Image Analysis, Geographic Information Systems and Some of Their Applications in Geology

Final Paper

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CONTENTS

ABSTRACT

The **objective** of this paper is to give an overview of image analysis and geographic information systems (GIS) and show how they can be useful for various applications in general and for geological applications. In addition to several local and international resources having relevant literature, ArcGIS and Image Analysis applications were the main tools that were used and studied to meet the requirements needed to achieve the objective. By using image analysis techniques, any area of interest can be studied and quantified by dividing it into different sub-areas each of which has different colour or level of contrast. In particular, a geologist can quantify the different components of rock sample, even up to a microscopic scale, using image analysis. In addition, GIS can be utilized in other aspects of geology and also as a database for storing geological data.

Introduction:

Weather it is the evolving biological genetic map, a microscopic map of a rock sample or a geographic map of a country, they all can be represented spatially and they are somehow similar tools for different scientists and engineers who share similar intended goal which is the benefit of the human being.

Being a geologist working at the oil&gas sector and had the chance to learn about GIS, I tried in this paper to find how GIS applications can be used as a tool for helping the geologist to perform certain tasks related to rock description, geological interpretation and simplify the process of organizing and storing geology data.

Geologists working in the field of hydrocarbon exploration as well as those who work for the academy will find this paper directly related to their interest.

There will be more information given to the concept of image analysis as it is one of the main tools that can be combined with GIS applications to perform some of the work that is related to the subject of interest. Namely, ArcGIS and Image Analysis for ArcGIS are the two applications that have been used and reviewed as the right tools for the needed purpose. At the end, some case studies will be presented.

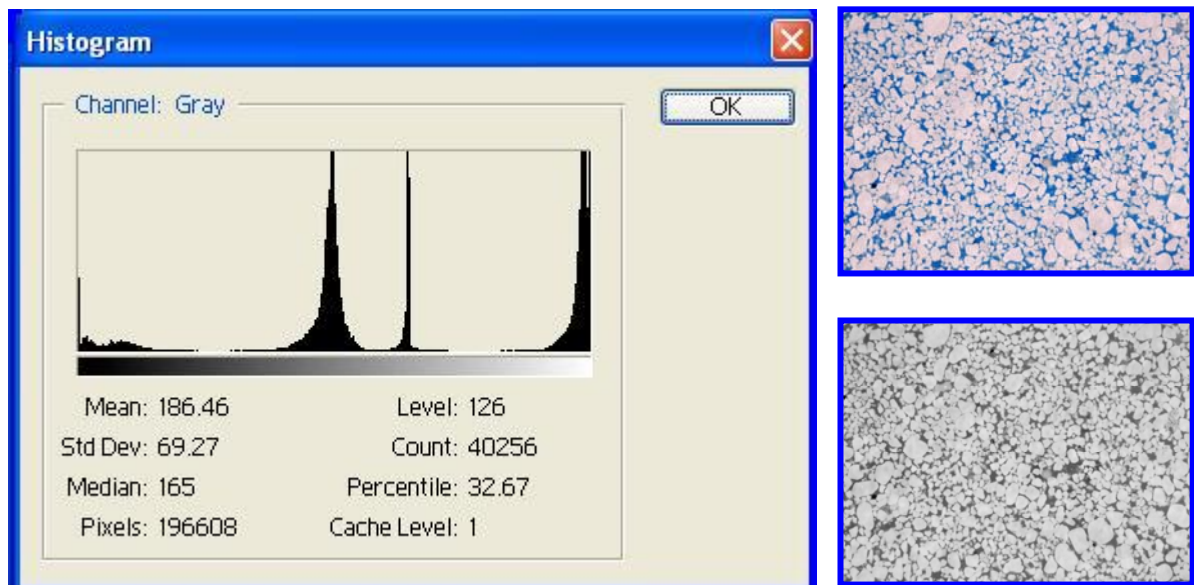# 1- <u>Image Analysis and GIS:</u>

1. A - The Concept of Image Processing and Analysis:

With stored digital images more possibilities exist, under the heading of 'image processing', which can be carried out on previously recorded images. Digital

images also lend themselves to various forms of automatic analysis with the aid of the computer. The simplest form of image is one in which the brightness or 'grey level' is directly proportional to the recorded intensity, but in many cases it is advantageous to modify this relationship. A useful way to view the contents of an image is the 'grey level histogram', in which the numbers of pixels for each value of grey level are plotted (Figure-1). If the histogram shows that the useful information content of the image is contained within a limited grey level range, it is advantageous to 'stretch' this region to fill the whole range from black to white. (Reed 1996: 106) The histogram values are then used to calculate the percentage or quantify a certain area in the image which has certain level of greyness. Further processing techniques are done using the computer to prepare the image for better quantification results.

Fugure-1: An example of an image and its grey level histogram.

1. B – Combining Image Analysis and GIS * :

An image of the earth's surface is a wealth of information. Images capture a permanent record of buildings, roads, rivers, trees, schools, mountains, and other features located on the earth's surface. But images go beyond simply recording features. Images also record relationships and processes as they occur in the real world. Images are snapshots of geography, but they are also snapshots of reality. Images date our earth and everything associated with it; they record a specific place at a specific point in time. They are snapshots of our changing cities, rivers, and mountains. The data in a GIS needs to reflect reality, and snapshots of reality need to be incorporated and accurately transformed into instantaneously ready, easy-to-use information. Today's geographic information systems have been carefully created with features, attributed behavior, analyzed relationships, and modeled processes.

There are five essential questions that any GIS need to answer: Where, What, When, Why, and How. Uncovering Why, When, and How are all done within the GIS; images allow us to extract the Where and What. Precisely where is that building? What is that parcel of land used for? What type of tree is that? The new extensions associated with ArcGIS use imagery to allow us to accurately address the questions Where and What, so we can then derive answers for the other three.

But our earth is changing! Urban growth, suburban sprawl, industrial usage and natural phenomena continually alter our geography. As our geography changes, so does the information we need to understand it. Because an image is a permanent

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* **http://www.gis.leica-eosystems.com/products/image_analysis_for_arcgis/default.asp**

record of features, behavior, relationships, and processes captured at a specific moment in time, using a series of images of the same area taken over time allows us to more accurately model and analyze the relationships and processes that are important to our earth.

Image Analysis for ArcGIS Software:

The new extension by Leica Geosystems is technological breakthroughs which allow transforming a snapshot of geography into information that digitally represents reality in the context of a GIS. Image Analysis™ for ArcGIS is a tool built on top of a GIS to maintain that GIS with up-to-date information. The extension transforms imagery directly into GIS for analyzing, mapping, visualizing, and understanding our world.

Image Analysis for ArcGIS™ is primarily designed for natural resource and infrastructure management. The extension is very useful in the fields of forestry, agriculture, environmental assessment, engineering, geology, infrastructure projects, and general geographic database update and maintenance.

Today, imagery of the earth's surface is an integral part of desktop mapping and GIS, and it's more important than ever to have the ability to provide realistic backdrops to geographic databases and to be able to quickly update details involving street use or land use data.

Image Analysis for ArcGIS gives the ability to perform many tasks:

- Import and incorporate raster imagery into ArcGIS.
- Categorize images into classes corresponding to land cover types such as vegetation.
- Evaluate images captured at different times to identify areas of change.
- Identify and automatically map a land cover type with a single click.

- Find areas of dense and thriving vegetation in an image.

- Enhance the appearance of an image by adjusting contrast and brightness or by applying histogram stretches.

- Align an image to a map coordinate system for precise area location.

- Rectify satellite images through Geocorrection Models.

1.C- Illustrated Functions of Image Analysis for ArcGIS:

1.C.1- Updating databases:

There are many kinds of imagery to choose from in a wide range of scales, spatial, and spectral resolutions, and map accuracies. Aerial photography is often the choice for map updating because of its high precision. With Image Analysis for ArcGIS imagery are used to identify changes and make revisions and corrections to geographic databases (Figure-2).
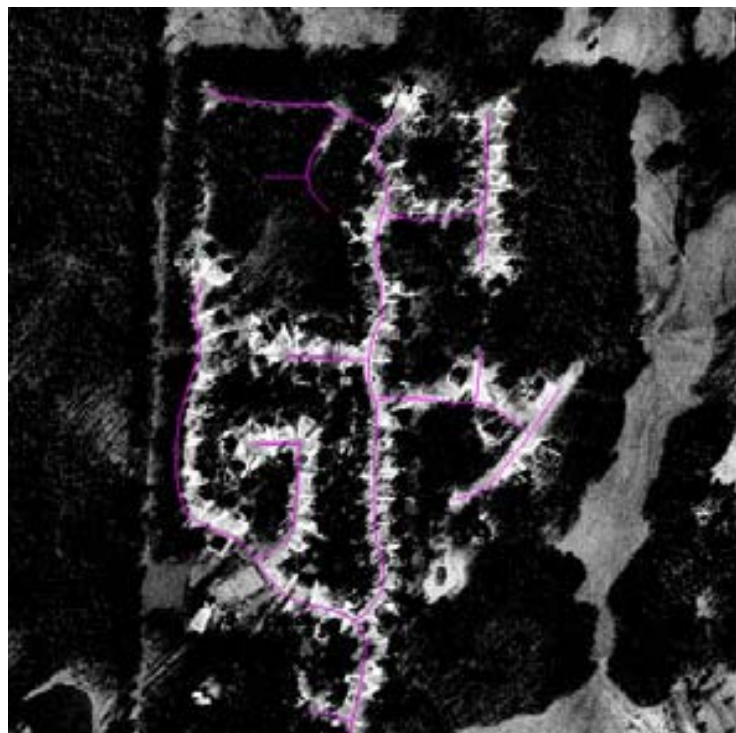

Figure-2: Air photo with shape file of streets.

***1.C.2- Categorizing land cover and characterizing sites*:**

Transmission towers for radio-based telecommunications must all be visible from each other, must be within a certain range of elevations, and must avoid some areas like wetlands. With Image Analysis for ArcGIS, we can categorize images into land cover classes to help identify suitable locations. Imagery and analysis techniques can be used to identify wetlands and other environmentally sensitive areas. The Classification features enable us to divide an image into many different classes, and then highlight them as we wish. In this case the areas not suitable for tower placement are highlighted, and the placement for the towers can be sited appropriately (Figure-3).
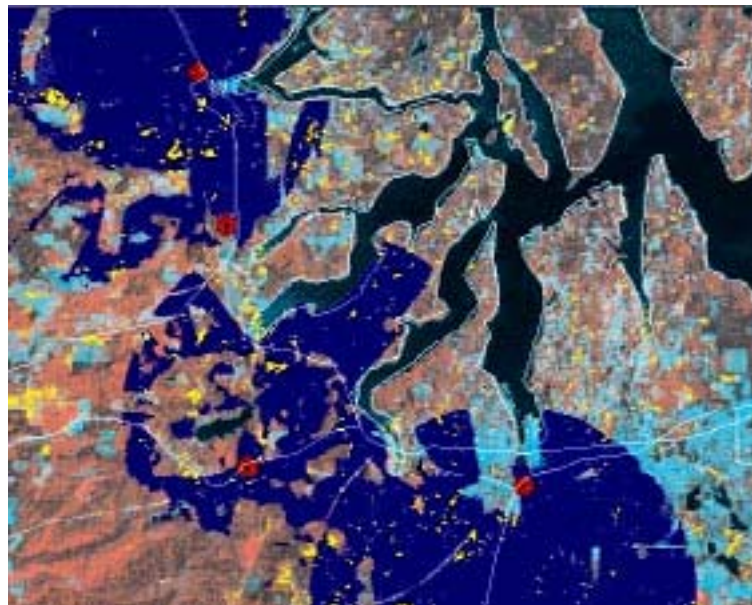

Figure-3: Classified image for radio towers

1.C.3- Identifying and summarizing natural hazard damage:

When viewing a forest hit by a hurricane, we can use the mapping tools of Image Analysis for ArcGIS to show where the damage occurred. With other ArcGIS tools, we can show the condition of the vegetation, how much stress it suffers, and how much damage it sustained in the hurricane.

In Figure-4 below, Landsat images taken before and after the hurricane, in conjunction with a shape file that identifies the forest boundary, are used for comparison. Within the shape file, we can see detailed tree stand inventory and management information.
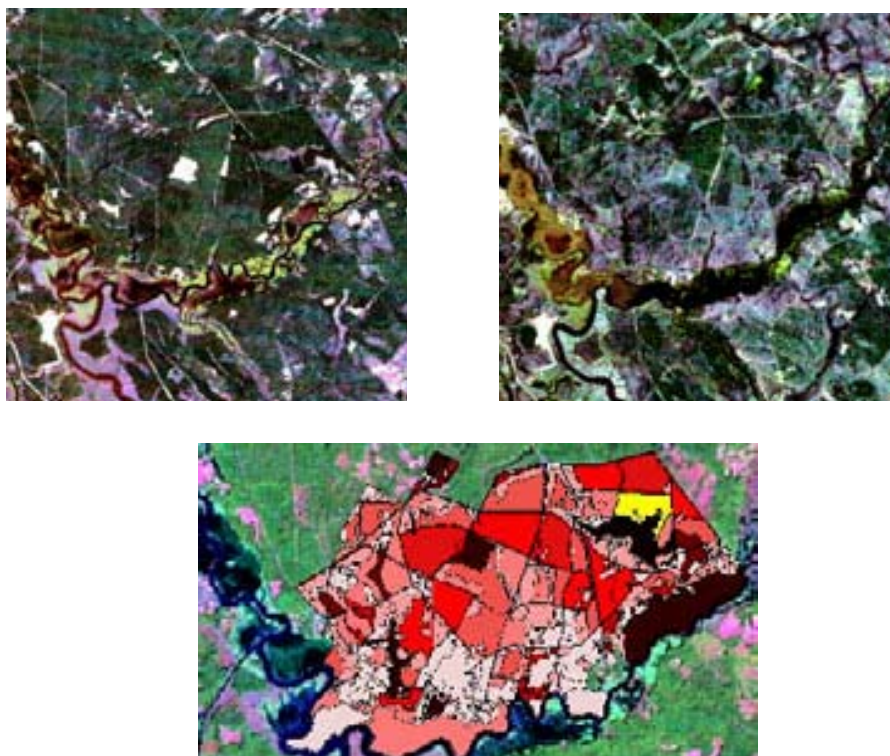

Figure-4: The upper two pictures show the area in 1987 and in 1989 after Hurricane Hugo. The lower image features the shape file.

1.C.4- Identifying and monitoring urban growth and changes:

Cities grow over time, and images give a good sense of how they grow, and how remaining land can be preserved by managing that growth. we can use Image Analysis for ArcGIS to reveal patterns of urban growth over time.

Here, in Figure-5, Land sat data spanning 21 years was analyzed for urban growth. The final view shows the differences in extent of urban land use and land cover between 1973 and 1994. Those differences are represented as classes. The yellow urban areas from 1994 represent how much the city has grown beyond the red urban areas from 1973.
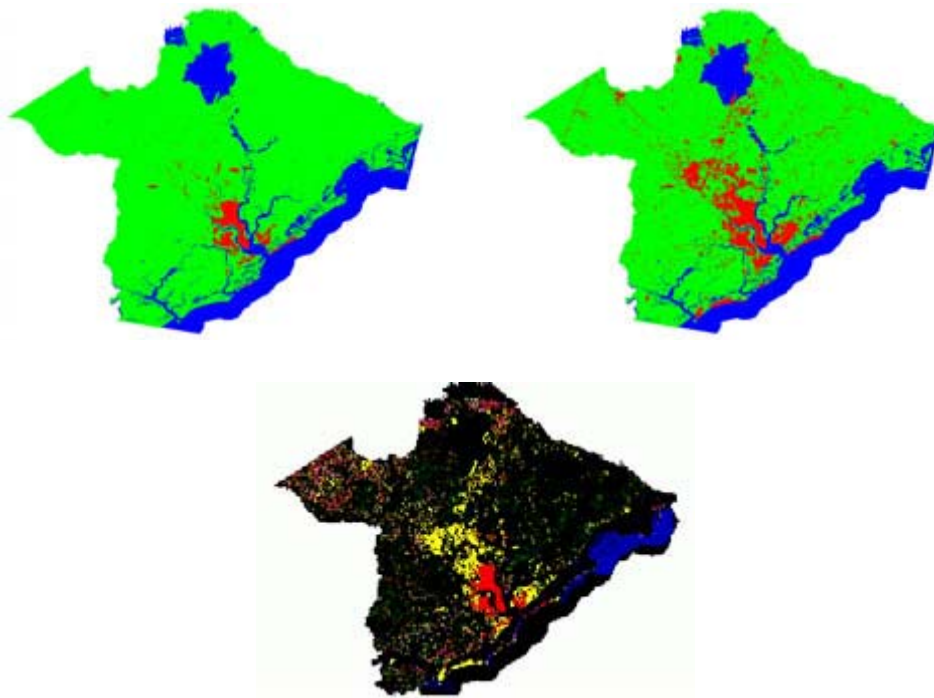

Figure-5: The top two images represent urban areas in red, first in
1974 and then in 1994. The bottom image shows the
actual growth.

1.C.5- Extracting features automatically:

Suppose we are responsible for mapping the extent of an oil spill as part of a rapid response effort. we can use synthetic aperture radar (SAR) data and Image Analysis for ArcGIS tools to identify and map the extent of such environmental hazards.

The following image (in Figure-6) shows an oil spill of the northern coast of Spain. The first image shows the spill, and the second image gives us an example of how we can isolate the exact extent of a particular pattern using Image Analysis for ArcGIS.
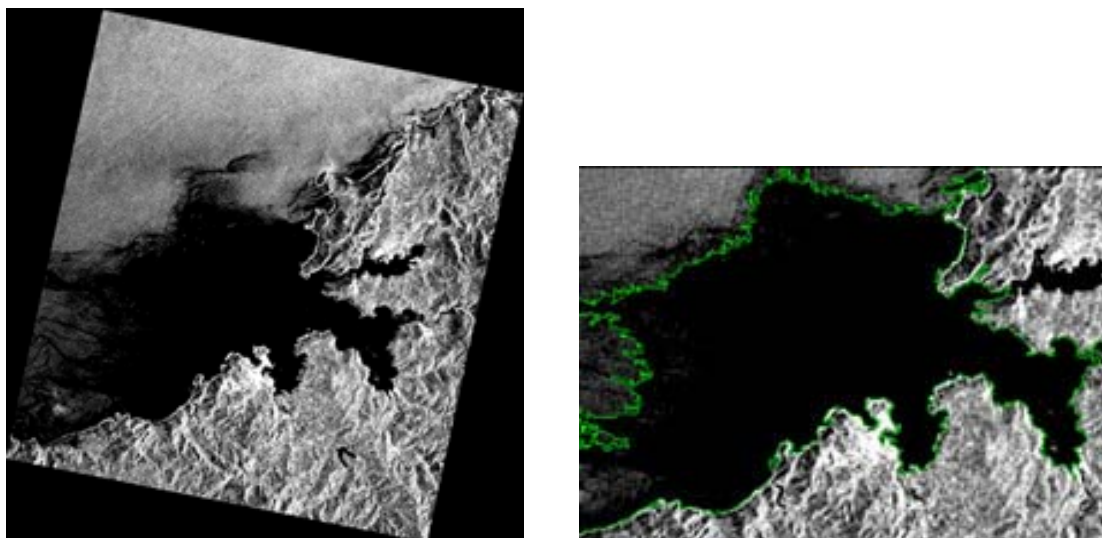
Figure-6: Images showing an oil spill off the coast of Spain and a polygon
grown in the spill using Seed Tool.

1.C.6- Assessing vegetation stress:

Crops experience different stresses throughout the growing season. we can use multispectral imagery and analysis tools to identify and monitor a crop's health.

In these images (Figure-7), the Vegetative Indices function is used to see crop stress. The stressed areas are then automatically digitized and saved as a shape file. This kind of information can be used to help identify sources if variability in growth patterns. Then, we can quickly update crop management plans.

Figure-7: Crop stress shown through Vegetative Indices

2- Image Analysis and GIS for Geology:

## 2. A – Image Analysis for Rock Description:

During exploration for hydrocarbons (e.g. oil and gas), one of the tasks assigned to geologists is to collect rock samples from the drilling wells and describe their compositional and textural properties. By the aid of a microscope, a thin section of the rock can be described, and using a digital camera mounted on the microscope and linked to a computer, live images can be seen on the screen and can be grabbed (Figure-8). One of the major physical properties of hydrocarbon bearing rocks/reservoirs, is porosity; which is the tiny pore spaces within the rock particles.

Figure-8: Workstation of Microscopic Digital Imaging.

Porosity must be present to occupy the needed fluids and it has to be quantified to measure the reservoir quality. During thin section preparation of a rock sample, a blue coloured epoxy is introduced into the pore spaces and when viewing the thin section under the microscope or on the image the porosity will be represented by a blue area (Figure-9).

By using the programming capabilities of image analysis applications, it is possible and very useful to quantify the porosity by detecting the percentage of the blue area and this can confirm or replace the lab measurement done by conventional core (rock) analysis.
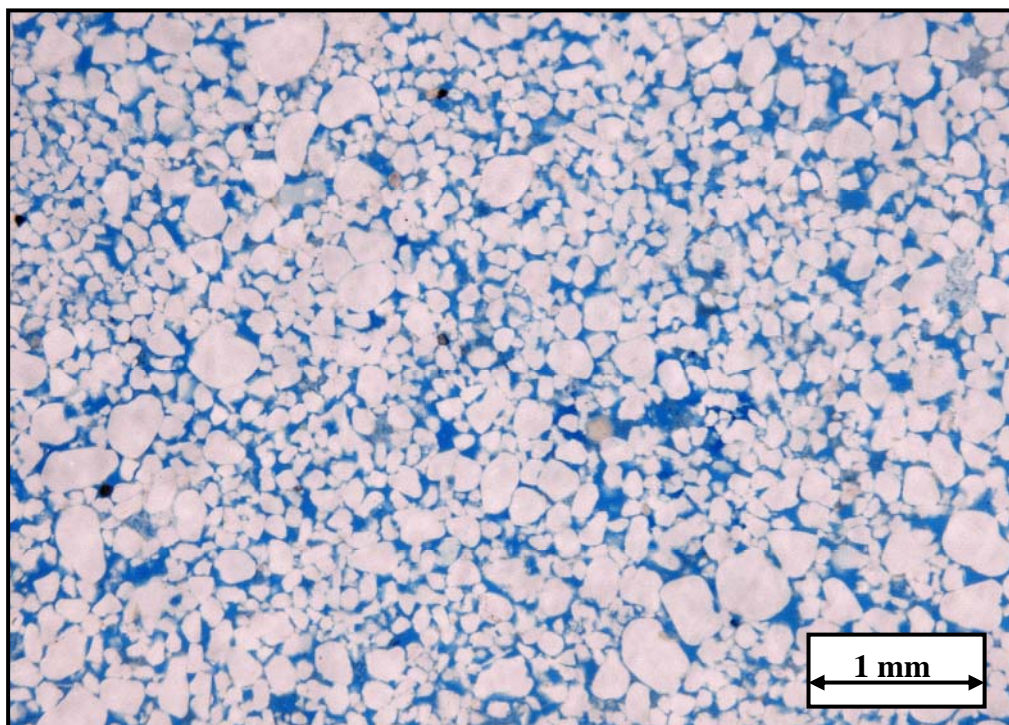
Figure-9: Microscopic digital image of a sandstone thin section.

2. B – Using GIS for Mapping Geological Data:

The current use of GIS application in the oil&gas industry is limited to the construction of base maps for aerial features like drilling well locations, fields boundaries, production plants, facilities, roads and projects (Figure-10).
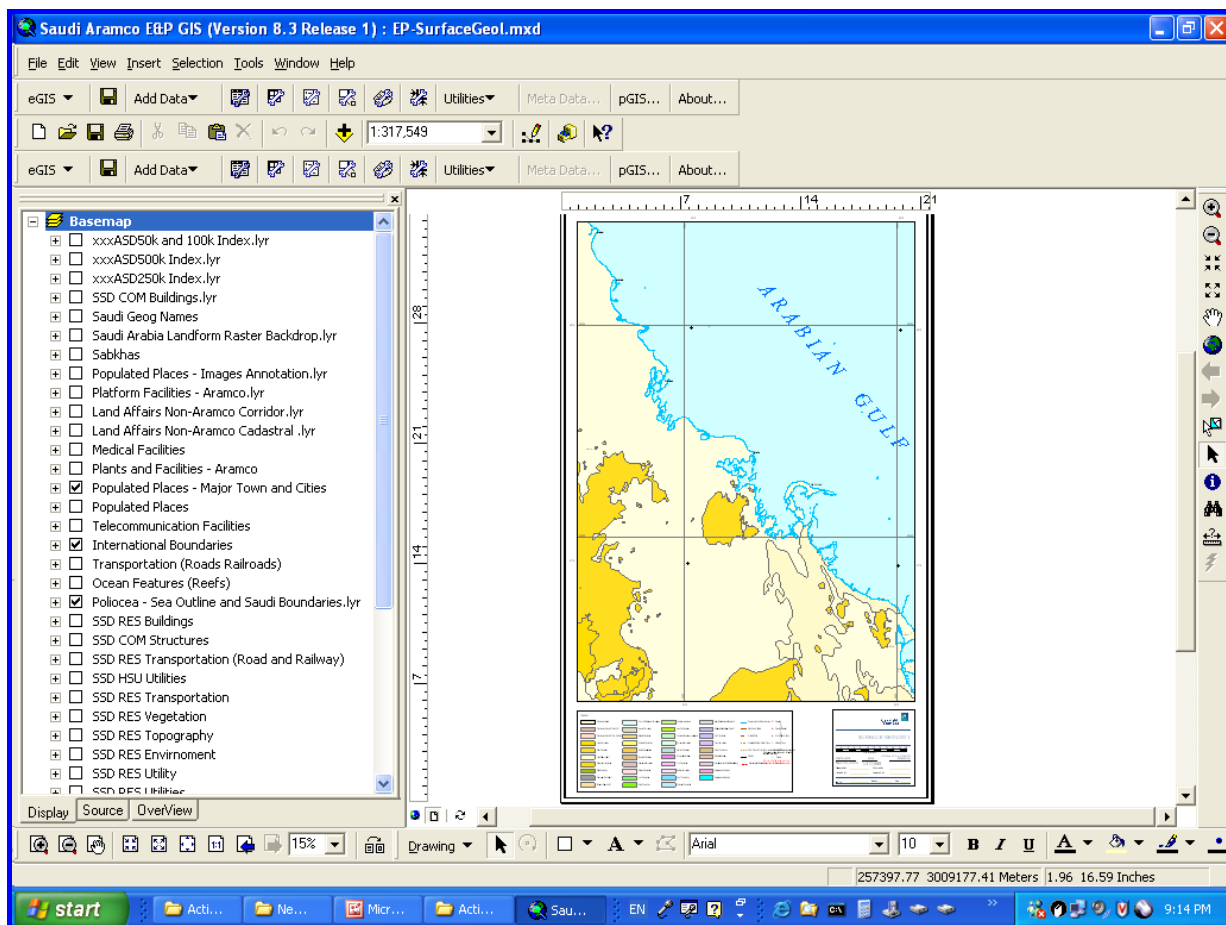
Figure-10: Example of a simple base map constructed using ArcGIS.

However, the drilled oil and gas wells provide tremendous number of geological samples and data and if GIS is more efficiently used it has the capability to help geologists to easily construct sub-aerial maps for interpretation and exploration

15

purposes. The following section has examples of simple illustrations explaining what is being proposed:

2.B.1- *Mapping Ancient Depositional Environments:*

The identification of ancient depositional environment is the challenging and important task for sedimentologists. By using the certain search criteria based on stored depositional attributes of previously drilled wells, GIS can help them to create subsurface maps containing different sedimentary areas such as ancient rivers or coast lines. This will lead to better prediction of new potential exploration targets (Figures-11).
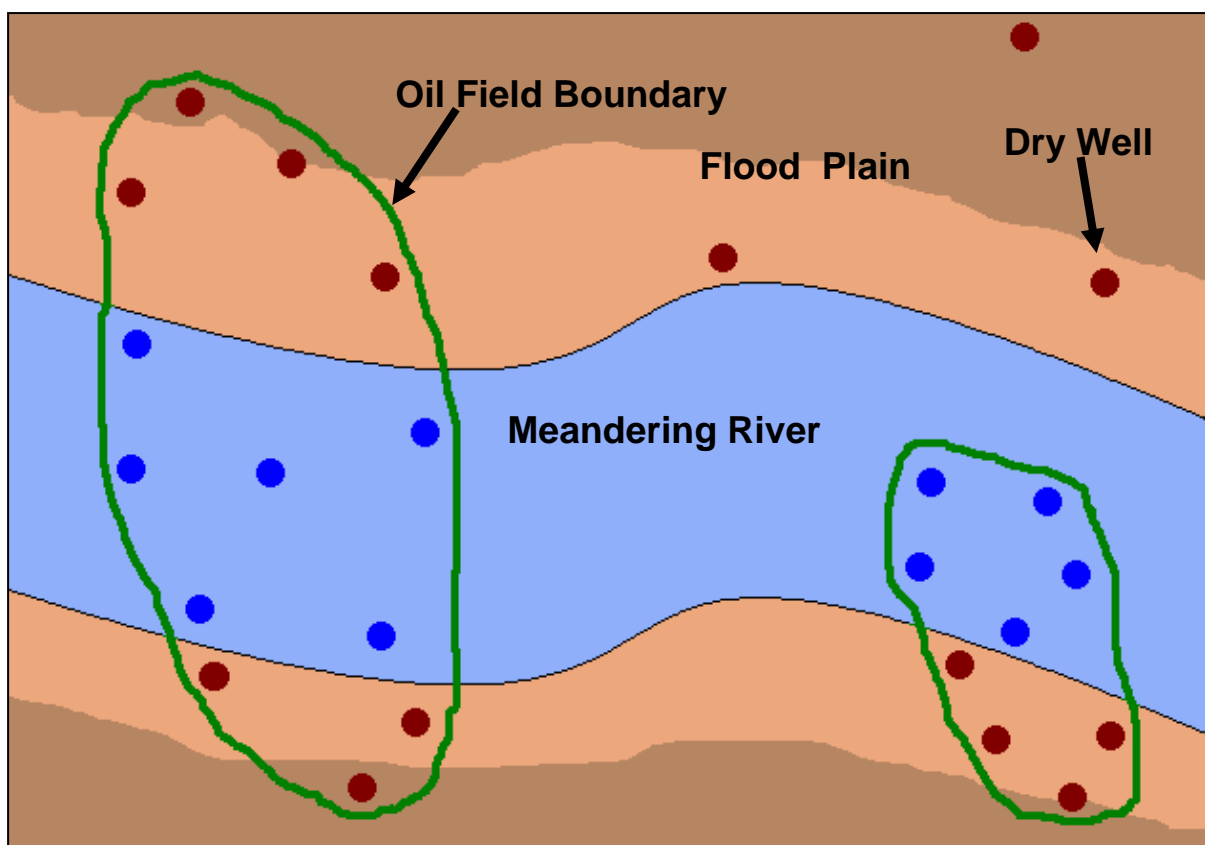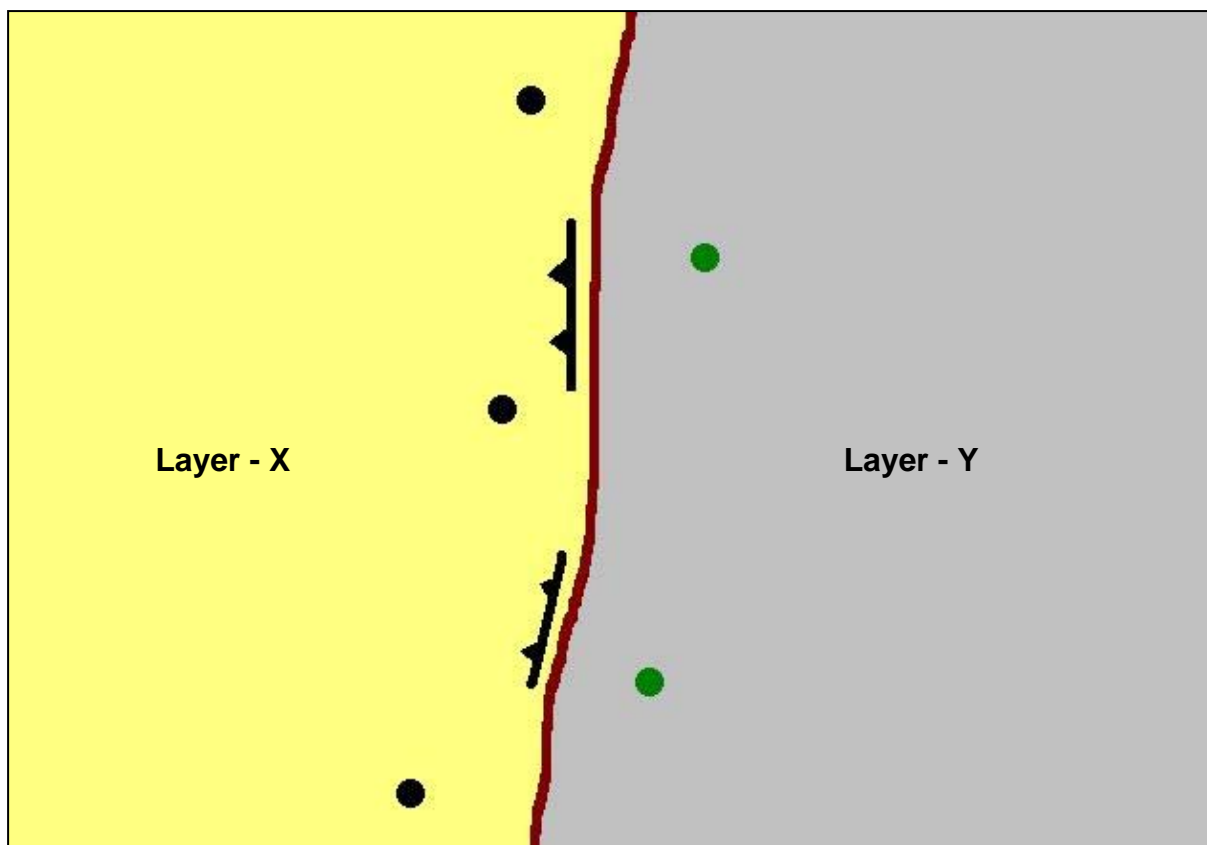

Figure-11: An illustration showing a proposal for using GIS applications to construct subsurface map of ancient depositional environment based on existing well data.

2.B.2- Mapping Subsurface Structures and Layers:

Subsurface geological structures and sub-crops can be also mapped based on available well data using GIS for exploration purposes.
Figure-12 shows a subsurface map of a fault line separating two different strata adjacent to each other because of a tectonic uplift followed by erosion at the hanging wall block of a reverse fault.

Figure-12: An illustration showing a proposal for using GIS applications to construct subsurface map of a reverse fault separating two sub-surface layers based on existing well data.

2. C – Using GIS as Geological Database:

2.C.1- GIS as a Geological Well Database:

The huge database of geological information collected from drilling and studying thousands of wells can be stored utilized better by the help of a GIS application. As a result, a treasure of attributes such as stratigraphic tops, compositional and textural features of rocks or thin section photographs could be stored properly and used for reference, correlation (comparison) or construction of maps. Figure-13 shows how ArcGIS was used to store two thin section images in two different layers to provide different optical properties of the described rock. The two images are on top of each other simulating what has been observed exactly under the polarized microscope. Switching between both of them is done by ticking or un-ticking the upper layer.

Figure-13: Two illustrations showing how ArcGIS can be used to simulate the microscope view of two images of the same thin section to recognise the minerals from their optical properties.

2.C.2- GIS as Rocks and Minerals Database:

There are many types of rocks and nearly 4000 minerals on Earth. Each one has its own physical and optical properties (Figure-14). It is proposed to use a GIS application like ArcGIS and its extensions to store photos of those rocks and minerals and use the annotation tool, identification tool and attribute tables to store them and their properties. This will be a very valuable catalogue that can be used as

a reference for academic educational purposes or as a quick guide for geologist working in different fields such as hydrocarbon or mining exploration (Figure-15).

Figure-14: Examples showing traditional storage of mineral photos and their optical properties in charts.
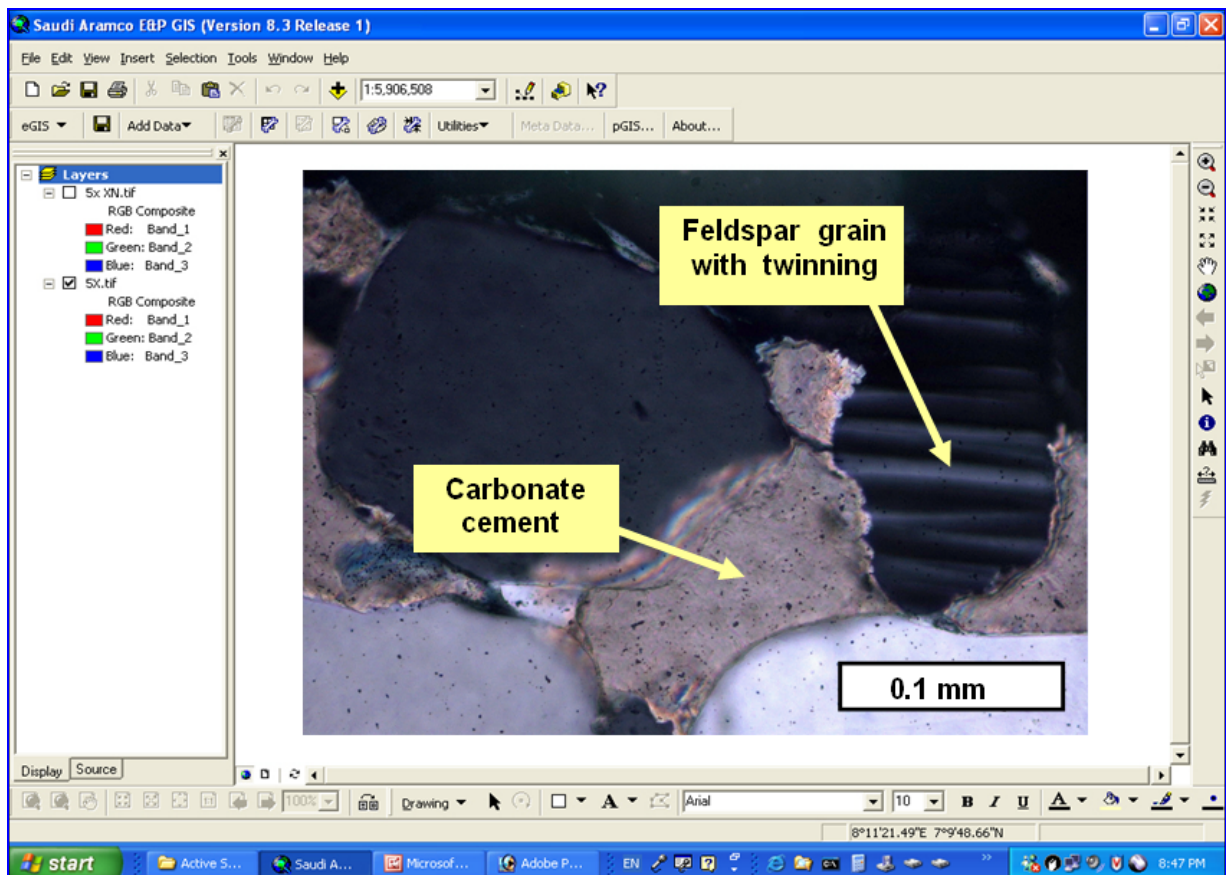
Figure-15: ArcGIS can be used to store images of rock thin sections and store their data using attribute tables or annotations.

3- <u>Case Studies:</u>

Several case studies were found in different references and because of time limitation some of them will be listed at the end of this paper and two of them will be mentioned below:

3. A – Quantifying macropore geometry and distribution in the Biscayne Aquifer using GIS and image analysis:

Image analysis and GIS techniques were used to quantify the geometry and spatial distribution of macropores in a limestone sequence at early stages of karst development. The study was conducted on core and digital borehole images obtained from the Biscayne aquifer in Miami-Dade County, Florida. The Biscayne aquifer is the main water source for South Florida, and owes its high transmissivities and porosities to an interconnected network of dissolution features. Poor core recovery is common due to limestone dissolution, especially across intervals characterized by high flow rates. Thus, hydrologic properties derived from core provide an incomplete picture of aquifer dynamics, and may not characterize the most significant flow pathways in the aquifer. High-resolution televiewers, on the other hand, capture a continuous image of dissolution features intersected by the wellbore. Remote sensing techniques were used to analyze the borehole images. The 55 foot section was remapped according to a pore versus matrix classification. Two populations of dissolution features were observed: irregular-shaped macropores and horizontal channels that are continuous across the wellbore. The horizontal channels are at various stages of development, ranging from incipient (small

aperture with limestone bridges) to mature (complete separation with apertures up to 50 cm). Geometric attributes of the macropores were obtained in the GIS environment, including macropore area, perimeter, centroid location and dimensions of the best-fit ellipse. The spatial distribution of macropore density and area is not random. Rather, stratigraphic intervals of enhanced macropore development alternate with intervals of lesser development. The ArcView Spatial Analyst Extension was used to generate profile histograms of 2-D porosity, defined as the percentage of surface area occupied by solution cavities within a moving rectangular window. Results identify horizontal solution channels as regions exceeding approximately 80% porosity. Stratigraphic horizons with 50-80% porosity are regions of enhanced macropore development. Upon further dissolution, these regions may develop into continuous horizontal channels. Thus, image analysis combined with GIS provides a unique perspective on characterizing major flow pathways in the Biscayne aquifer. (Manda *et al.* 2003)

2. B – Earth science in the new millennium; a geological and geophysical GIS database for South Carolina:

The evolution of Geographic Information System (GIS) technology over the past decade provides a powerful new tool for spatial integration and analysis of large and complex datasets. Application of GIS techniques is now prevalent in many aspects of Earth science research, with wide use in both the public and private sector for resource management, hazard assessment, and local and regional planning. This project develops a relational database for existing geological and geophysical data, traditionally captured in large-format paper maps, for the State of

South Carolina. At present, the database consists of (1) base map and cultural data, (2) digital elevation data (3) selected geologic maps, (4) subsurface stratigraphic data, (5) gridded gravity field data, and (6) magnetic field data for the state of South Carolina. This effort is part of an ongoing tectonic and geomorphic study, with a specific focus on understanding the geologic evolution of the state and the south-eastern U.S. over the past 60 million years. Preliminary results from this work, based on this prototype database, suggest that the passive margin of eastern North America has been tectonically active over the past tens of millions of years. Such observations have the potential to challenge traditional and long-held views of plate tectonics and global sea level history. This work complements existing GIS technology for the State of South Carolina, developed through the USC Department of Geography, and fills a critical void for geological and geophysical information of the state. Easy and reliable access to geological and geophysical data for the state through the internet will benefit both the public and the private sector. (Varga *et al.* 2001)

Conclusions:

It has been found that image analysis applications can provide very useful tools for quantitative calculations and spatial analysis, especially if they are combined with geographic information systems. The application is broad ranging from detecting the amount of porosity and other components of geological samples to classifying geographic features such as soil types. In addition, by feeding GIS with available attributes of the rocks gathered from oil&gas wells, the use of queries based on certain search criteria can help geologists to construct subsurface maps to be used for hydrocarbon exploration.

Recommendations:

The following points are recommended:

- Oil & gas companies should pay more attention to the capabilities of GIS applications not only for constructing base maps but also to use it for geological interpretation and for well database storage and review.

- Image Analysis applications such as the one build for ArcGIS can be utilized by geologist to quantify rock porosity. Other components of the rock are difficult quantify because they need more advanced research to teach the software to recognise them optically.

- GIS is proposed to build a worldwide catalogue for storing the photographs and different properties of rocks and minerals. This will provide a handy and sharable reference for geologist in all fields and in the academy.

Acknowledgment:

I would like to acknowledge the support of Dr. Baqer Al-Ramadan from City and Regional Planning at KFUPM who was the source of the needed knowledge and the efforts to complete this paper and also I acknowledge the GIS lab assistant Mr. Raziuddin for his help.

References:

Manda, A. K., Gross, M. R., Cunningham, K. J. and Wacker, M. A., 2003, Quantifying macropore geometry and distribution in the Biscayne Aquifer using GIS and image analysis, *Abstracts with Programs - Geological Society of America*, **35**, **6**, Page 53**.**

REED, S., 1996, *Electron Micrprobe Analysis and Scanning Electron Microscopy in Geology,* (Cambridge, U.K.: Cambridge University Press), pp. 106.

Varga, M. K., Clark, J. C. and Knapp, J. H., 2001, Earth science in the new millennium; a geological and geophysical GIS database for South Carolina, *Abstracts with Programs - Geological Society of America*, **33**, **2**, Page 23**.**

http://www.gis.leica-eosystems.com/products/image_analysis_for_arcgis/default.asp

Attachment:

The following two pages are lists of extra GEO REF titles related to the subject. They grabbed my attention and they show the importance of what has been discussed in the paper.

1 TI: A simple photogrammetric method to improve quantitative image analysis in geoscience research.
AU: Caracuel-Jesus-E; Cardenal-Javier; Delgado-Garcia-Jorge; Garcia-Lopez-Santiago
SO: Journal of Sedimentary Research. 70; 6, Pages 1337-1340. 2000.
PY: 2000
In Database: GeoRef 1997-2001.

2 TI: A review of image segmentation methods; integration of image analysis and GIS for intelligent feature recognition.
AU: Forghani-Ali
SO: Proceedings of the Thematic Conference on Geologic Remote Sensing. 12; 2, Pages 352-361. 1997.
PY: 1997
In Database: GeoRef 1997-2001.

3 TI: Visualization software advances GIS data analysis.
AU: Wilson-J-D
SO: Earth Observation Magazine. 4; 10, Pages 37-38, 40-41. 1995.
PY: 1995
In Database: GeoRef 1993-1996.

4 TI: Methods for using a GIS in a quantitative analytical study of estuarine marshes.
AU: Delaney-Tim-P; Webb-James-W
BK: In: GIS/ LIS '95 annual conference and exposition proceedings.
BA: Anonymous
SO: GIS/LIS - Proceedings, Annual Conference and Exposition. 1995; Pages 277-286. 1995.
PY: 1995
In Database: GeoRef : 2002-2004/12.

5 TI: A study on automatic GIS database construction and revision.
AU: Shi-Zhongchao
BK: In: Leading edge of earth science technology.
BA: Oshima-Shoichi (prefacer)
SO: Chigaku Zasshi = Journal of Geography. 109; 6, Pages 957-963. 2000.
PY: 2000
In Database: GeoRef : 2002-2004/12.

6 BK: A study on the construction of GIS based geo-information data base management system.
CA: Korea Institute of Geology, Mining and Materials, Seoul,
SO: Yongu Pogoso = KIGAM Research Report. 1999.
PY: 1999
In Database: GeoRef : 2002-2004/12.

7 TI: Spatial and temporal reasoning techniques in geological modeling.
AU: Chiaruttini-C; Roberto-V; Buso-M
BK: In: Modelling techniques in geology and geophysics by the aid of geoscientific information systems (GIS).
BA: Goetze-H-J (editor); Schmidt-S (editor)
SO: Physics and Chemistry of the Earth. 23; 3, Pages 261-266. 1998.
PY: 1998

8 TI: GIS and database management for geologists.
AU: Percy-David
BK: In: Geological Society of America, Cordilleran Section, 98th annual meeting.
BA: Anonymous
SO: Abstracts with Programs - Geological Society of America. 34; 5, Pages 85. 2002.
PY: 2002
In Database: GeoRef : 2002-2004/12.

9 TI: Recording the fossil record; a GIS database of Middle Devonian fossils in the Michigan Basin.
AU: Ferguson-Chad-A; Bodenbender-Brian-E; Jones-Jennifer-L; Ahmed-Khurrum
BK: In: Geological Society of America, 2000 annual meeting.
BA: Anonymous
SO: Abstracts with Programs - Geological Society of America. 32; 7, Pages 131. 2000.
PY: 2000
In Database: GeoRef : 2002-2004/12.

10 TI: A study on automatic GIS database construction and revision.
AU: Shi-Zhongchao
BK: In: Leading edge of earth science technology.
BA: Oshima-Shoichi (prefacer)
SO: Chigaku Zasshi = Journal of Geography. 109; 6, Pages 957-963. 2000.
PY: 2000
In Database: GeoRef : 2002-2004/12.

11 TI: Development a comprehensive core database utilizing GIS for analysis and archiving.
AU: White-W-Scott; Nielson-Dennis-L; Nash-Gregory-D
BK: In: Federal Geothermal Research Program update; fiscal year 1995.
CA: U. S. Department of Energy, Geothermal Division, United States, sponsor
SO: Pages 2.51-2.58. 1996.
PY: 1996
In Database: GeoRef : 2002-2004/12.

12 TI: Using GIS and database technology to build, update, and extract more out of each larger area geological compilation map.
AU: Chorlton-Lesley-B
BK: In: 1999 GSA annual meeting and exposition; abstracts with programs.
BA: Anonymous
SO: Abstracts with Programs - Geological Society of America. 31; 7, Pages 247. 1999.
PY: 1999
In Database: GeoRef : 2002-2004/12.

13 TI: Reference manual and GIS geospatial database of oil-industry and other human activity (1979-1998) in the Beaufort Sea.
AU: Wainwright-Peter
BK: In: Alaska OCS region; Beaufort Sea information update meeting; proceedings.
CA: MBC Applied Environmental Sciences, Costa Mesa, CA, United States, compiler
SO: OCS Report - MMS. Pages 19. 2000.
PY: 2000
In Database: GeoRef 1997-2001.