0.51410
1212880	146431	1.12340	-0.69130	0.80470	-0.27740	0.51560	0.60210	0.62090	0.63480	0.55750
1211540	145556	0.91070	-0.62440	1.06190	-0.26310	0.60950	0.53030	0.44710	0.53030	0.49250
1210199	147306	0.99430	-0.58630	1.03550	-0.34380	0.50680	0.49100	0.45050	0.56410	0.64040
1213774	147744	0.77620	-0.46680	0.62720	-0.36460	0.42110	0.35710	0.47500	0.43050	0.32640

Data file, "data_set_01.csv", contains coordinates in the first two columns. Columns 3 through 6 contain amplitude attributes. Columns 7 through 11 contain isochron data. These seismic attributes were found to respond to variation of Red River development from seismic modeling and empirical observation. The first step is to cluster these data with Cluster 3 tool. This tool will produce from 2 to 10 clusters. Since the data are not correlated with any well data, this tool produces natural clusters. The patterns that are produced will represent areas that are seismically similar. Examples of maps produced by the Cluster 3 Tool are shown in Figures 73 , 74 and 75.

Figure 73. A map created by Cluster 3 with 9 cluster groups for seismic attributes used in example 1.

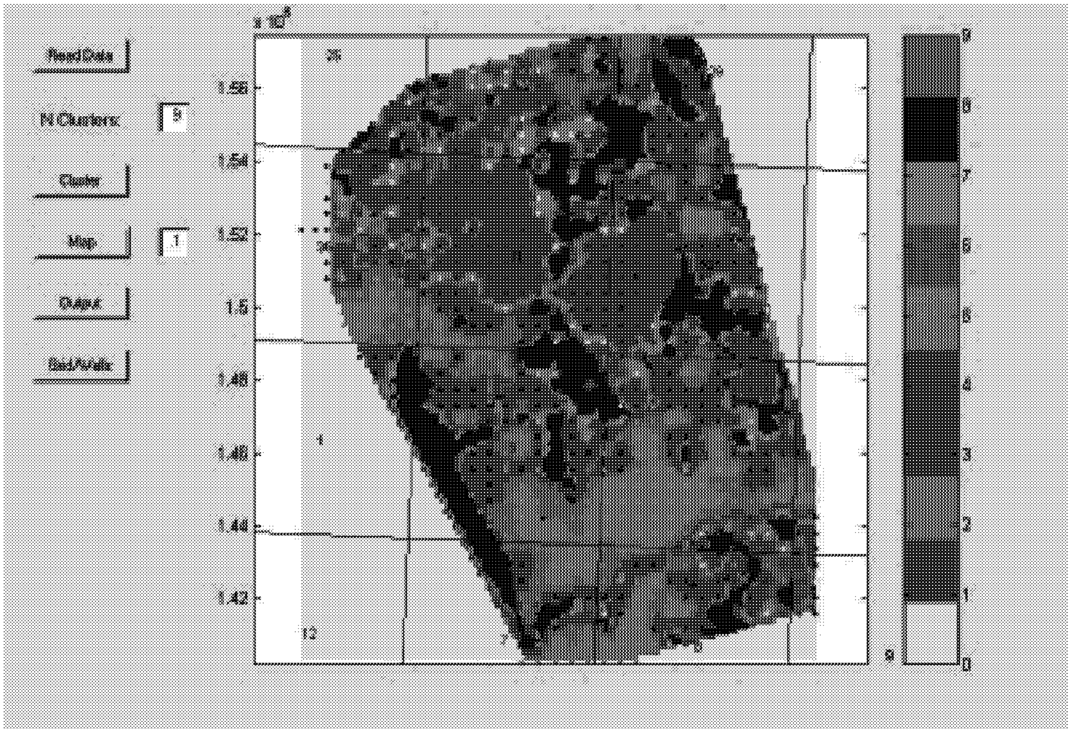


Figure 74. A map created by Cluster 3 with 6 cluster groups for seismic attributes used in example 1.

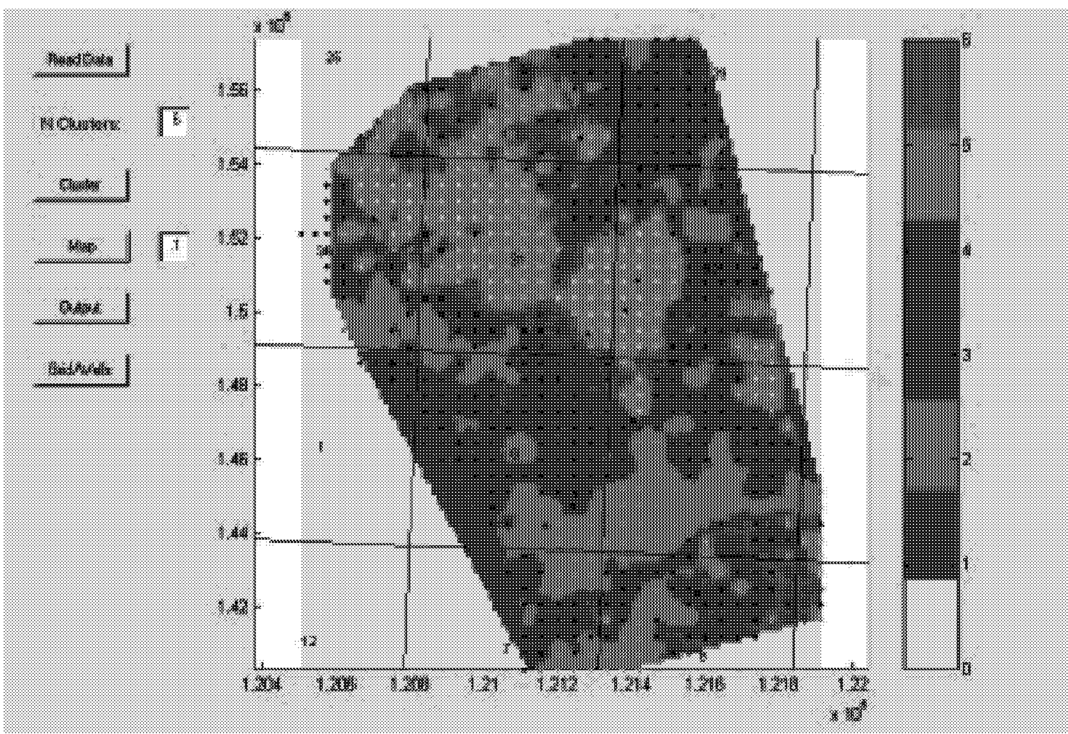
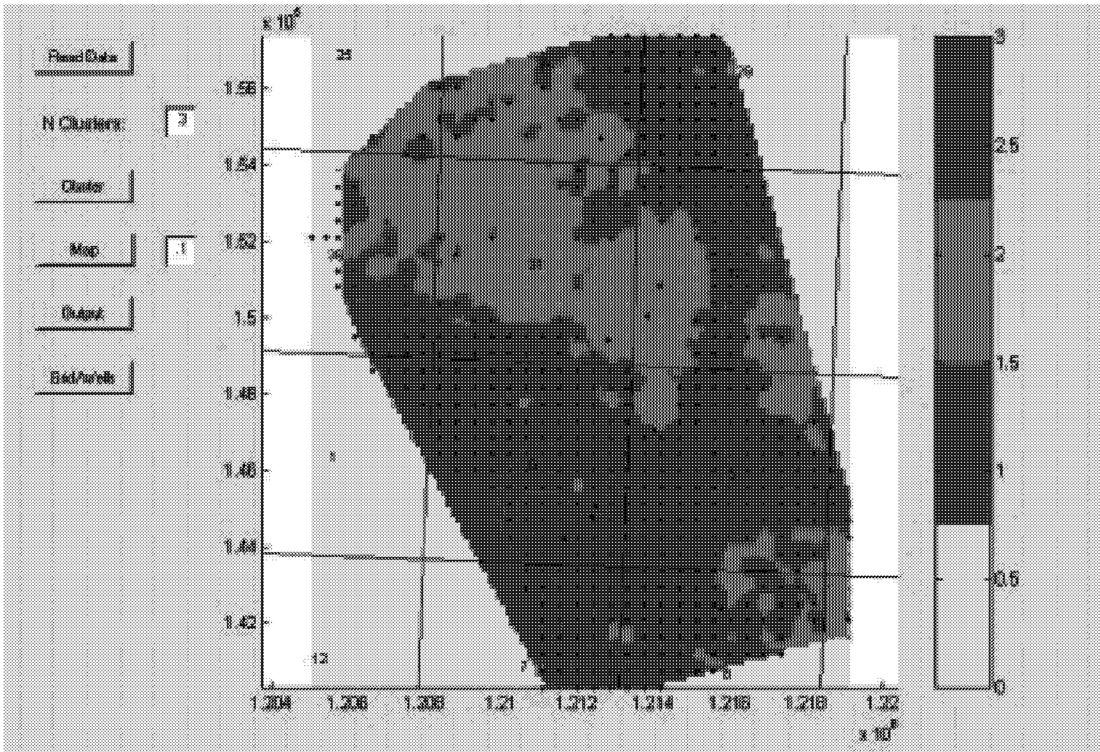


Figure 75. A map created by Cluster 3 with 3 cluster groups for seismic attributes used in example 1.



Changing the number of clusters will give the user a feel for the dominant clusters. The different cluster areas are related to changes in thickness and impedance. They are also probably related to reservoir heterogeneity. The cluster maps do not provide us information about the reservoir. The cluster assignments are arbitrary and the order has no meaning.

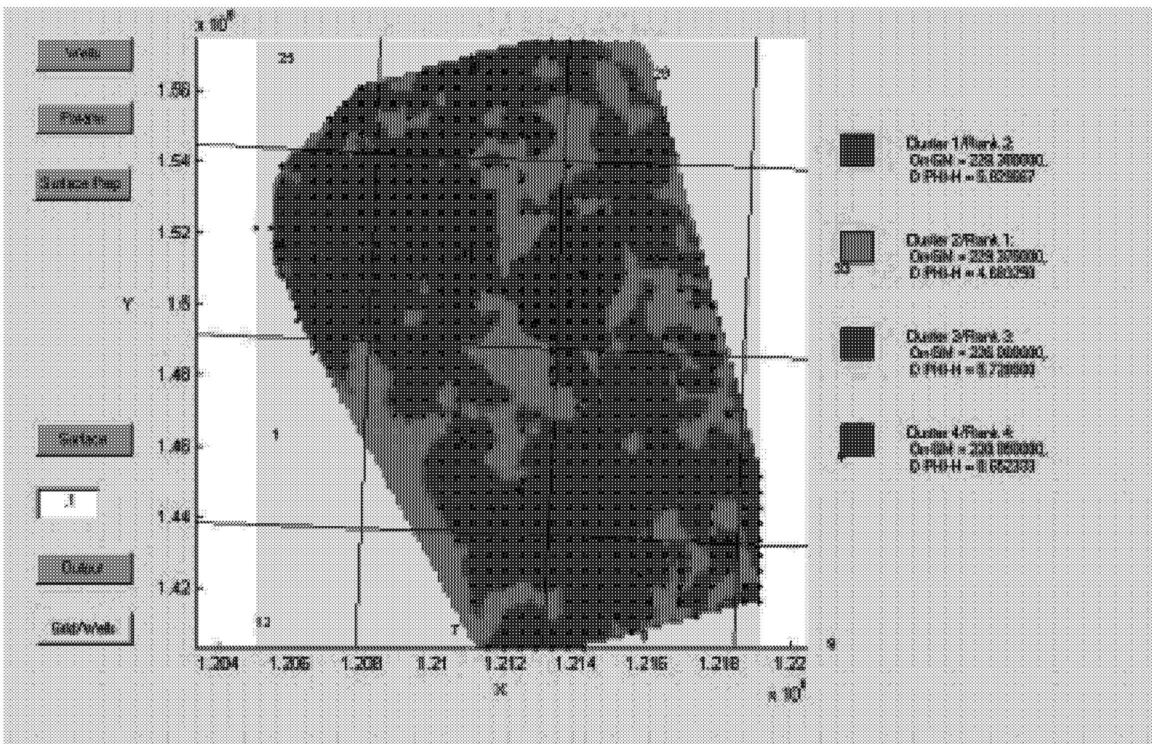
Reservoir attributes can be assigned to the seismic clusters with the Cluster 1 and 2 tools. We will do this with the Cluster 2 tool and use the same data as used previously except three columns are inserted before the independent seismic data. A portion of the input file for use with the Cluster 2 Tool is shown in Figure 76.

Figure 76. Portion of input data file 2 used in tutorial example 1.

east	north	API	Orr-GM	D PHI-H	P1amp_norm	T1amp_norm	P2amp_norm	T2amp_norm	P1max-Owiz_n	T1z-Owiz_norm	T1min-Owiz_nc	P2max-Owiz_n
1211646	144209	3301100915	226.0	5.729	1.31120	-1.07060	1.15990	-0.40780	0.53910	0.52360	0.56370	0.53650
1212474	145067	3301100488	228.5	7.679	0.92050	-0.76770	0.70980	-0.27930	0.50350	0.45110	0.65560	0.59370
1212374	144767	3301100432	228.0	7.931	1.01780	-0.92930	0.80690	-0.32100	0.53460	0.50970	0.55100	0.52270
1215767	142373	3301100343	230.8	6.404	1.18840	-0.94600	0.79960	-0.23520	0.55440	0.53100	0.54830	0.33240
1207014	152537	3301100339	226.1	3.155	1.11600	-1.10620	0.81000	-0.02200	0.33260	0.28620	0.21850	0.34990
1213827	150045	3301100311	213.6	0.000	0.73520	-0.31820	0.59680	-0.21650	0.18330	0.09050	0.52450	0.56800
1212031	153869	3301100305	227.2	0.512	0.90270	-0.56280	0.86150	-0.20400	0.55940	0.49150	0.57730	0.49850
1212821	149427	3301100262	225.2	1.058	1.04380	-0.24690	0.49140	-0.10180	0.54140	0.34090	0.56100	0.35590
1214039	147068	3301100259	221.8	2.543	0.85860	-0.55220	0.65220	-0.07130	0.47180	0.48380	0.48260	0.40910
1214184	150850	3301100258	216.9		0.58930	-0.36430	0.62930	0.12660	0.38940	0.21150	0.33200	0.09840
1212611	154710	3301100198	227.7	0.899	0.76230	-0.63470	0.69910	-0.32530	0.41480	0.34250	0.44840	0.31220
1208412	146869	99896			1.24110	-0.53320	0.43900	-0.22670	0.57260	0.65670	0.72680	0.91660
1208412	146431	99894			0.84210	-0.30020	0.74640	-0.32580	0.59210	0.60990	0.61450	0.81390
1208859	146869	99893			0.87420	-0.76480	0.59090	0.07390	0.53090	0.71170	0.68650	0.96500
1208859	146431	99892			0.77810	-0.16070	0.65290	-0.51620	0.70520	0.70830	0.55980	0.86200
1208412	147306	99891			1.14520	-0.60710	0.79840	-0.11120	0.60970	0.70940	0.72350	0.86870
1212880	145118	99890			1.24240	-0.97770	0.79310	-0.57290	0.39450	0.55290	0.55790	0.66460
1208859	145993	99889			0.58930	-0.21920	0.98340	-0.70720	0.63910	0.62900	0.52500	0.71990
1213774	147306	99887			0.78400	-0.60040	0.51000	-0.18820	0.48110	0.50630	0.42490	0.47100
1214668	147744	99886			0.83830	-0.98010	0.74950	-0.28210	0.40330	0.42990	0.56820	0.46150
1209305	145993	99885			0.68860	-0.31420	0.79540	-0.67800	0.79690	0.90950	0.74740	0.87170
1213327	147306	99884			0.83280	-0.50590	0.83570	-0.31960	0.55460	0.50570	0.84560	0.87430
1214221	146431	99883			1.31390	-1.38410	1.10610	-0.66490	0.54810	0.54980	0.43240	0.36770
1213774	146869	99882			0.94250	-0.62930	0.90390	-0.10060	0.60300	0.62560	0.72570	0.60110

File "data_set_02.csv" provides information about the thickness of the upper Red River and porosity development in the D Zone. This file is imported into the Cluster 2 routine. Four cluster groups are created and ranked according to Upper Red River thickness. The output map is shown in Figure 77.

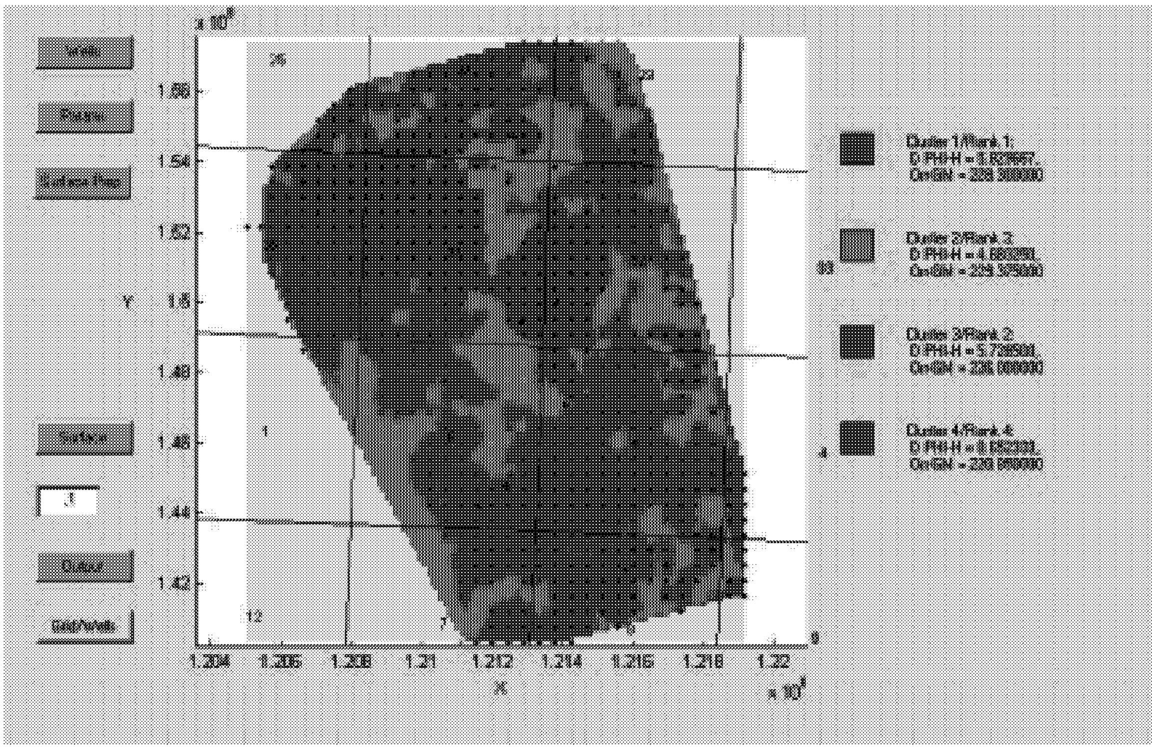
Figure 77. Cluster map created by Cluster 2 of Upper Red River thickness from seismic attributes used in example 1.



The cluster results are output to file named "data_set_02_dump.csv"

Similarly, "data_set_03.csv" is processed with Cluster 2. Four cluster groups are created and ranked according to Red River D Zone porosity-thickness. Figure 78 shows the resulting cluster map.

Figure 78. Cluster map created by Cluster 2 of Red River D Zone porosity-thickness from seismic attributes used in example 1.



The cluster results are output to file named "data_set_03_dump.csv"

We have now created two files that represent a correlation with seismic attributes for depositional setting and porosity. The cluster maps created with Cluster 2 should be compared to those created with Cluster 3. By doing so, it should be apparent that the areas of similar natural clusters have meaningful relationships with Red River reservoir development.

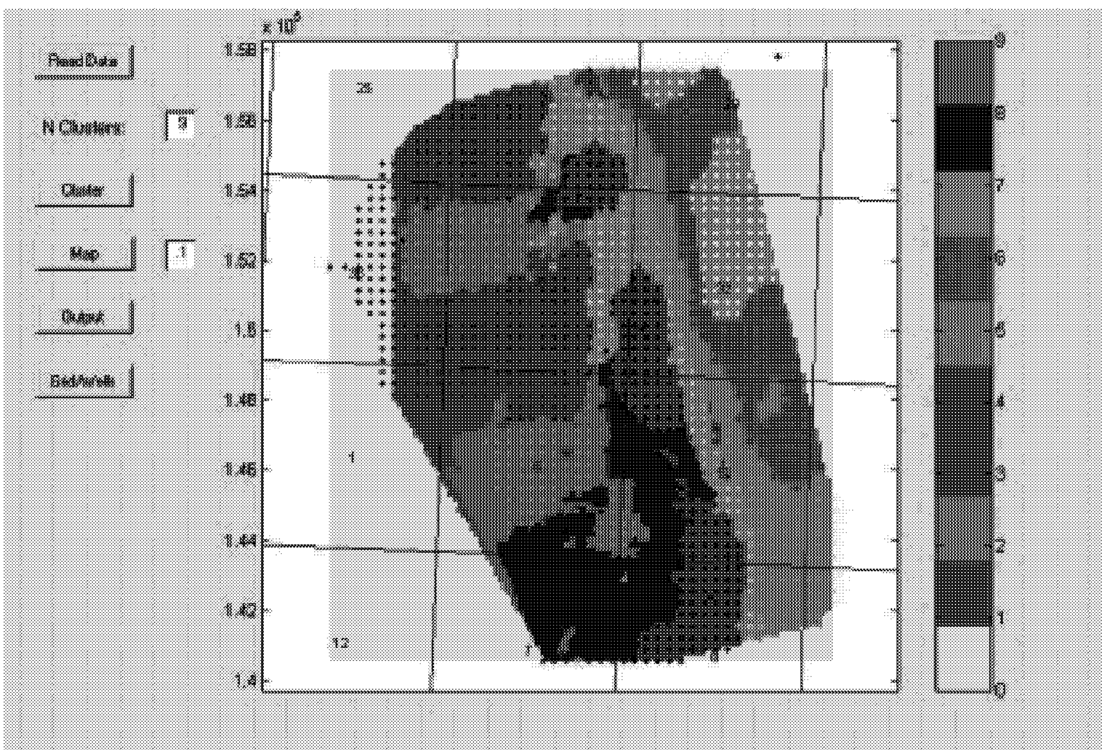
Data file "data_ set_04.csv" contains seismic time and interval picks for 9 events from the Cretaceous through Ordovician. A portion of this file is shown in Figure 79.

Figure 79. Portion of input data file 4 used in tutorial example 1.

x	y	Ke_time	Kn_time	Kgh_time	Kmo_time	Mk_time	Mmc_time	Dtf_time	T1z_time	Owiz_time
1205757	150806	643	858	989	1116	1552	1620	1708	1807	1863
1205757	151137	644	859	989	1113	1552	1621	1708	1808	1863
1205757	151468	643	858	988	1112	1551	1620	1709	1808	1863
1205757	151799	642	857	987	1112	1551	1618	1711	1809	1862
1205757	152130	640	857	986	1110	1548	1618	1711	1809	1863
1205757	152461	639	857	985	1111	1551	1619	1709	1808	1864
1205757	152792	638	855	983	1113	1551	1619	1711	1807	1864
1205757	153123	638	855	984	1114	1551	1619	1715	1807	1863
1205757	153454	641	856	984	1114	1544	1620	1711	1807	1862
1205357	151799	642	857	987	1112	1551	1618	1711	1809	1862
1204957	151799	642	857	987	1112	1551	1618	1711	1809	1862
1206085	150475	642	858	990	1117	1552	1619	1706	1807	1862
1206085	150806	642	858	990	1116	1551	1619	1708	1807	1863
1206085	151137	643	859	989	1114	1551	1620	1709	1808	1863
1206085	151468	642	858	988	1113	1553	1620	1708	1808	1862
1206085	151799	640	857	987	1113	1552	1619	1710	1808	1862
1206085	152130	641	855	986	1112	1550	1620	1713	1807	1861
1206085	152461	641	855	983	1116	1546	1618	1713	1807	1862

We will use "data_set_04.csv" data to describe structure and structural growth. Cluster 3 is used to produce natural clusters of the seismic time and intervals. A map of 9 cluster groups is shown in Figure 80. These clusters represent patterns of structure and growth that occurred between Ordovician and Cretaceous time.

Figure 80. A map created by Cluster 3 with 9 cluster groups for seismic time used in example 1.



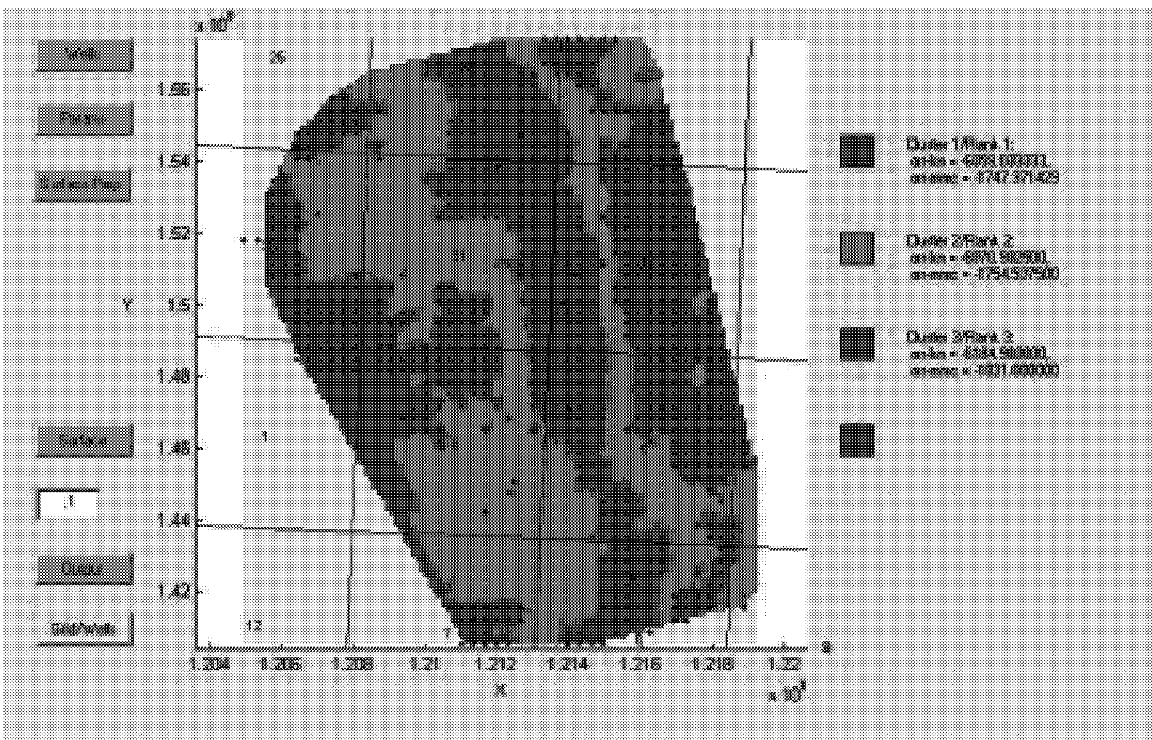
We will now assign some geological and engineering meaning to these natural patterns. Data file "data_set_05.csv" contains the same information as "data_set_04.csv" except that well information is inserted in columns 3 through 5 (Figure 81). The well information is the thickness between the Red River, Niobrara and Mission Canyon.

Figure 81. Portion of input data file 5 used in tutorial example 1.

x	y	API	orr-kn	orr-mmc	Ke	Kn	Kgh	Kmo	Mk	Mmc	Dtf	T1z	Owiz
1212611	154710	3301100198	-6058	-1740	655	862	993	1118	1551	1618	1711	1802	1855
1212031	153869	3301100305	-6066	-1740	652	862	992	1117	1552	1616	1709	1799	1854
1213827	150045	3301100311	-6042	-1741	656	862	995	1123	1559	1620	1714	1806	1857
1214039	147068	3301100259	-6061	-1747	652	859	989	1117	1547	1611	1705	1797	1852
1212821	149427	3301100262	-6067	-1747	652	859	991	1120	1554	1618	1713	1805	1858
1212474	145067	3301100488	-6059	-1751	645	855	989	1118	1546	1612	1707	1799	1854
1211646	144209	3301100915	-6052	-1752	642	856	993	1118	1548	1613	1708	1799	1854
1212374	144767	3301100432	-6052	-1753	643	854	990	1117	1547	1612	1707	1798	1853
1215767	142373	3301100343	-6060	-1757	652	863	997	1126	1553	1615	1713	1801	1856
1214184	150850	3301100258		-1759	660	864	996	1125	1561	1623	1713	1807	1859
1207014	152537	3301100339	-6120	-1762	643	855	984	1117	1551	1614	1703	1803	1856
1216262	152792	95	-6185	-1831	666	872	1005	1129	1568	1635	1738	1831	1888
1207727	148819	1555			635	854	984	1112	1545	1612	1708	1803	1859
1206414	148488	1554			636	855	983	1115	1541	1610	1710	1803	1859
1209040	148488	1553			636	852	982	1108	1554	1613	1708	1801	1857
1206414	148819	1552			636	856	984	1116	1544	1613	1712	1804	1859
1206742	148488	1551			636	854	982	1114	1539	1609	1709	1803	1859
1207070	149482	1550			637	856	987	1118	1551	1617	1715	1805	1860
1208055	148819	1549			637	852	983	1113	1548	1614	1710	1802	1858
1210025	144847	1548			637	857	988	1119	1552	1613	1706	1800	1856

Cluster1 is used with "data_set_5.csv" to produce three cluster groups, as shown in Figure 82. These cluster groups represent areas of similar structural growth history. The thinnest areas, with maximum growth, are ranked as 1.

Figure 82. Cluster map of Niobrara -Red River thickness from seismic time.



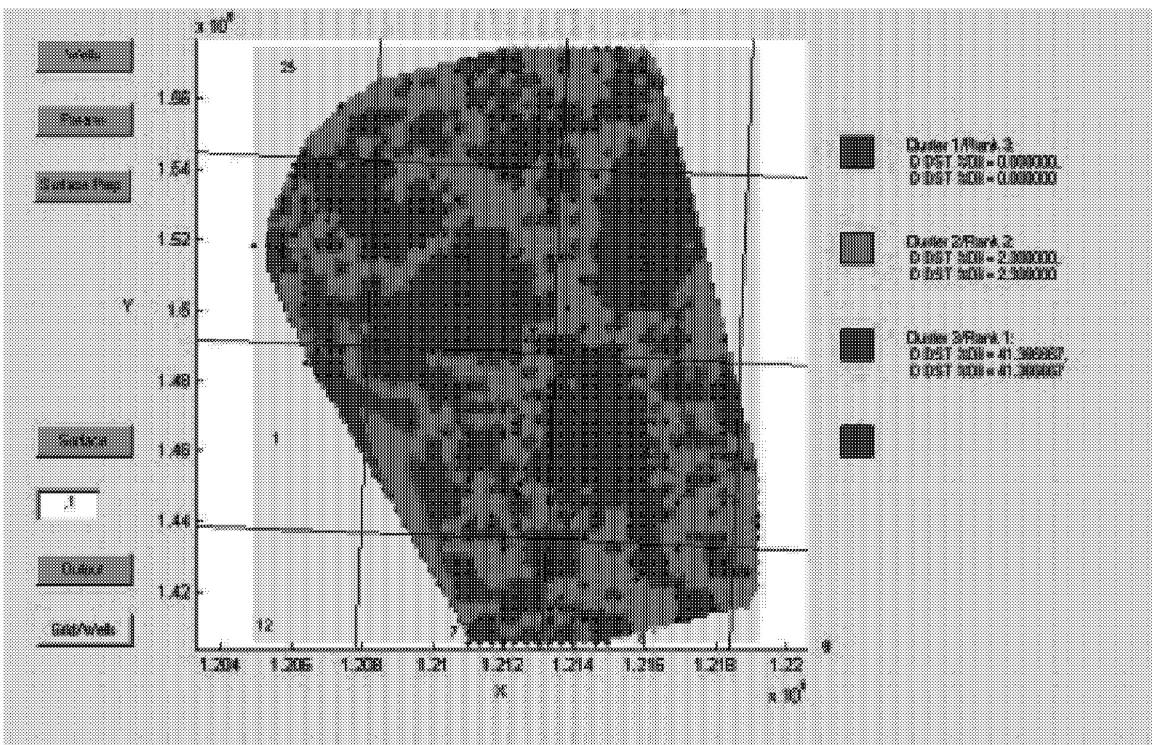
Note that the data file uses a negative value with the interval thickness in Figure 81. We want the greatest value to have a rank of one. An output file is saved to "data_set_05_ dump."

Figure 83. Portion of input data file 6 used in tutorial example 1.

x	y	API	D DST %Oil	D DST %Oil	Ke	Kn	Kgh	Kmo	Mk	Mmc	Dtf	T1z	Owiz
1211646	144209	3301100915	0	0	642	856	993	1118	1548	1613	1708	1799	1854
1212474	145067	3301100488			645	855	989	1118	1546	1612	1707	1799	1854
1212374	144767	3301100432	6.8	6.8	643	854	990	1117	1547	1612	1707	1798	1853
1215767	142373	3301100343	0	0	652	863	997	1126	1553	1615	1713	1801	1856
1207014	152537	3301100339	0	0	643	855	984	1117	1551	1614	1703	1803	1856
1213827	150045	3301100311			656	862	995	1123	1559	1620	1714	1806	1857
1212031	153869	3301100305	61.8	61.8	652	862	992	1117	1552	1616	1709	1799	1854
1212821	149427	3301100262			652	859	991	1120	1554	1618	1713	1805	1858
1214039	147068	3301100259	60	60	652	859	989	1117	1547	1611	1705	1797	1852
1214184	150850	3301100258	4.7	4.7	660	864	996	1125	1561	1623	1713	1807	1859
1212611	154710	3301100198	2.3	2.3	655	862	993	1118	1551	1618	1711	1802	1855
1207727	148819	1555			635	854	984	1112	1545	1612	1708	1803	1859
1206414	148488	1554			636	855	983	1115	1541	1610	1710	1803	1859
1209040	148488	1553			636	852	982	1108	1554	1613	1708	1801	1857
1206414	148819	1552			636	856	984	1116	1544	1613	1712	1804	1859

Data file "data_set_06.csv" will be used in the next step. A portion of this file is shown in Figure 83. This file contains the same seismic information as "data_set_05.csv." The well information is from oil-cut measured by drill-stem-tests. We will correlate structure and growth with oil-cut. A similar correlation exercise could use hydrocarbon saturation from well-log evaluations. Cluster 1 is used to create the three-cluster map that is shown in Figure 84.

Figure 84. Cluster map of D Zone oil-cut from seismic time.

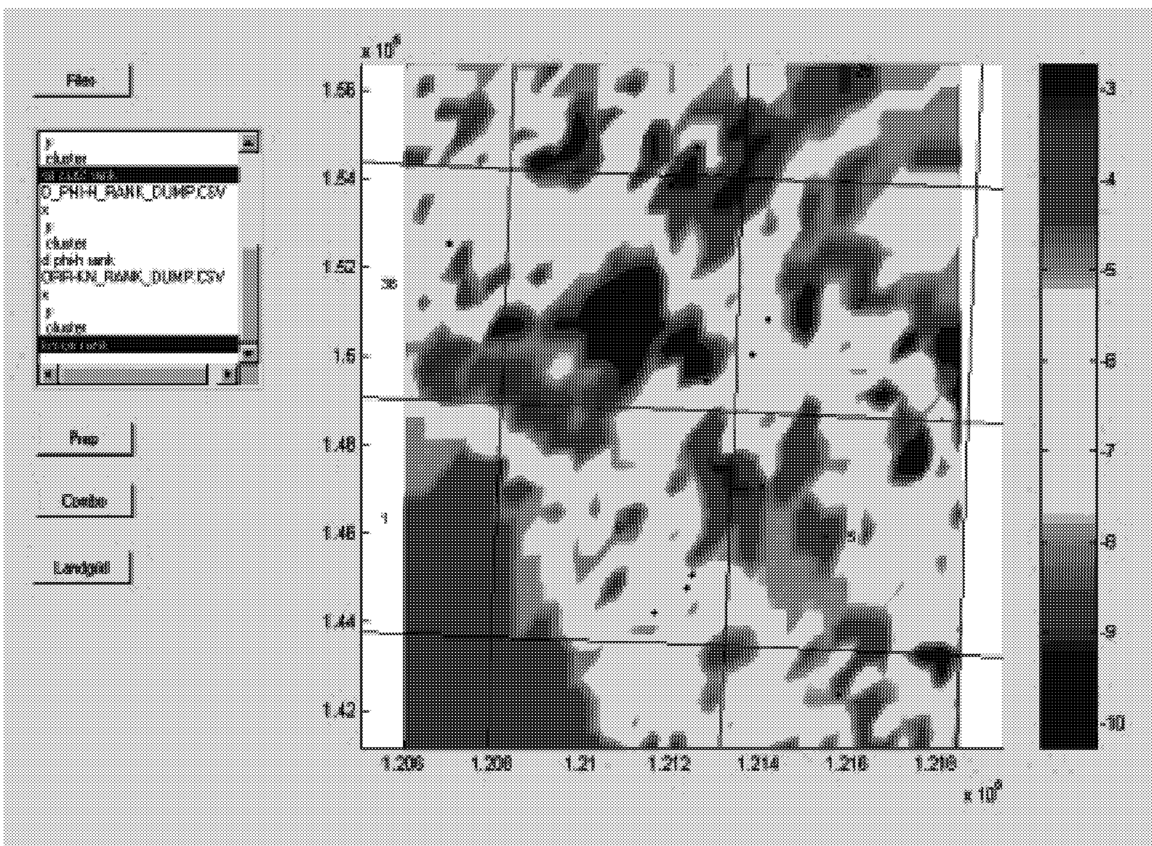


We have made a correlation of seismic interval times with measurements of reservoir fluid (oil-cut). Areas similar to those where oil was sampled by drill-stem-test are ranked as 1. An output file is created and saved as"data_set_06_dump."

The 3 output files (data_set_02_dump.csv, data_set_05_dump.csv and data_set_06_dump.csv) are next imported into the Manual Combine routine. The rank data columns are selected and the "data prepare" button is pressed. After processing the files, select a weight factor of 1 for each input file. The manual combine routine will multiply each rank by the user-supplied weights and sum the result at each node.

The map shown in Figure 85 is a display of the equal-weight summation from the 3 input files. The user should try different weights to observe changes in the "Z" or potential map. The "Z" map represents oil potential from the Red River D zone based on the 3 input criteria, structural growth for interval thickness, structural growth for oil-cut and depositional thickness. An important parameter that has not been assessed is present-day structure.

Figure 85. An example of a "Z" map produced by the Manual Combine Tool for example 1.



TUTORIALS

Example 2

In example 2, we will use the Entrapment routine. The Entrapment routine requires two files. The first file to be read is a depth file. The depth data must be in column 4. Also, the depth values decrease going down (sub sea format). The second file is a rank file produced by either Cluster 1 or Cluster 2. The rank file should characterize either rock quality or depositional setting. A rank of 1 is good and a rank of 4 is poor. The practice files for example 2 are located under the directory \example_2\input_files\.

Step 1. Call the Entrapment routine and press the "Files" button. Select file "data_set_21_knorr.csv" as a depth file. After the depth file is loaded, select file "data_set_23_rank.csv" as the rank file.

Step 2. Press the "Parameters" button. A new window is displayed. Change the capillary factor to 0.3. Press the "Apply" button and close the window.

Step 3. Press the "Depth" button.

Step 4. Press the "Rank" button.

Step 5. Press the "Pressure" button. The "Pressure" must be pressed after any changes are made in the "Parameters" window. Values are displayed for "azimuth and "angle." These describe a first-order trend through the pressure map.

Step 6. Press the "Residual Pressure" button. Press the "Flip Colors" button. The residual pressure map is the entrapment map. Negative pressure indicates a greater likelihood for oil entrapment. The zero-pressure contour can be thought of as the oil-water-contact. Pressure greater than zero will indicate a low entrapment potential.

Step 7. Press the "Output" button to export a file containing the computed residual pressures. Name the file " data_set_21_dump.csv."

Step 8. Experiment with changes to "azimuth" and "angle" values. Use small changes until you are comfortable with the results. Press the "residual Pressure" button again. Changing these parameters will tilt the residual pressure map. This option is intended as a means to study effects from hydrodynamic tilting.

Repeat the exercise with "data_set_22_orr.csv" as the depth file and "data_set_02_dump.csv" that was created in the example 1 exercise.

After the input files are loaded, depth and rank data can be displayed as shown in Figure 86 and Figure 87.

Figure 86. Display of depth file from Entrapment Tool used in example 2.

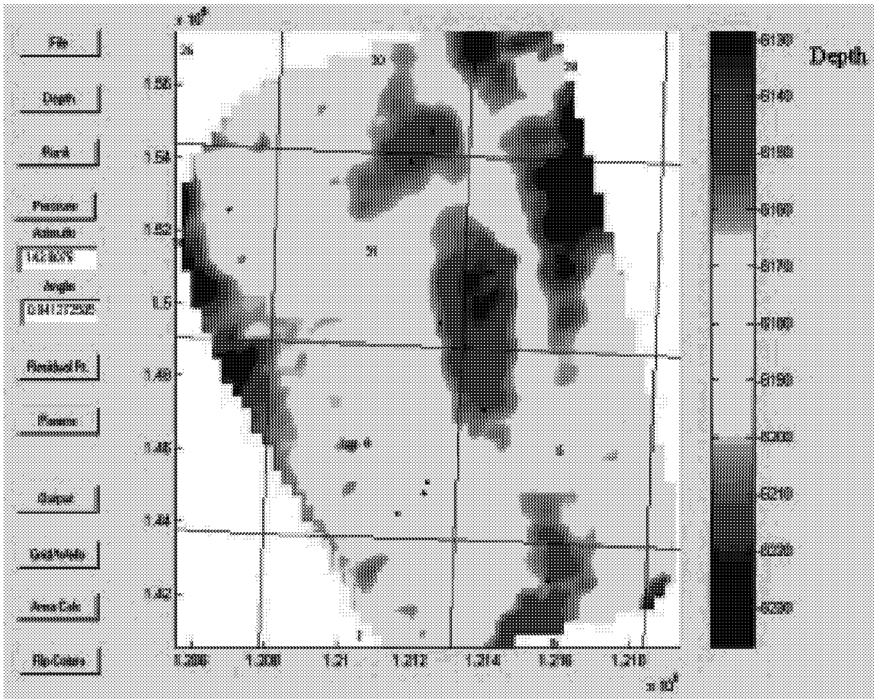
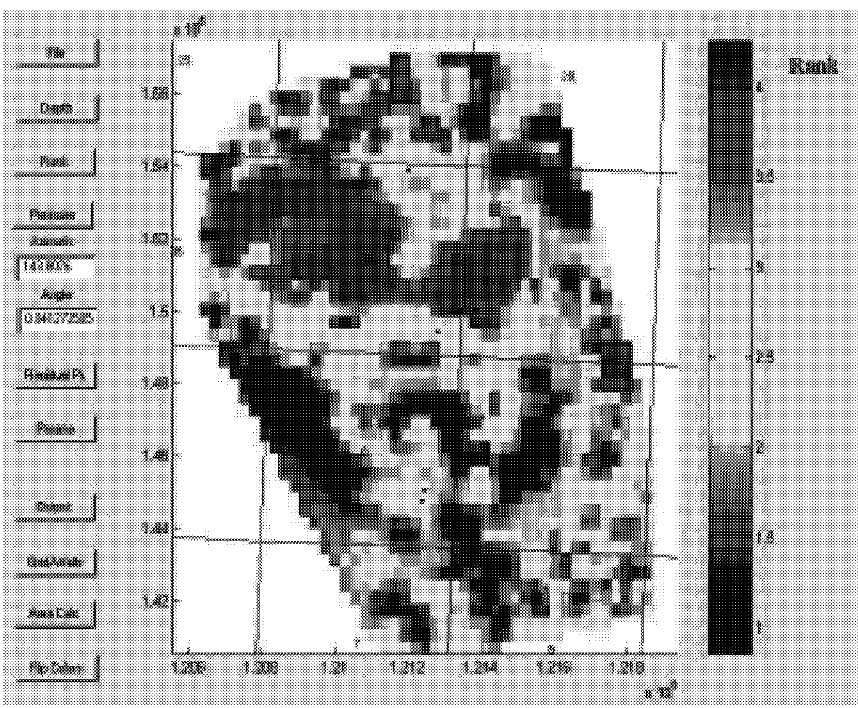


Figure 87. Display of rank file from Entrapment Tool used in example 2.



The parameters window should be completed as shown in Figure 88. After applying the parameters, a map of computed pressure can be displayed as shown in Figure 89.

Figure 88. Display of parameters window from Entrapment Tool used in example 2.

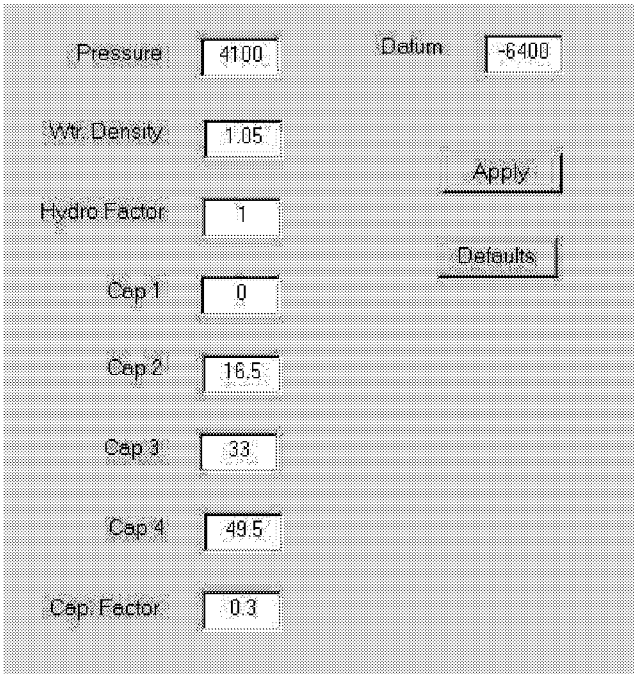
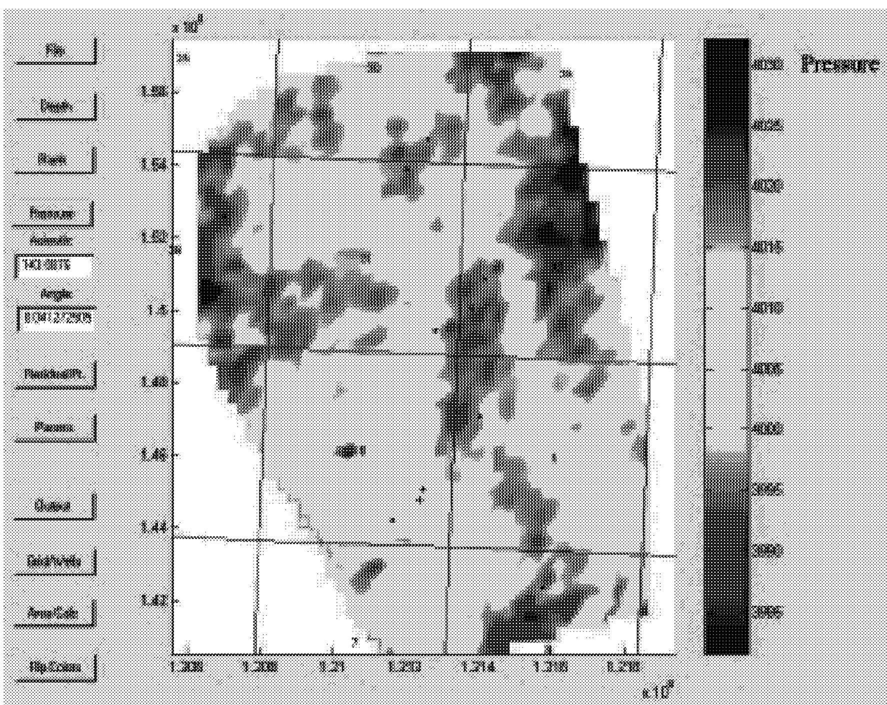


Figure 89. Display of computed pressure from Entrapment Tool used in example 2.



Displays of residual pressure for different capillary factors are shown in Figure 90 and Figure 91.

Figure 90. Display of computed residual pressure from Entrapment Tool used in example 2. Capillary factor set at 0.3.

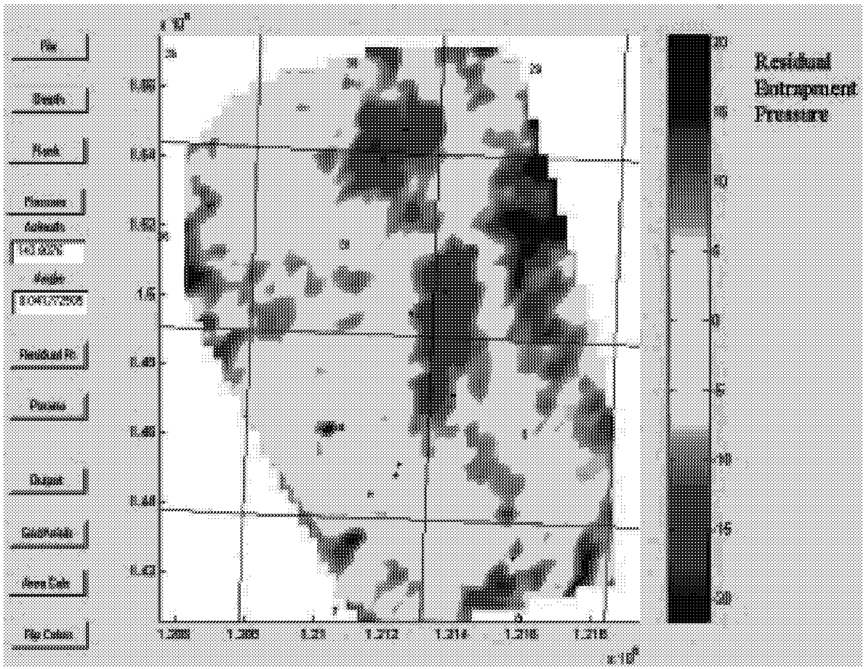
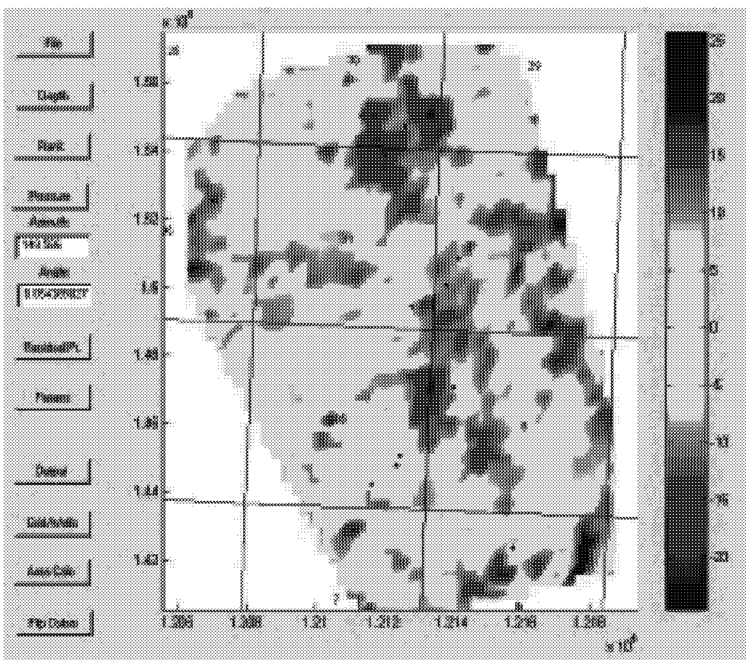


Figure 91. Display of computed residual pressure from Entrapment Tool used in example 2. Capillary factor set at 0.5.



Example 3

In example 3, we will use Neural Solver 2 to create a "Z" map. The ranking of the "Z" map will based on initial 24-month production. The independent data (input) will be from output files that are similar to those created in example 1 and example 2. In example 1, we created several cluster maps and output files. The cluster rank from those output files were used to create a "Z" map with Manual Combine Tool. In example 2, we created maps indicating entrapment potential and output files. The practice files for example 3 are located under the directory \example_3\input_files\.

The weights used in the Manual Combine Tool are subjective. Neural Solver 2 can apply objective weighting to those same files using some parameter of "goodness" from the well control. In this example, we will use production as a measure of "goodness." A portion of the objective file for example 2 is shown in Figure 92.

Figure 92. Objective file used by Neural Solver 2 in example 2.

east	north	WELL API	BOPD 24 mo	Log BOPD 24 mo	OIL CUT 24 mo
1214039	147068	3301100259	112.5	2.05	0.60
1212821	149427	3301100262	60.3	1.78	0.74
1212031	153869	3301100305	74.3	1.87	0.94
1213827	150045	3301100311	79.8	1.90	0.98
1207014	152537	3301100339	0.1	-1.00	0.09
1215767	142373	3301100343	14.3	1.16	0.41
1211646	144209	3301100915	20.0	1.30	0.50

The objective file for Neural Solver 2 contains information about the wells. The first row is reserved for labels. The first 2 columns are coordinates. Column 3 is a numeric well identifier. The following columns contain the dependent data. There is no limit to the number of columns and there can be blank cells in the dependent data.

We will import five independent data files. Three files were created by Cluster 2. Two files were created by Entrapment. Before these files can be used by Neural Solver 2, we must perform a modification to the files. Open each cluster output file in a spreadsheet program and sort by cluster. Delete all rows with a cluster and rank value of "0." Save the file in comma-separated-variable format. Open each entrapment output file in a spreadsheet program and sort by "residual pressure." Delete all rows with "NaN." Save the file in comma-separated-variable format. The files that are provided with this tutorial have already been processed in this manner. Examples of the input files for example 3 are shown in Figure 93 and Figure 94.

Figure 93. An example of a cluster output file where rows with cluster of "0" are to be deleted.

x	y	cluster	rank	mean 1	mean 2
1205730	140303	0	0	NaN	NaN
1205730	140446	0	0	NaN	NaN
1205730	140590	0	0	NaN	NaN
1205730	140733	0	0	NaN	NaN
1205730	140877	0	0	NaN	NaN
1205730	141020	0	0	NaN	NaN
1206068	149771	0	0	NaN	NaN
1206068	149914	3	2	0.884407	-0.864156
1206068	150058	3	2	0.884407	-0.864156
1206068	150201	3	2	0.884407	-0.864156
1206068	150345	4	3	0.857518	-0.805291
1206068	150488	4	3	0.857518	-0.805291
1206068	150631	3	2	0.884407	-0.864156

Figure 94. An example of an entrapment output file where rows with "NaN" are to be deleted.

x	y	residualpr.
1206306	147090	NaN
1206306	147434	NaN
1206306	147779	NaN
1206306	148124	NaN
1206306	148468	NaN
1206306	148813	NaN
1206306	149157	NaN
1206306	149502	NaN
1206306	149846	11.63
1206306	150191	9.61
1206306	150536	6.96
1206306	150880	9.15
1206306	151225	10.30
1206306	151569	8.67
1206306	151914	6.88
1206306	152258	6.94

Neural Solver 2 requires that the input files reside in separate directories. Place the independent data files in a directory such as c:\temp2 and the objective file in c:\temp2\objective. After the files have been prepared and placed in appropriate directories, we are ready to execute Neural Solver 2 and produce a "Z" map.

Step 1. Press the "input files" button. A window box will appear. Enter the path to the independent data files and close the window.

Step 2. Select the appropriate data columns from the input files with a ctrl-left click.

Step 3. Press the "objective file" button" and select the objective file.

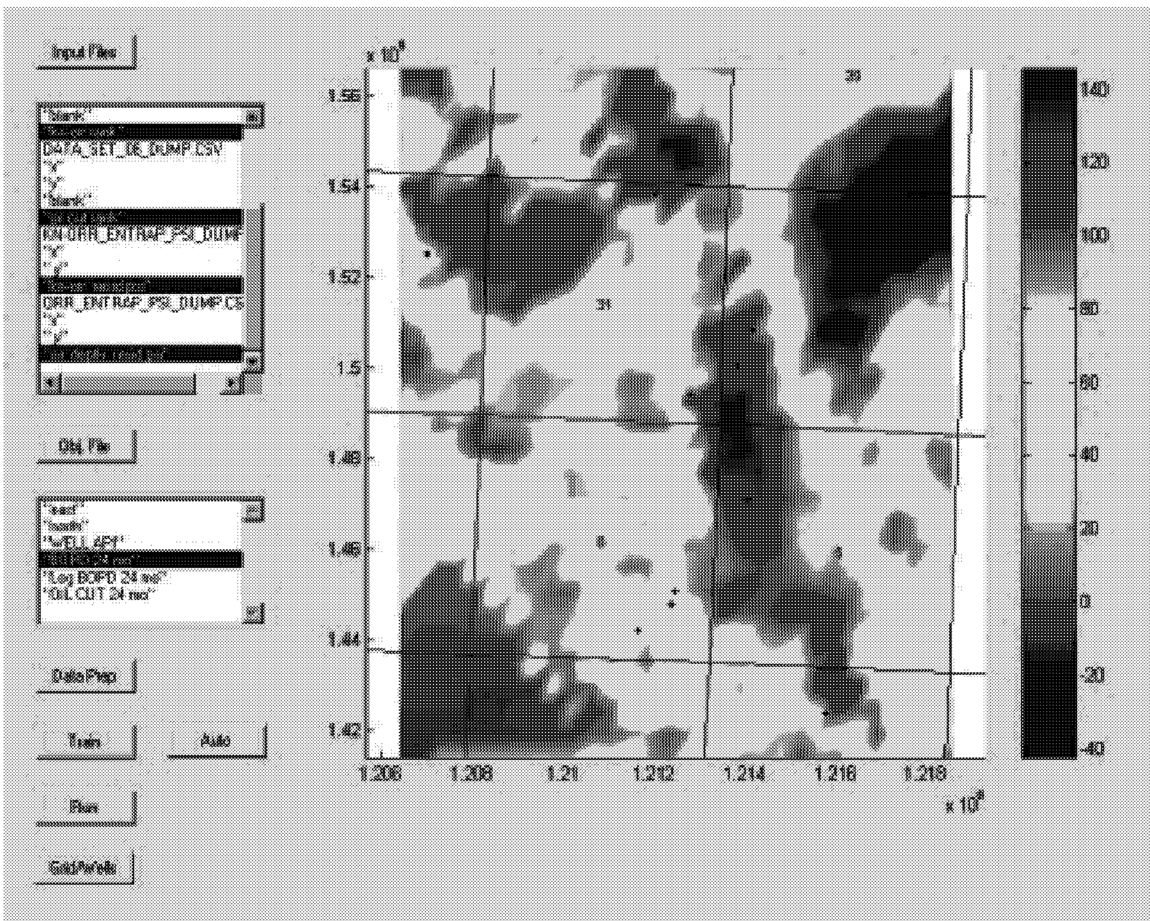
Step 4. Press the "data prepare" button. The program will overlay and merge the files. This process could take several minutes.

Step 5. Select an objective for training such as "BOPD 24 mo."

Step 6. Press the "train" button.

Step 7. Press the "run" button. A map will be created with values of the selected objective training column as shown in Figure 95.

Figure 95. A "Z" map of bopd from Neural Solver 2 used in example 3.

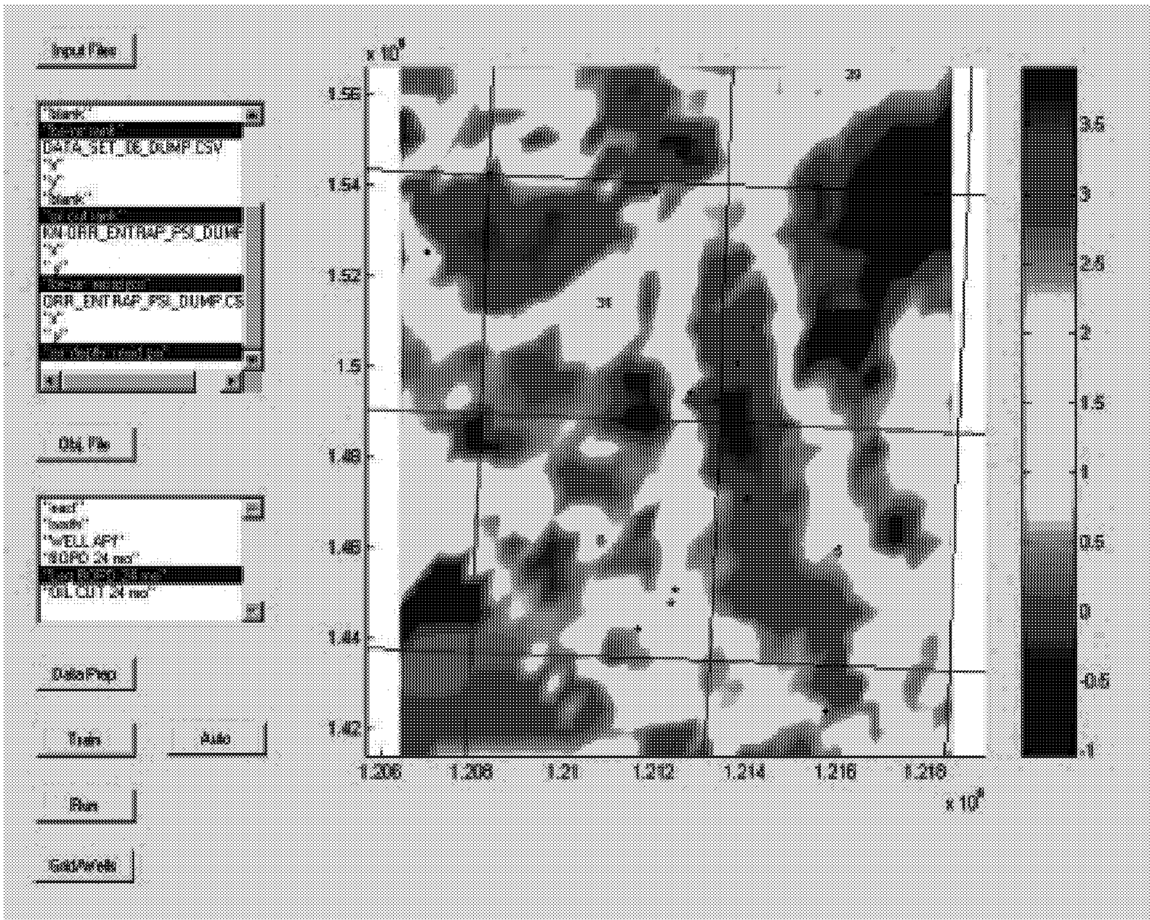


Step 8. Select an objective for training such as "Log BOPD 24 mo."

Step 9. Press the "train" button.

Step 10. Press the "run" button. A map will be created with values of the selected objective training column as shown in Figure 96.

Figure 96. A "Z" map of Log bopd from Neural Solver 2 used in example 3.

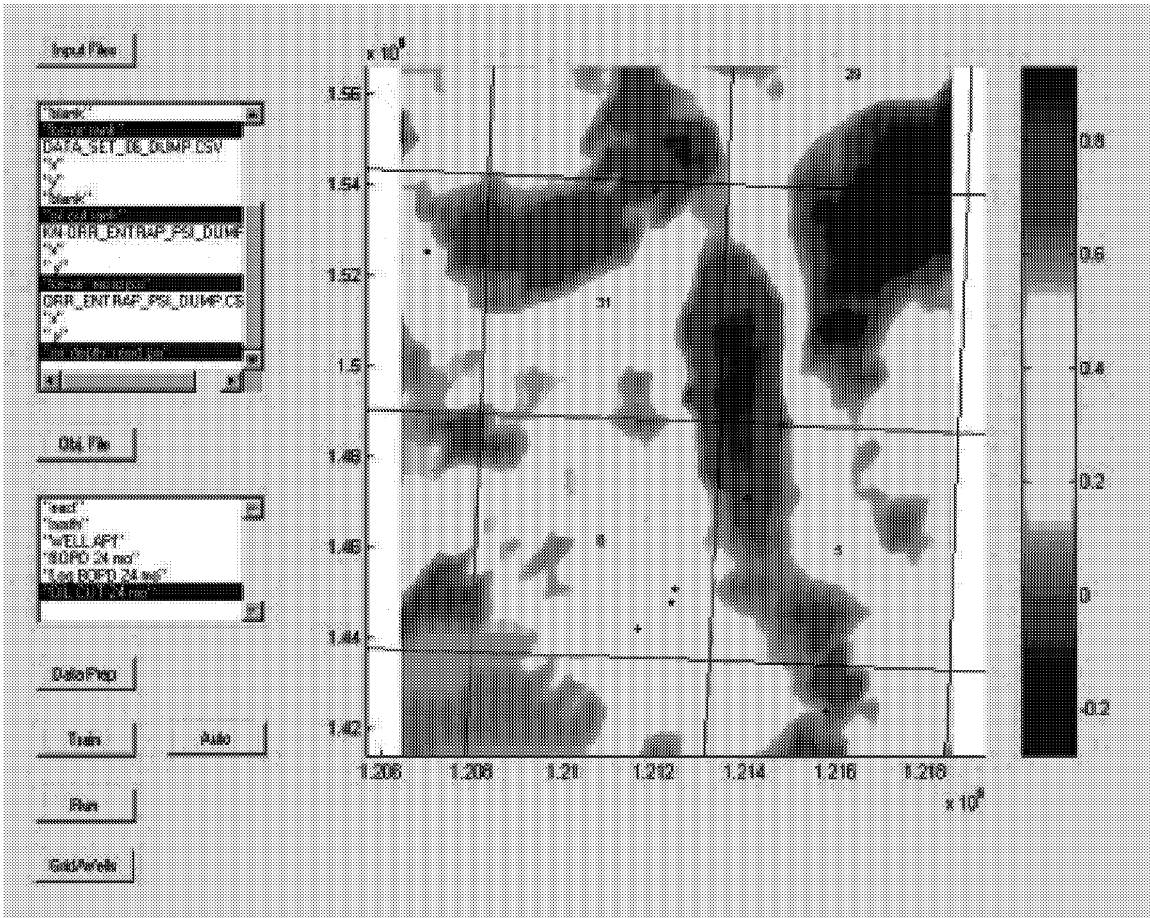


Step 11. Select an objective for training such as "OIL CUT 24 mo."

Step 12. Press the "train" button.

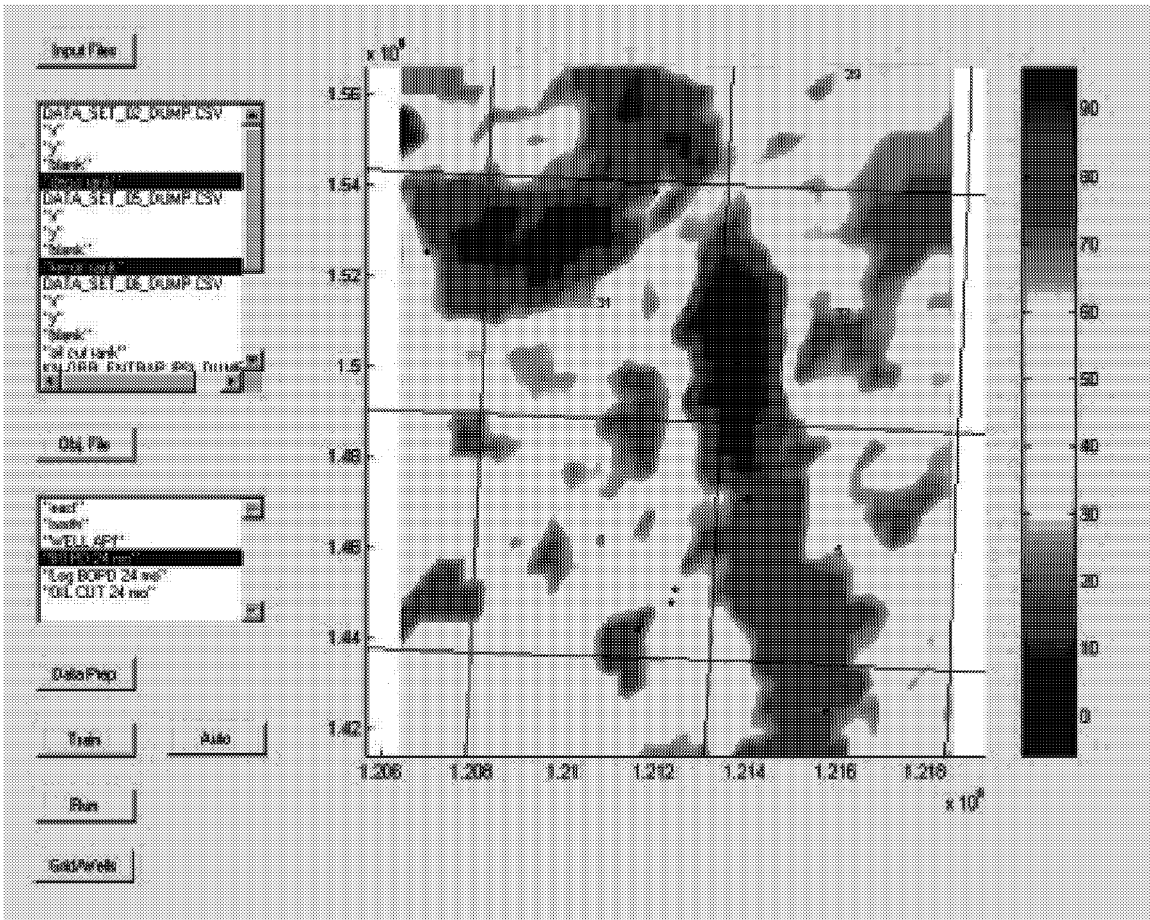
Step 13. Press the “run” button. A map will be created with values of the selected objective training column as shown in Figure 97.

Figure 97. A “Z” map of oil-cut from Neural Solver 2 used in example 3.



The input selections can be changed. In Figure 98, only two of the five input files were used in creation of a "Z" map based on BOPD. After making new selections from the input files, the "data prepare" button must be pressed again. Press "train" and "run" to create a new "Z" map as shown in Figure 98.

Figure 98. A "Z" map of bopd from Neural Solver 2 with different training used in example 3.



Tutorial example 3 provide examples of how Neural Solver 2 can be used to create a "Z" map. The "Z" map is scaled or ranked using common indicators of performance or quality. The objective file used in example 3 contains information from production history. However, any measure of hydrocarbons could be used in the objective file. The input files were created with other ICS tools in a process of converting seismic information into reservoir characterizations of depositional setting, structural growth and entrapment.

Example 4

In example 4, we will use Neural Solver 1 to transform seismic attributes to a thickness that represents depositional setting and to porosity-thickness that represents storage. The independent data (seismic attributes) will be transformed from a training data set that is comprised of data from wells in other 3D seismic surveys. The results will be compared to those predicted by multiple-linear-regression. Finally, we will compare all predictions to a natural cluster map of the seismic attributes. The practice files for example 4 are located under the directory \example_4\input_files\.

The training file consists of two well-reservoir attributes in columns 4 and 5. The following columns contain normalized seismic attributes at the well locations. Figure 99 shows a portion of the training file for example 4.

Figure 99. Training data file for Neural Solver 1 used in example 4.

east	north	API	Orr-GM	D PHI-H	P1amp	T1amp	P2amp	T2amp	P1max-Owi	T1z-Owi	T1min-Owi	P2max-Owi	T2min-Owi
1212611	154710	3301100198	228	0.899	0.7623	-0.6347	0.6991	-0.3253	0.4148	0.3425	0.4484	0.3122	0.3748
1214184	150850	3301100258	217		0.5893	-0.3643	0.6293	0.1266	0.3894	0.2115	0.3320	0.0984	0.2421
1214039	147068	3301100259	222	2.543	0.8586	-0.5522	0.6522	-0.0713	0.4718	0.4838	0.4826	0.4091	0.4565
1212821	149427	3301100262	225	1.058	1.0438	-0.2469	0.4914	-0.1018	0.5414	0.3409	0.5610	0.3559	0.3643
1212031	153869	3301100305	227	0.512	0.9027	-0.5629	0.8616	-0.2040	0.5594	0.4915	0.5773	0.4985	0.4203
1213827	150045	3301100311	214	0.000	0.7352	-0.3182	0.5968	-0.2165	0.1833	0.0905	0.5245	0.5680	0.3337
1207014	152537	3301100339	226	3.155	1.1160	-1.1062	0.8100	-0.0220	0.3326	0.2862	0.2185	0.3499	0.5299
1215767	142373	3301100343	231	6.404	1.1884	-0.9460	0.7996	-0.2352	0.5544	0.5310	0.5483	0.3324	0.4599
1212374	144767	3301100432	228	7.931	1.0178	-0.9293	0.8069	-0.3210	0.5346	0.5097	0.5510	0.5227	0.4047
1212474	145067	3301100488	229	7.679	0.9205	-0.7677	0.7098	-0.2793	0.5035	0.4511	0.6556	0.5937	0.4179
1211646	144209	3301100915	226	5.729	1.3112	-1.0706	1.1599	-0.4078	0.5391	0.5236	0.5637	0.5365	0.4315
1257953	158110	3301100195	222	0.185	1.3008	-0.1707	0.7682	-0.6727	0.2355	0.1400	0.2527	0.1904	0.0000
1254615	155311	3301100200	227	0.501	1.2569	-0.1692	0.1974	-0.4385	0.5455	0.4916	0.5753	0.9367	0.8936
1257096	151448	3301100208	227	3.990	1.2462	-0.6679	0.9064	-0.2698	0.0335	0.1160	0.2279	0.2793	0.3749
1257814	154290	3301100254	238	5.461	1.2329	-1.2286	1.1246	-1.0977	0.2648	0.2167	0.1808	0.2366	0.2750
1254737	158993	3301100423	240	5.183	1.3195	-0.5736	0.8788	-1.2517	0.5437	0.5204	0.3798	0.4413	0.4350
1255263	151907	3301100458	222	5.987	0.9846	-0.3734	0.4769	-0.3001	0.4222	0.4318	0.4538	0.5380	0.4800
1259006	157371	3301100819	228	3.080	1.1775	-0.5732	0.7372	-0.8168	0.4033	0.2955	0.4963	0.5489	0.5377
1258348	159293	3301100865	221	6.480	1.0704	-0.8793	0.7149	-0.0568	0.7623	0.6421	0.5840	0.5671	0.7579
1253880	156077	3301100940	232		1.2875	-0.9866	0.3959	-0.3335	0.6485	0.6713	0.4693	0.4710	0.6843
1283178	124373	3301100182	218	0.981	1.2806	-0.4184	0.1939	-0.5021	0.4429	0.4259	0.4946	0.4735	0.4660
1272141	144429	3301100197	224	0.000	0.9621	-0.6378	0.1549	-0.3869	0.2530	0.2504	0.3823	0.3934	0.4472
1262805	137627	3301100202	221	0.000	0.7185	-0.5480	0.2703	-0.3420	0.5058	0.5577	0.5121	0.5833	0.5517
1265331	142139	3301100232	216	0.000	0.4862	-0.4947	-0.3459	-0.2151	0.6251	0.1125	0.2577	0.4902	0.6569
1284605	125742	3301100319	232	5.400	1.2547	-1.2426	0.8563	-0.3888	0.4140	0.5768	0.5558	0.4378	0.3833
1282194	134270	3301100345	230	3.054	1.2607	-1.3750	1.0449	-0.0320	0.5234	0.6318	0.5795	0.3881	0.3829
1274567	142442	3301100869	238	6.290	0.9770	-1.2449	1.0848	-1.0239	0.6840	0.7313	0.6972	0.5981	0.4671
1274863	145756	3301100900	234	3.690	1.0344	-0.8369	0.7266	-0.3427	0.4268	0.3965	0.3730	0.4211	0.3884
1273363	141848	3301100902	235	6.030	0.8040	-1.1655	1.0848	-0.8177	0.8344	0.5819	0.4980	0.4739	0.3935
1274784	148404	3301100910	236	6.417	1.2715	-1.2422	1.0750	-0.4202	0.5155	0.5287	0.5055	0.4273	0.4245
1273647	140673	3301100914	233	5.859	1.0054	-1.4157	1.0848	-0.9047	0.3486	0.4407	0.4345	0.4290	0.4016
1245259	175743	3301100210	209	0.606	1.7123	-0.5923	0.4669	-0.1294	0.3873	0.2915	0.4685	0.3474	0.4073
1243509	172196	3301100247	216	8.037	1.7001	-1.2746	1.5685	-0.9857	0.5329	0.6039	0.6887	0.6572	0.1696
1246967	174526	3301100341	236	2.439	0.8023	-1.1093	0.8203	-0.6667	0.6473	0.5397	0.5464	0.6090	0.5897
1241906	116615	3301100178	215		0.9593	-0.6381	1.1172	0.0758	0.2404	0.2256	0.2953	0.1199	0.2181
1241441	115313	4006320064	211	1.049	0.5539	-0.2121	0.6972	0.2128	0.0000	0.0449	0.1613	0.0049	0.4447
1230006	101570	4006320053	202		1.2291	-1.0406	0.6363	-0.2207	0.4163	0.3181	0.3350	0.4374	0.5597
1224141	98031	4006320072	204	3.182	0.6084	-0.7058	0.6816	0.1722	0.0268	0.2530	0.1700	0.1483	0.4537
1223850	96526	4006320075	219	3.169	0.6351	-1.0446	1.4009	-0.0035	0.2697	0.4548	0.3710	0.3729	0.4898
1227557	101962	4006320086	200	2.381	0.4793	-0.6169	0.5570	0.2502	0.2605	0.3328	0.3496	0.4012	0.5930
1221182	100717	4006320210	212		0.8579	-0.5789	0.3459	0.3009	0.2547	0.2976	0.3300	0.6910	0.8237
1227459	98763	4006320554	223	8.532	1.1334	-1.3077	1.6435	0.1571	0.3345	0.5413	0.5641	0.5460	0.3654

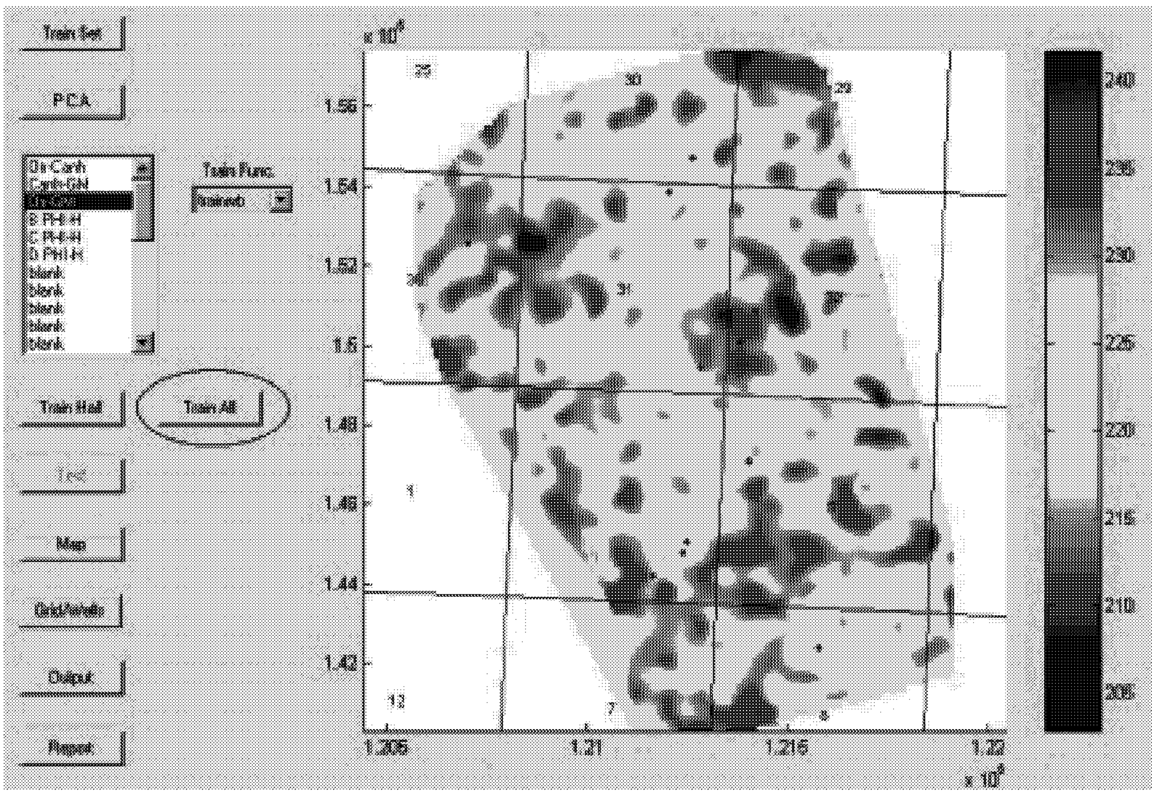
Step 1. The training file “data_set_4_train.csv” is imported into Neural Solver 1.

Step 2. The “PCA” button is pressed and the data column labeled “Orr-GM” is selected in the window box.

Step 3. Default training is used and the “train all” button is pressed.

Step 4. The “map” button is pressed. Map file “data_set_4_map.csv” is selected. A map is created that shows the seismic attributes transformed into the thickness from Orr to GM as shown in Figure 100.

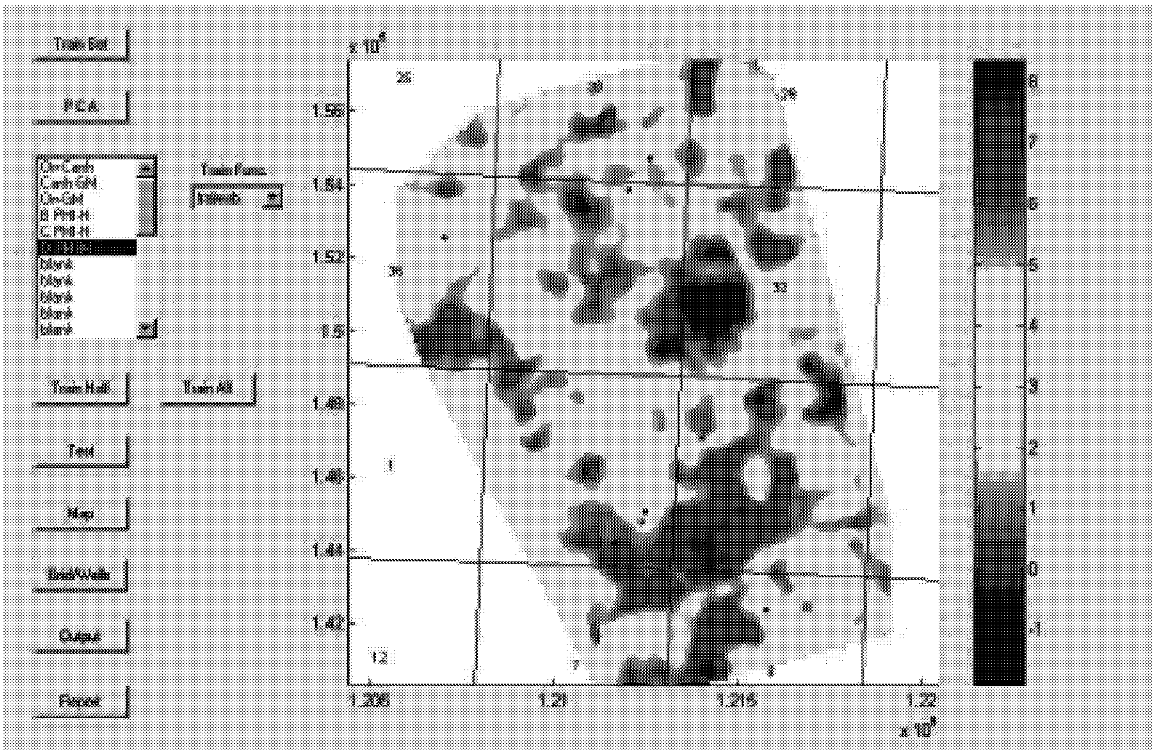
Figure 100. A map of Orr-GM thickness from Neural Solver 1 used in example 4.



Step 5. The data column labeled “D PHI-H” is selected in the window box.

Step 6. The “map” button is pressed. Map file “data_set_4_map.csv” is selected. A map is created that shows the seismic attributes transformed into D Zone porosity-thickness as shown in Figure 101.

Figure 101. A map of D Zone phi-h from Neural Solver 1 used in example 4.



For comparison, a multiple linear-regression equation can be derived from “data_set_4_train.csv” for either “Orr-GM” or “D phi-h.” Applying those equation coefficients to the appropriate data columns in “data_set_4_map.csv”, we can predict either Orr-GM thickness or D phi-h with the Multiple-Linear Regression Tool.

Figure 102 shows the prediction of Orr-GM thickness using regression coefficients shown in Figure 103.

Figure 102. A map of Orr-GM thickness from MLR tool used in example 4.

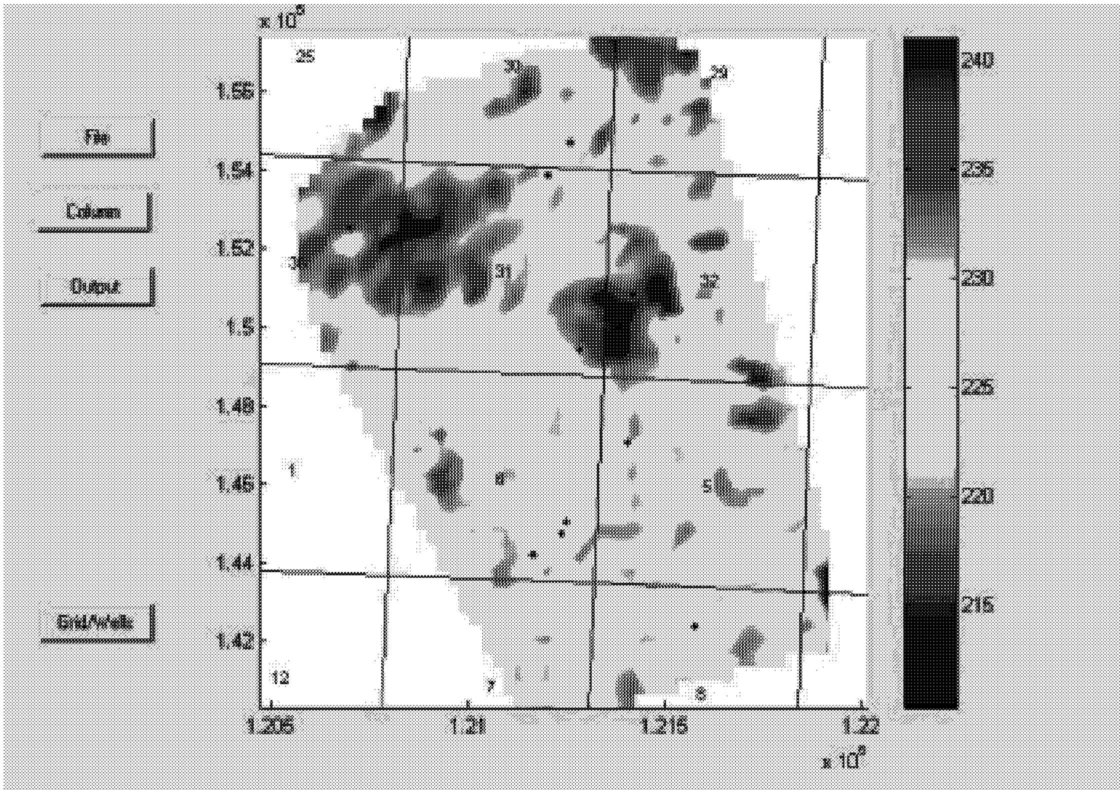


Figure 103. Coefficients for Orr-GM thickness applied with MLR tool used in example 4.

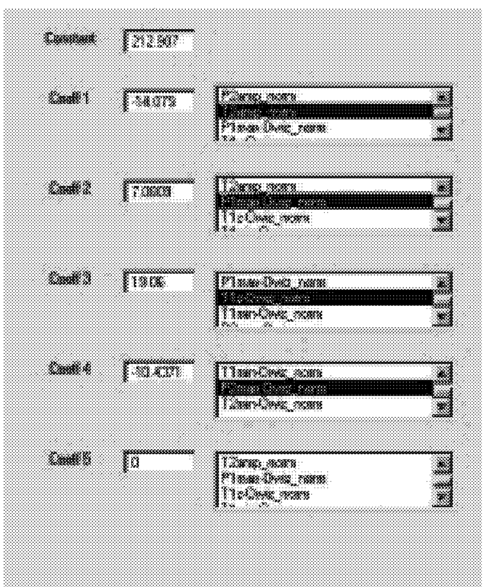


Figure 104 shows the prediction of D phi-h using regression coefficients shown in Figure 105.

Figure 104. A map of D phi-h from MLR tool used in example 4.

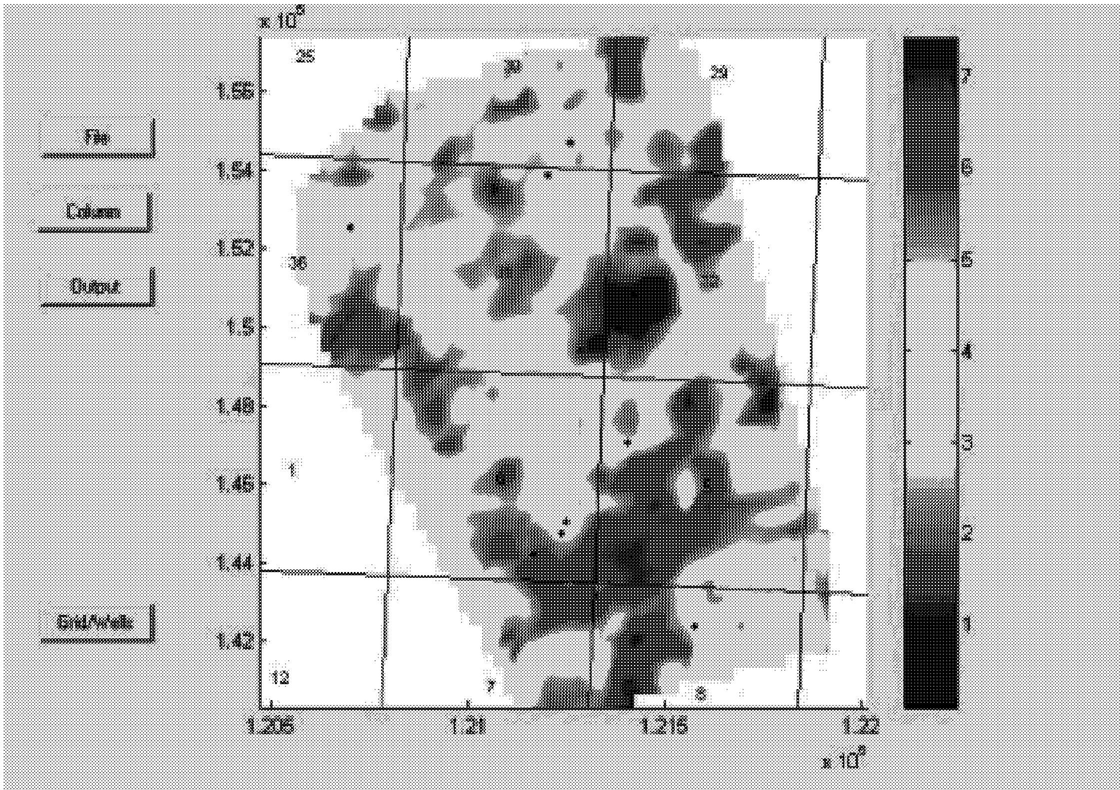
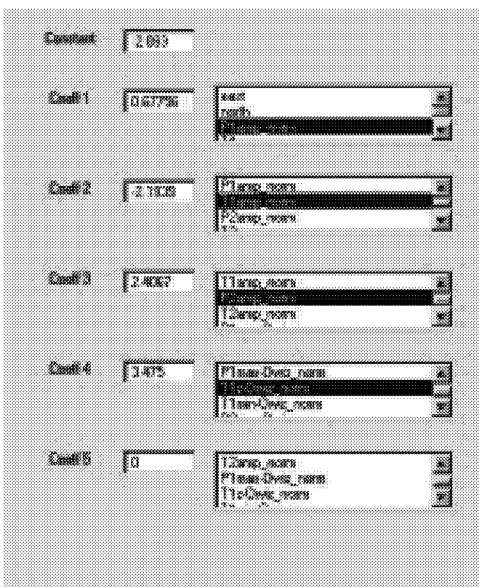
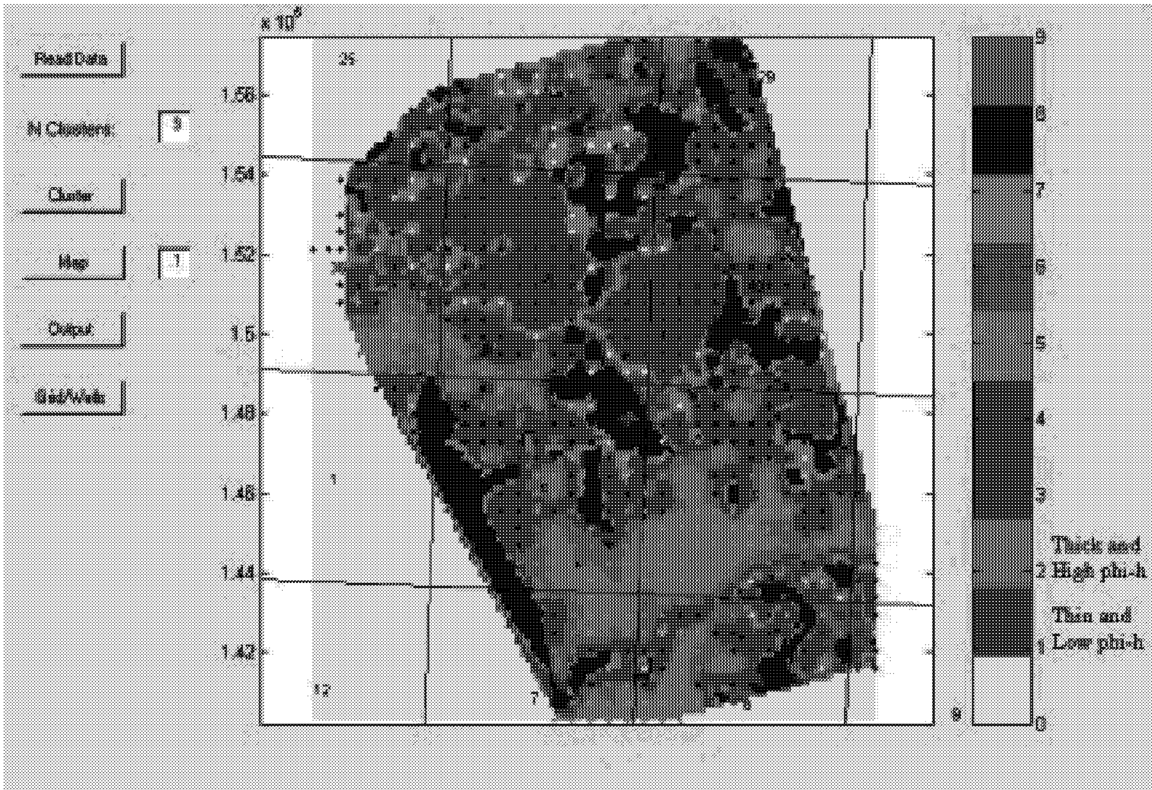


Figure 105. Coefficients for D phi-h applied with MLR tool used in example 4.



When the Cluster 3 Tool is used with "data_set_4_map.csv", a nine-cluster map can be produced as shown in Figure 106

Figure 106. Cluster map of seismic attributes from Cluster 3 used in example 4.



Referring back to example 1, we can apply the transformations made by Neural Solver 1 and multiple-linear regression to the cluster map made by Cluster 3 for the same seismic attributes. Comparing the maps prepared in this example allows us to conclude with high confidence that cluster 1 represents a thin depositional setting with very poor D Zone phi-h. Similarly, we can conclude that cluster 2 represents a thick depositional setting with excellent D Zone phi-h. If our drilling target is the D zone, we should focus our efforts in those areas populated with seismic attributes found in cluster 2.

CONCLUSION

Integrated software has been written that comprises the tool kit for the Intelligent Computing System (ICS). The software tools in ICS are for evaluating reservoir and hydrocarbon potential from various seismic, geologic and engineering data sets. The ICS tools provide a means for logical and consistent reservoir characterization. The tools can be broadly characterized as 1) clustering tools, 2) neural solvers, 3) multiple-linear regression, 4) entrapment-potential calculator and 5) combining tools.

The clustering tools are simple to use and yet robust in their ability to correlate seismic data with reservoir information collected from wells. A large number of independent parameters can be quickly assessed for correlation to selected reservoir parameters. The most important independent parameters are ranked by the cluster routine and are clearly identified for the user. Output from clustering tools and depth information can be used in an entrapment-potential calculator to quantify trapping conditions. Multiple output files from clustering and neural solver tools can be weighted and summed in a combine tool to generate a "goodness" or reservoir "Z" map.

Neural solver tools are more difficult to use and require more control (dependent data) for training information than the clustering tools. However, they can be used successfully for making reservoir predictions at a 3D seismic survey where there few or no wells if training can be accomplished from another 3D seismic survey or surveys where there is a sufficiently large well population. This approach has been successfully tested by the author at six 3D seismic surveys in Bowman County, North Dakota and Harding County, South Dakota.

A fuzzy-logic combine tool has also been developed and offers promise as a consistent-rule means of assessing reservoir potential. A simple set of fuzzy rules has been developed but rule definitions need to be refined and expanded. After this is done, a tutorial will be developed that will allow users of the Fuzzy Combine Tool to modify or customize the rules for a specific reservoir of interest.

Example data sets with detailed instruction are provided in the tutorial section. These allow the user an opportunity to successfully run each of the ICS tools and to use the tools in an integrated manner toward reservoir characterization and risk assessment.