KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DEPARTMENT OF CITY & REGIONAL PLANNING

COLLEGE OF ENVIRONMENTAL DESIGN

CRP 514: Introduction to GIS

Term Paper on GIS-based exploration applications for

Petroleum Secondary Migration & Trap Information System

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Introduction:

GIS is a prearranged set of hardware, software, geographic information, and user, built to efficiently obtain, storing, updating, manipulating, analyzing and displaying all geographic reference data form ”Understanding GIS, ESRI, 1997”, the analytical ability of GIS is one of the largest benefits of this technique , as well GIS simplifies the analysis and incorporation of a lot of diverse data types like satellite images, , well location, seismic surveys, surface geology, digital aerial photo mosaics, subsurface and cross section interpretations, and existing infrastructure information.

Regarding petroleum industry, an efficient geographic information system is an assistant tool in evaluating the potentiality of oil in promising areas where the new petroleum discoveries is the most vital factor to keep unbeaten in this critical field industry. Petroleum exploration is a very complex field depends on a large amount of variables, which generally raise the cost of exploration, therefore; the analysis capabilities of GIS programs will absolutely be able to lower the costs by analyzing the potential of petroleum site and also the potential yield of the field.

Geographic information systems have come to the forefront of industry trying to improve the way of acquiring petroleum exploration and development information as well processing, management, and delivering. In general, petroleum exploration is has a lot of issues which may face any exploration team, As the geographic information system (GIS) is a powerful tool that can be used in solving the geographically related issues, its intuitively that GIS can supply the team with a new ways of analyzing, visualizing, and integrating data enhanced by diverse range of data presentation including maps (reconnaissance maps as the most common type), charts, data tables, and query results furthermore, GIS is a particularly effective means of providing functionality for all of the disciplines represented on the team, but it’s important to say that GIS cannot replace and take the tasks of all existing software applications although it can be used to integrate and link other programs. in spite of that GIS can be efficiently applied in various petroleum industry settings, it’s used in exploration with particular interest and one specific exploration application involves the creation of reconnaissance maps “Barrell, K.A., 2000”.

This current study tackles the application of GIS technology in the petroleum industry, specifically, those applications related to exploration stages of the industry, as known; GIS technology is somehow a new field in general and not been wide common among industries related to petroleum field.

First of all It's important to state that petroleum industry is a very critical and sensitive, so nobody can expect to get much data related to preparatory result viewing stages of building GIS in this industry and in some cases the output results as well, even in published papers, author are someway are restricted to show just a limited range of inputs and outputs, this problem had been already encountered through the current two case studies.

Literature overview:

Although the GIS application is relatively a new technology to the world of petroleum industry, it will no doubt confirmed as a valuable tool for its capability to apply and facilitate analysis, some of these studies and programs here below:

- Saudi Arabian Oil Company (ARAMCO) explores the advantages
  of enterprise GIS and developing innovative GIS solutions for more than a decade in surveying and exploration procedures related to surveying missions, monitoring the performance of contractor teams, and analyze geophysical data collected during the surveys. (GIS best practice; GIS for Petroleum, ESRI 2007)

- GIS application in Oil and Gas industry, OMV Petrom Romania.
  Manuela Badea, Elena nedelcu, OMV Petrom S.A., Romania
  OMV is an important central-eastern Europe company in oil and gas, employing ESRI GIS applications focus on exploration and production (E&P) through building analysis tools, to reduce data redundancy, allowing easy multi-access ways to data in many applications, and developing the overall exploration and production work flow.

- Effects of "Hurricanes in the Gulf of Mexico" in reducing rates of oil and gas production (2004, 2005), GIS could spatially represent the predictable hurricane passageways and evaluate risk factors that make petroleum companies awake for the future storms and hurricanes.

- ArcGIS in the oil and gas exploration work flow. Petroleum development, Oman.
  Kevin McLay, Roland Muggli, Safia Mazrui, San Diego, July 2003
  Integration and Mapping of well data and analysis of trap configuration for the producing fields.

CASE STUDY 1: (GIS-based modeling of secondary hydrocarbon migration pathways; applied in the northern Songliao Basin, northeast of China)

This case studies the possibilities of modeling of secondary hydrocarbon pathways, which was applied in the northern Songliao Basin, northeast china. The model based on definite algorithms constructed in a raster Digital Elevation Model (DEM) for the top boundary of petroleum carrier bed, such models need a huge amount of geological data regarding timing, distribution of source rocks, migration phases, main reservoirs, and paleo-structural traps before and during petroleum migration times, timing factor is a very serious parameter in success of any hydrocarbon traps, because these traps must be configured before migration processes (Richard, C, Selly 1998), all these data are available in addition to drilling data which would be the key factor to evaluate the modeling results later on.

The DEM is a GIS method that utilized widely to investigate the flowing of subsurface ground water (Li et al., 2002), the main differences between Hydrocarbon and water migration flow is that water flows downwards, while oil and gas migrate upwards because water flowing on earth surface or subsurface by gravity force, while oil and gas migration are mostly driven by the differences of buoyancy and capillary pressure. As a result, it's possible to use the same principle that used in hydrology modeling to secondary migration modeling of hydrocarbons, to a certain degree of logic this would be acceptable as both of them are fluid flow processes controlled by gradient of the surface or the flowing boundary as shown in *(figure 1)*.

Expelled hydrocarbons from the source rocks will migrate upward along the directions of dip and perpendicular to the strike of a carrier bed, this journey makes the modeling of secondary migration route possible (England et al., 1987). Petroleum migration pathways through a basin can be determined by the three dimension geometry modeling of the top boundary of reservoir rock overlying by a seal rock where hydrocarbons migrate along the reservoir's top boundary via most helpful routes, (Hindle, 1997)., therefore, determination of the 3D geometry in the hydrocarbon-carrier formation is the basic of modeling the secondary hydrocarbon migration pathways.

Methodology:

In order to simplify the hydrocarbon pathway delineation let us think about a point source Area; as current study definition, a point source is a point in the carrier bed from which hydrocarbon begins to take definite route(s) that lead to entrapment zone. In reality, hydrocarbons don't driven out through a point when talking about the huge accumulation of reserves within a large area of carrier bed.

Similar to procedures in hydrological modeling *(Figure 1)*, a DEM model for the top boundary of the carrying bed is created, and then, a 3X3 searching window was applied for tracking hydrocarbons migration paths on the DEM model

The tracking begins with assumption of point source is located in a definite pixel, at the beginning, a 3X3 search window was built and the source point was put in the center of this window, so the source point has eight neighboring cells *(Figure 1)*, after that, the delineation would be to the neighbor cell which has a highest value of altitude (geologically, considered to be the most shallowest zone -from earth surface- with preferable permeability), this searching process must be repeated until the central cell of the searching window travels to a trap configuration where real accumulation happened, or in some cases extends to outside of the study area, finally, all these selected pixels were connected together to form a line which is the hydrocarbon migration pathway, But there are several issues need to real illustrations as the following.

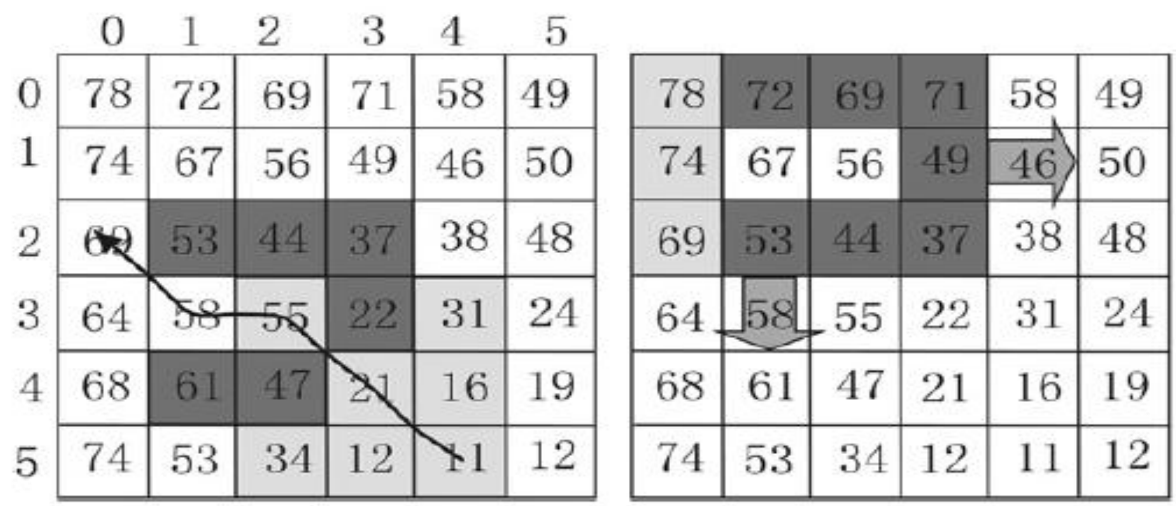


Figure 1: *Modeling of hydrocarbons migration left and hydrological water flow model right. (after Xuefeng Liu et al., 2008).*

Termination issue:

termination relates to possibility of creating convex point which might be encountered and leads to ending the searching process, in geology, *convex point represent the definite location of trap where hydrocarbon can't migrate any more*, in this case, the model suggests that the accumulation region is laying in the convex point *(Figure 2A)*. In contrast, the model will terminate the search if the tracking reached to the boundary pixel where no convex found indicating that the migration expands outside of the DEM raster *(Figure 2B)*.

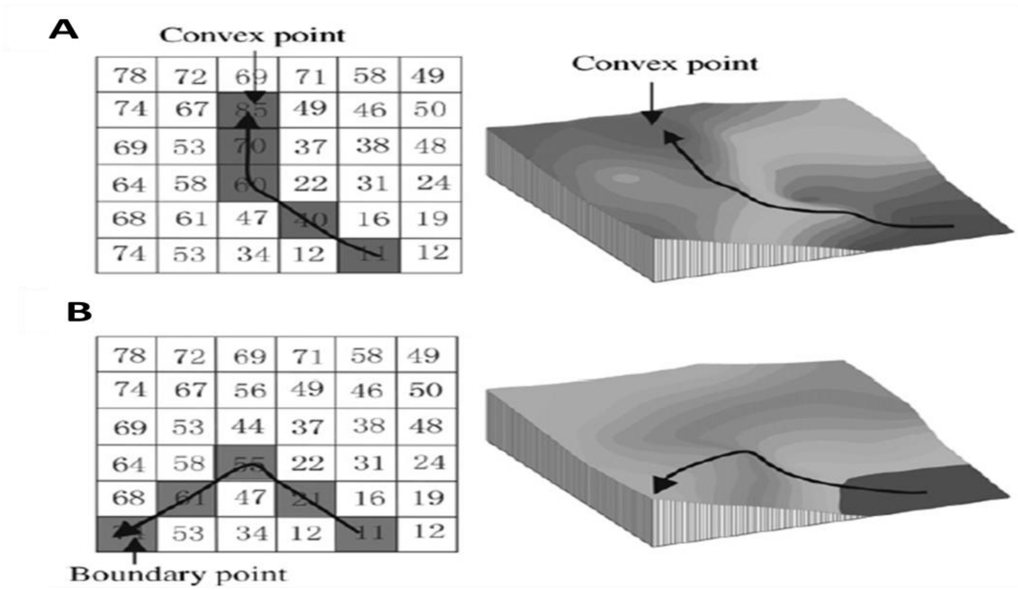


Figure 2: *Modeling of a hydrocarbon migration pathway endinging at a convex point (A), and at a boundary point of raster DEM (B) (after Xuefeng Liu et al., 2008).*

Divergence and convergence:

If all or some of eight pixels around the central pixel having the same maximum height value, the model will suggest that the migration path will split into two or more paths (according of number of co-altitude pixels). In such case, all pixels with an equal highest altitude must be taken into account assuming each one as a new, separate starting point, the search procedure will be repeated till the next pixel is found *(Figure 3A)*; as shown, the same maximum altitude (61) found in pixel (2,1) and (2,3) enclosing to centre pixel (3,2) so both of them can be believed to be starting points creating two independent pathways, as a result the main path branched into two dashed paths starting from divergence pixel (3,2).
As reverse to divergent paths, convergence issue will come into mind if two or more passageways meet at a pixel, the new central pixel will be judged if it is located at any pathway determined previously, so the search process will terminate into one point, otherwise, the search will go on separately. As shown in *(Figure 3B)*, the search process of the two paths were terminated and merged at pixel (1, 2), clearly this procedure is very effective to evade the over calculation and optimizing searching algorithm.

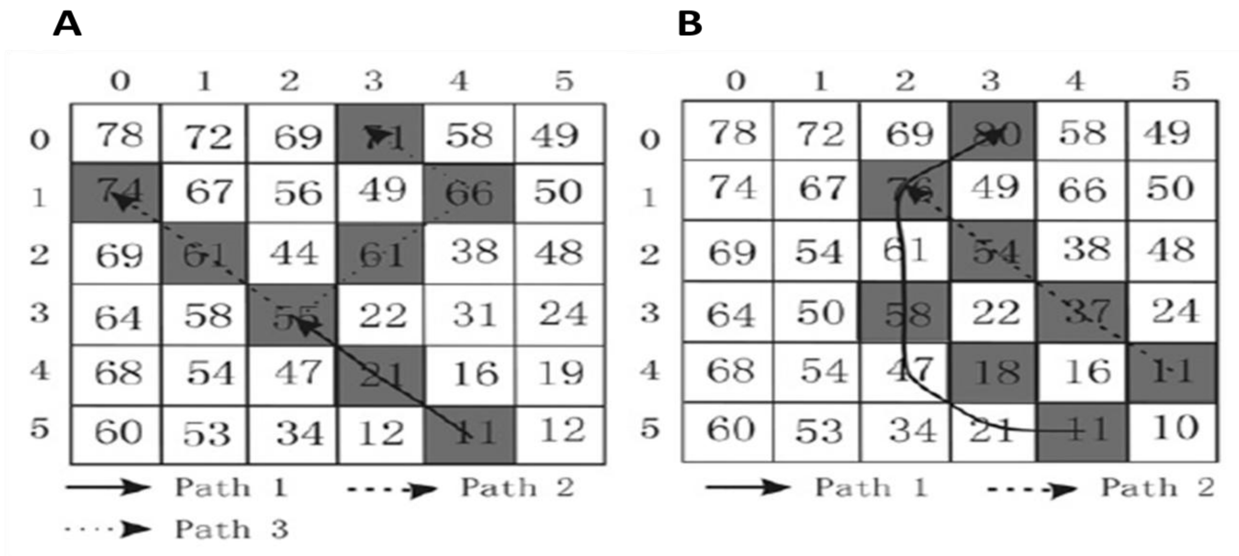


Figure 3: *Modeling pathway divergent (A), and convergent (B). (after Xuefeng Liu et al., 2008).*

Situations of polygon hydrocarbon source

In GIS modeling, the actual petroleum life, migration can be considered starting from a polygon, but as this GIS application is not common in the petroleum industry, this study considered the migration starts from points on the boundary of the polygon are the start points, which it is also make the delineation easier. Basing on real petroleum geology scenarios, when migration journey go longer; hydrocarbon tend to migrate in convergent channels to the trap area, in other words, the number of paths decrease per distance increasing from the source point. Overall summary of searching scenarios, can obtained in *(Figure 4)*; as shown below there are six pixels at the boundary can be considered as a polygon , these pixels are associated with six proposed migration paths, there is one path(3,4) end at the convex point, two paths (8,0) and (4,8) ends at boundary pixels and extending out of the study **area**, and three paths converge with path 1 at pixels (4,4), (5,4),and (6,4).

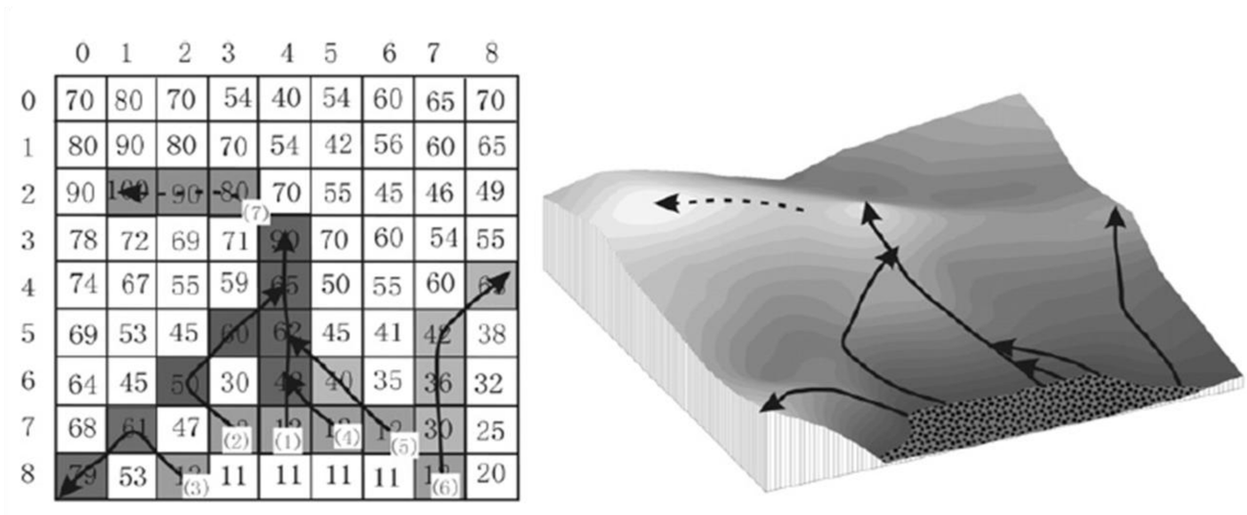


Figure 4: *Migration pathways model for a polygonal source area, (after Xuefeng Liu et al., 2008).*

Remigration of hydrocarbons:

From previous discussion, hydrocarbons will accumulate in a convex point where a trap is created, but if hydrocarbons expelled out from the generating area were huge amount that could fill the trap with a surplus; in this case excess hydrocarbons will re-migrate out of the totally filled trap until arriving a new convex trap. Obviously, the key to decide the remigration Passage-ways of hydrocarbons is to get the pixel where the overflow begins. The overflow point is geologically can be situated at a point between two traps called ‘saddle’ (*Figure 5).* According to this study, all saddles had been located in place, and then every remigration path was tracked as aforementioned process. All pixels that situated in the enclosure region of the starting trap are excluded to avoid flowing back of hydrocarbons into the starting trap.

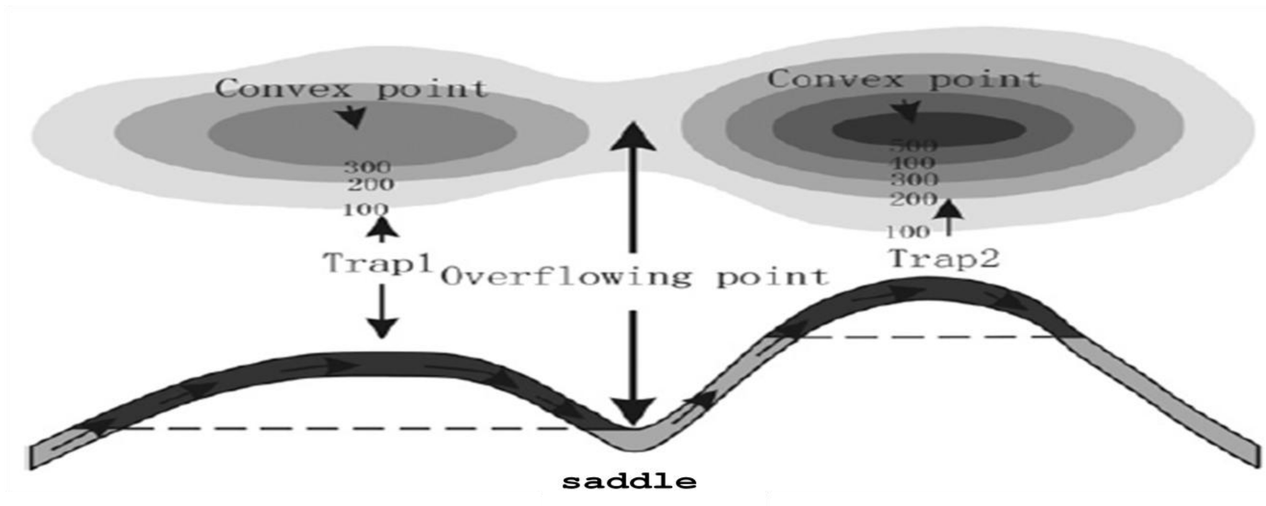


Figure 5: *Geological sketch of an overflow point (modified after Xuefeng Liu et al., 2008).*

By reference to *(Figure 4),* pixel (2, 3) is considered as an overflow point with height 80, and pixels (2, 2) and (3, 4) have the same greatest height value (90) among the eight enclosing pixels, , according to the algorithm parameters, both pixels are the next searching pixels, but pixel (3,4) is naturally excluded by considering that it is an already existing and occupied convex point, so pixel (2,2) can be confirmed as the next object convex. The resulted remigration pathway of hydrocarbons from trap 1 to trap 2 is path 7.

<u>Application of DEM methodology (northern Songliao Basin, China):</u>

The largest Mesozoic and Cenozioc non-marine sedimentary basin in east of China and the most significant oil-producing is Songliao Basin which locates in the north east of China, *(Figure 6).* As shown in the map below; it's bordered by the Daxin'an Mountains to the west, Zhang Guangcai Mountains to the southeast, and the Xiaoxin'an Mountains to the northeast.

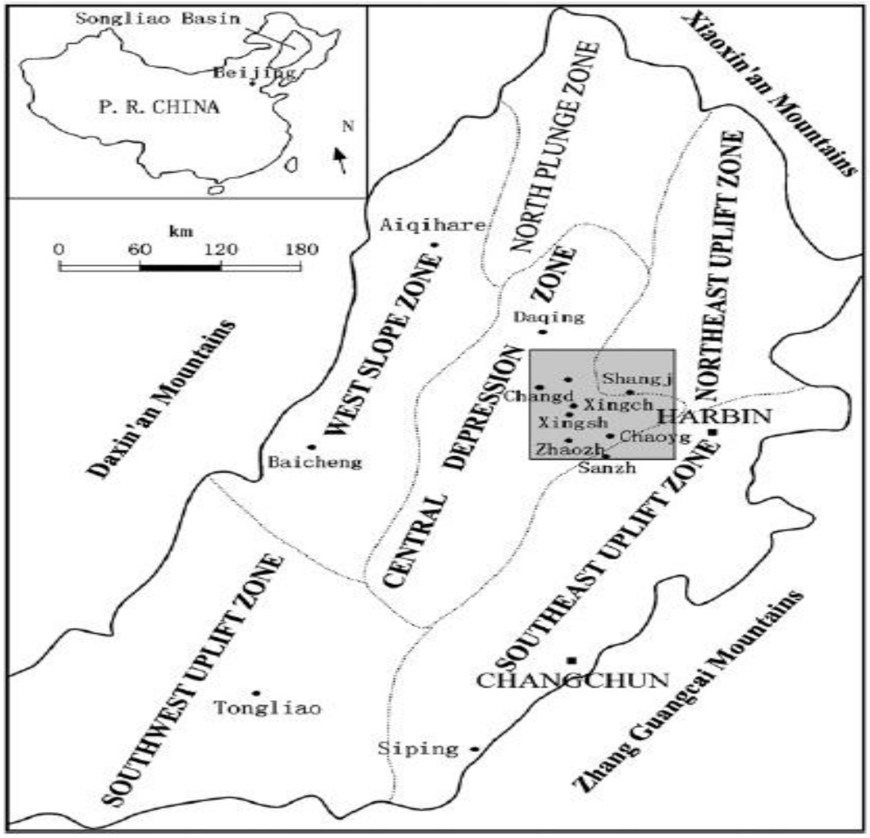


Figure 6: *The main structure elements in Songliao Basin, the study area is indicated by shaded zone (after Xuefeng Liu et al., 2008).*

The geological setting of the basin *(Figure 7).* Shows that the basin is underlain by Precambrian-Paleozoic metamorphic and volcanic rocks, the tectonic and sedimentary setting in the Songliao Basin examined three large sedimentary and tectonic evolution stages, which represent the evolution of extensional faulted depressions during late Jurassic to early Cretaceous, thermal subsidence during late Early Cretaceous to early Late Cretaceous, and structural inversion during late Cretaceous to Cenozoic. According to (Ren et al.,2004) the stratigraphy composes of upper Jurassic Huoshiling Formation, lower Cretaceous Shahezi Formation, Yingcheng Formation, Denglouku Formation, and the members 1 and 2 of the Quantou Formation.

Study illustrates that there are three sets of - lacustrine mudstone and coal beds -Hydrocarbon sources, these sources developed correspondingly upward in all of member 1 of Huoshiling Formation, Shahezi Formation, and member 2 of Yingcheng Formation, concerning its big thickness and high total organic carbon (TOC) contents; Shahezi Formation represents the most hydrocarbon-generative among the three source rocks. In the studied area, reservoir rocks are found mainly in the Denglouku Formation, lower Quantou Formation, and member 4 of the Yingcheng Formation. Geologically, these reservoirs consist of clastic sediments including alluvial fans, braided river conglomerates and fluvial, deltaic sandstones. Member 1 and 2 of the Quantou Formation are mainly consisted of mudstones interbedded with sandstones, so they represent effective cap rocks. The expelled natural gas from Huoshiling and Yingcheng Formation first migrated to the Denglouku Formation, then laterally traveled along the top boundary of Denglouku Formation which overlain and e regionally sealed by cap rocks of members 1 and 2 of Quantou Formation, after all, natural gas accumulated and formed suitable traps of hydrocarbon reservoirs. The research of natural gas upon reservoir history signifies that the hydrocarbons was expelled out of deep buried sources during the end of both early and late Cretacious, while the reservoir was formed mainly during Late Cretaceous (Ren et al., 2004), therefore the paleo-tectonics of the top of Denglouku Formation (carrier bed) which created during the end of Quantou Period could be approximately regarded as simultaneous structure in the natural gas main forming-reservoir period, anyway, this paper regarded the paleotectonics events of the top of Denglouku Formation formed during the end of Quantou Period as the predominant structural factor that has guided the configuration of natural gas reservoirs.

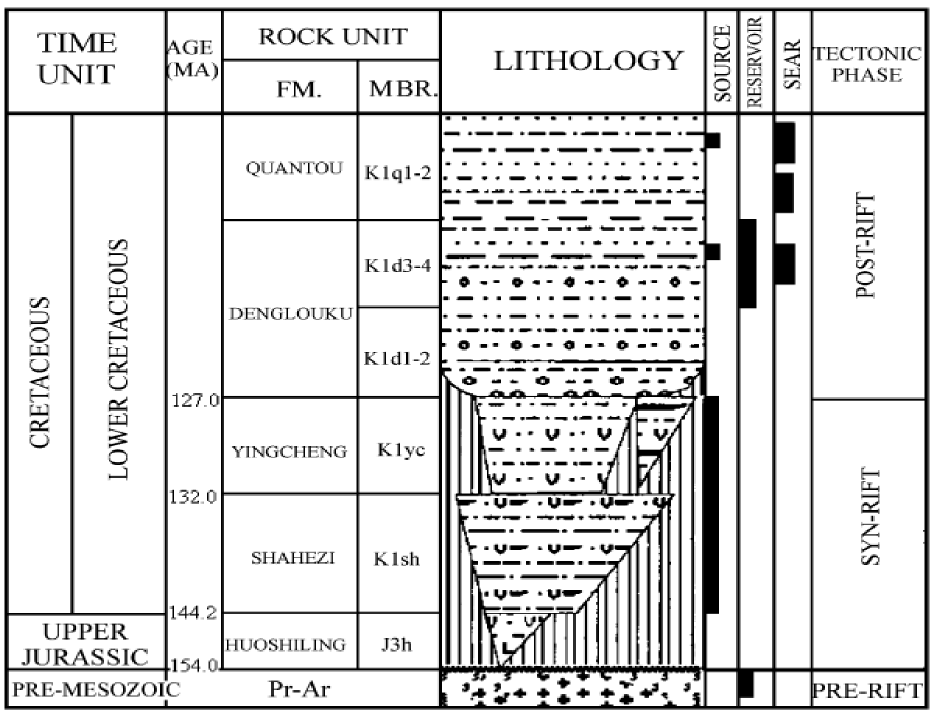


Figure 7: *The Stratigraphic column, stages of tectonic phases, and distribution of hydrocarbon elements in northern Songliao Basin (after Xuefeng Liu et al., 2008)*.

Modeling framework:

SuperMap 3.2 is a general GIS software developed by the institute of geography, Chinese Academy of Sciences, this software is used for modeling of hydrocarbon migration pathways, as shown in *(Figure 8)* the model building framework include data preparation, processing, search for secondary migration pathways and finally visualizing results.

Data Preparation and processing:

As any geological model, a lot of geological data are required including times and phases of hydrocarbon migration as well as the spatial allocation of generative source rocks, main reservoirs, and paleostructure traps before and during the period of hydrocarbons migration. According to the study; (Ren et al., 2004) was the basis of all data related to the key phases of migration and sources distribution, at the same time, the paleo-structure contour map of Member 4 top; Denglouku Formation (main carrier layer), and the spatial distribution map of structural traps were adopt from.

The DEM data set of the top Denglosuku Formation was created from the matching data set of paleo-structure contour lines by spatial interpolation, after that, SuperMAP GIS function of vector-raster transformation was used to transform The polygon data set of structure tectonic traps; member-4 of the Denglouku Formation, and also the line data set of hydrocarbons source area boundary from vector to raster sets, then the pixel sets inside structural traps and on the hydrocarbons source boundaries were taken out via raster data extraction function which installed to the GIS platform.

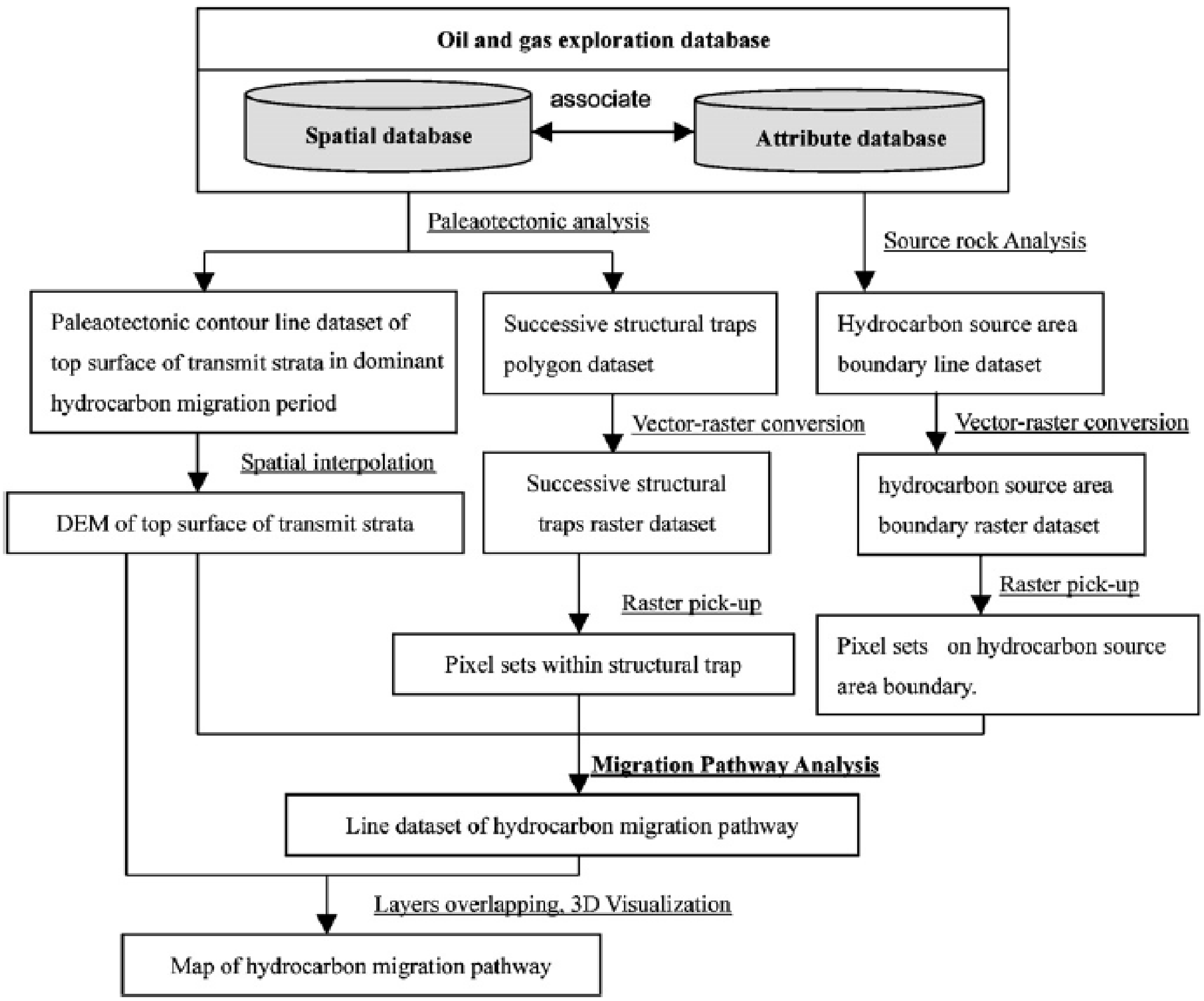
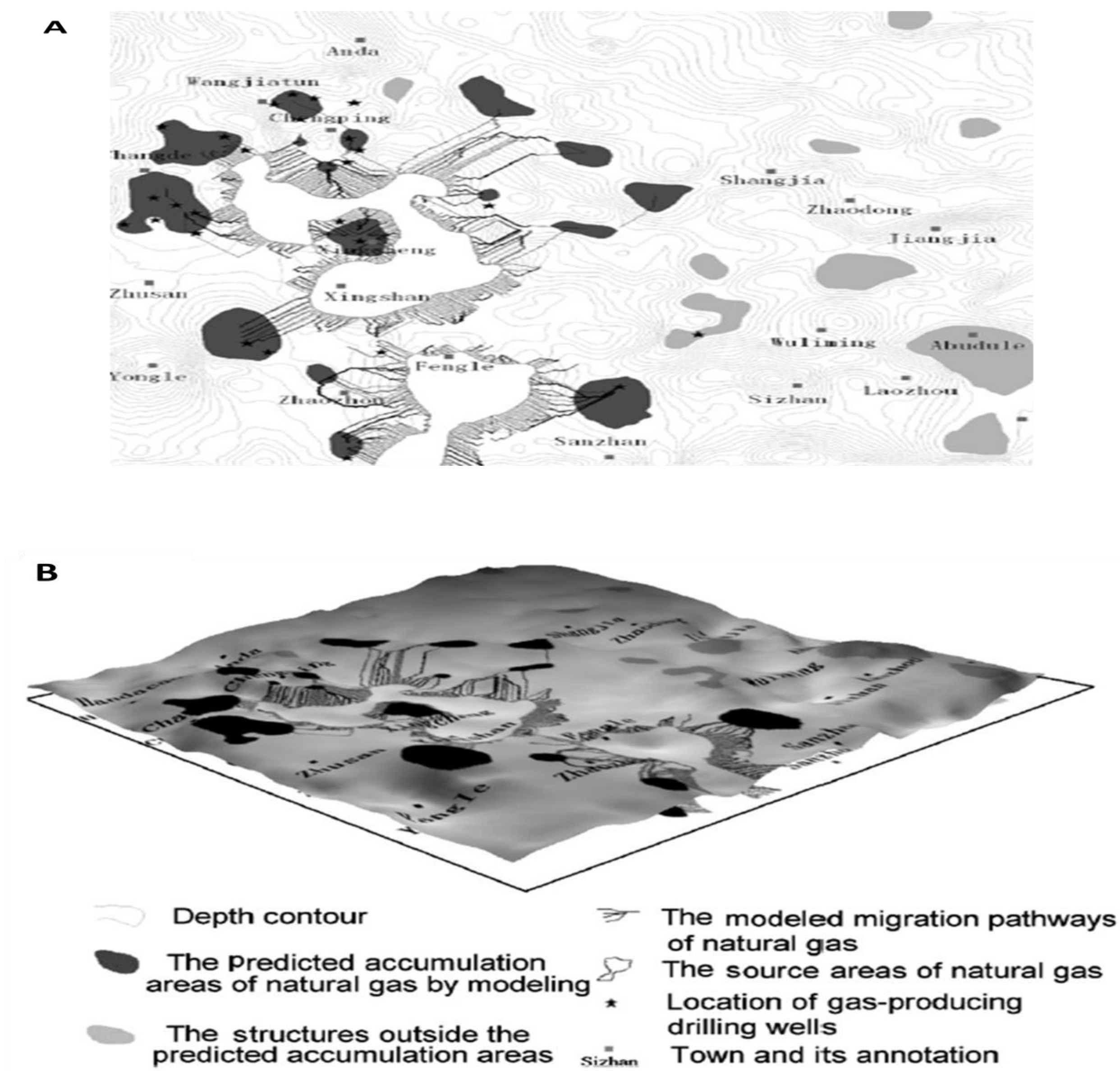


Figure 8: *work flow of secondary hydrocarbons migration modeling (after Xuefeng Liu et al., 2008).*

Migration pathways and Results Visualization:

All paths of migration was tracked starting from every pixel in the pixel set of hydrocarbons gaseous generating area boundaries, and by the same tracking module; hydrocarbon remigration from trap to another also tracked taking the spill point (overflow point) as a new starting point. All migration pixel sets were lastly converted to vector line set. The line data set of migration pathways were superimposed upon the polygon sets of structural traps of member 4; Denglouku Formation and the DEM data set related to the main carrier bed, whereupon the 3D visualization function of SuperMAP 3.2 was used to visualize the results *(Figure 9).*



Figuer 9: *two dimensional (A), and three dimensional (B) visualization of the migration pathways. (after Xuefeng Liu et al., 2008).*

CASE STUDY 2: (Establishment of a trap information system based on GIS)

Another GIS based study was applied using geological data of Talimu Basin, northwest of China, to build an integrated trap information system where the basic frame work relied on huge attribute and spatial database, in addition to eight modules including input, query, statistics, expert system, fuzzy assembling, neural network, output, and decision making module *(Figure 10).* The purpose of this study was to dedicate GIS abilities to show all trap-related data by an easy means.

Methodology:

The framework of this GIS system was compose of two databases and eight modules described as below

Attribute database:

Represents the heart of the system and is based on a relation database. Because the trap system depend mainly on earth sciences facts, It is unsurprisingly contained of attribute tables for traps, hydrocarbon fields data regarding geographic and tectonic location, , potential reserves, exploration information reservoir data, sealing data, results evaluation, and decision making. There are also technical tables concerning to source rocks, faults, drills, logs, production test records and seismic exploration.

Spatial database:

The spatially related database consists of spatial location, shape and relationships among traps. Spatial database store and manage various data sets such as 2-dimension, 3-dimention seismic lines, 3-dimension seismic areas extension, wells and faults locations beside the abstract attribute data such as area, height and depth of traps, spatial location, spatial shape and spatial relationships of traps.

Input module:

Performs the input process of attribute data, either via the user interface of the attribute database or the spatial database. Spatial data can be input only through the user interface of the spatial database.

Query module:

Information Queries can be carried out by the user through this module A query order is performed either throughout the user interface of the attribute database or the spatial database. The request maybe a simple query or conditional query through linking tables. This system offers 10 operator symbols and 33 functions for the user to create complex query conditions.

Statistic module:

By statistical module, the user can carry out all statistics data analyses, such as summation, averaging, maximum and the minimum values, and calculating the variance. Visual results are also doable like charts; pie charts and graphs; area graphs, bar graphs.

Expert system module:

This module used for evaluation of the geological success of traps basing on a production rule knowledge, by that, the module able to performs rule-based interpretation and uses certainty factors to reflect the degree of geological success of traps. Via this module, user can build the knowledge base, recover data, process the inferences, and lastly create the success possibility per trap.

Fuzzy assembling module:

Using the fuzzy set concept the module also implement an evaluation of geological traps success, but from a different view which by execute fuzzy inference, generate membership grad, the module evaluates the success possibility of the traps in the area of interest. User can select variable data fields, regain data from the database and process calculation of fuzzy, and lastly generate the results.

Neural-network module:

It's a synthetic neural network also to assess the success of traps. This network is relied on three layers of BP (back propagation) network model. User is able to select data fields as variables, recover, and expect the results of untried traps by neural training model of the existed successful traps.

Decision-making module:

Bearing in mind the possibility of geological success, this module organizes traps in exploration wise, the capability of the module to anticipate the reserves and their costs, aid make traps ranking and there for make a decision regarding further exploration or even production.

Output module:

This module is carrying out information output; the results can be displayed as tables, maps or files where can be ready for printing or plotting.

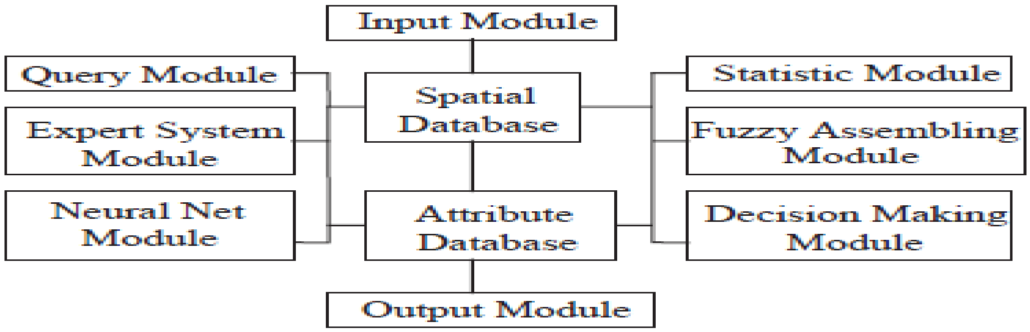


Figure 10: *The framework of the GIS-based trap system (after W. Chuan, P. Suping, 2003)*

Results of the trap system:

As this study concerns with the hydrocarbon trap it's expected to take the oil and gas exploration characteristics into consideration to build the software, so the application of system can sort out into user map interface, information query of traps, statistical analysis, trap evaluation and exploration decision making.

User map interface:

From the geological map *(Figure 11)*, the user can query and carry out statistical analyses by selecting some areas of the map, or select more detailed map of that area, for example, the highest interface is the map of basin distribution in China. If Talimu Basin was selected, it's easy to get back all the data about that basin and carry out some statistical analysis in addition to get to the more detailed map of that basin. The sequence from the highest map to the lowest map (more detailed map) –as classified in the software- is: "basin; tectonic region; distribution of traps (with the position and orientation of the faults, 2D seismic lines, 3D seismic extents, not seismic geophysical and geochemical extents, boreholes and geographical contents); structural map of traps; and seismic sections across the higher altitude of traps" so it's simple to use and understand the map interface.

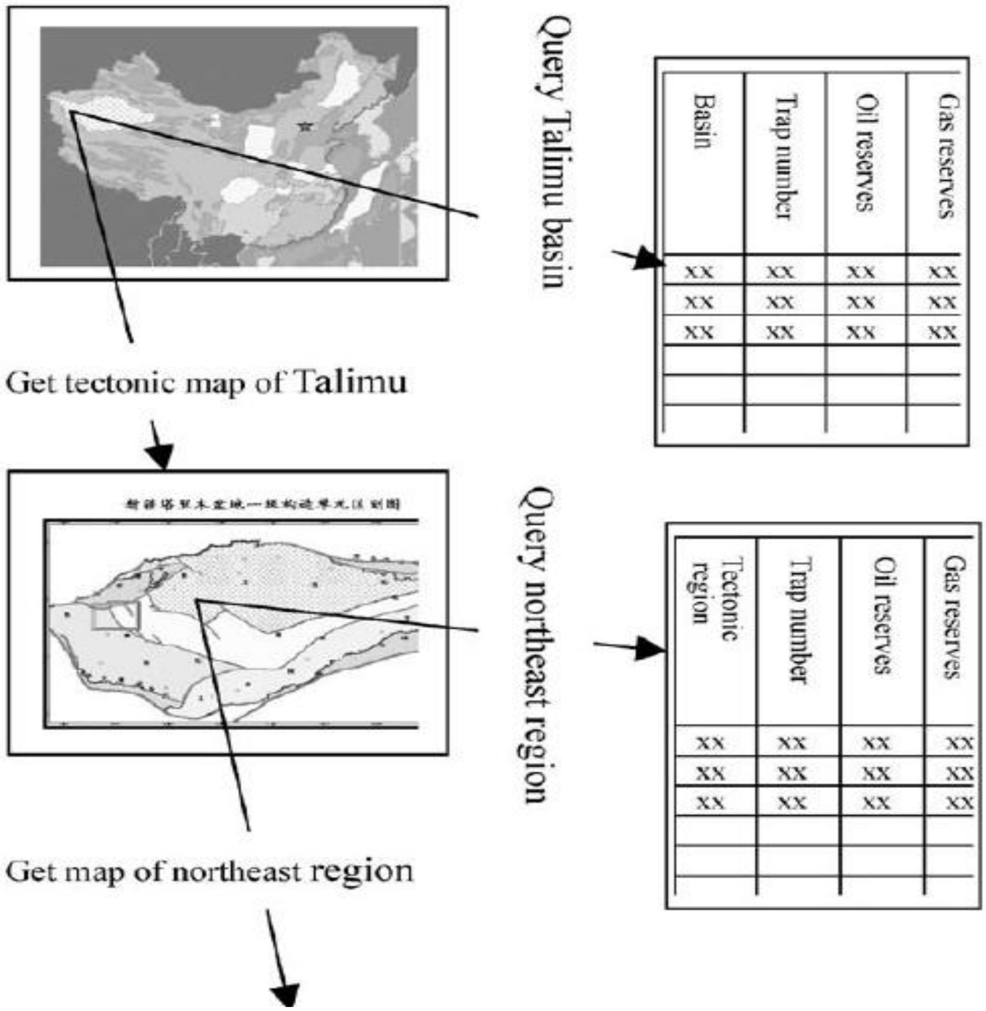


Figure 11: *some function of map interface (after W. Chuan, P. Suping, 2003)*

Trap information query:

The scheme can carry out both simple and complex queries with ability to make conditions on trap information, e.g.; if the name of a trap inserted to the query interface, all the information about that trap can be quickly and simply retrieved, by contrast, , it's also possible to get complex query like selecting all traps less than 2500 m depth.

Because the system is based on GIS data, related images can be displayed at the same time during check of the attribute data, moreover; the user can concurrently observe the spatial attributes; spatial shape and exploration level beside inspect some related images as faults, seismic lines, and wells *(Figure 12)*.

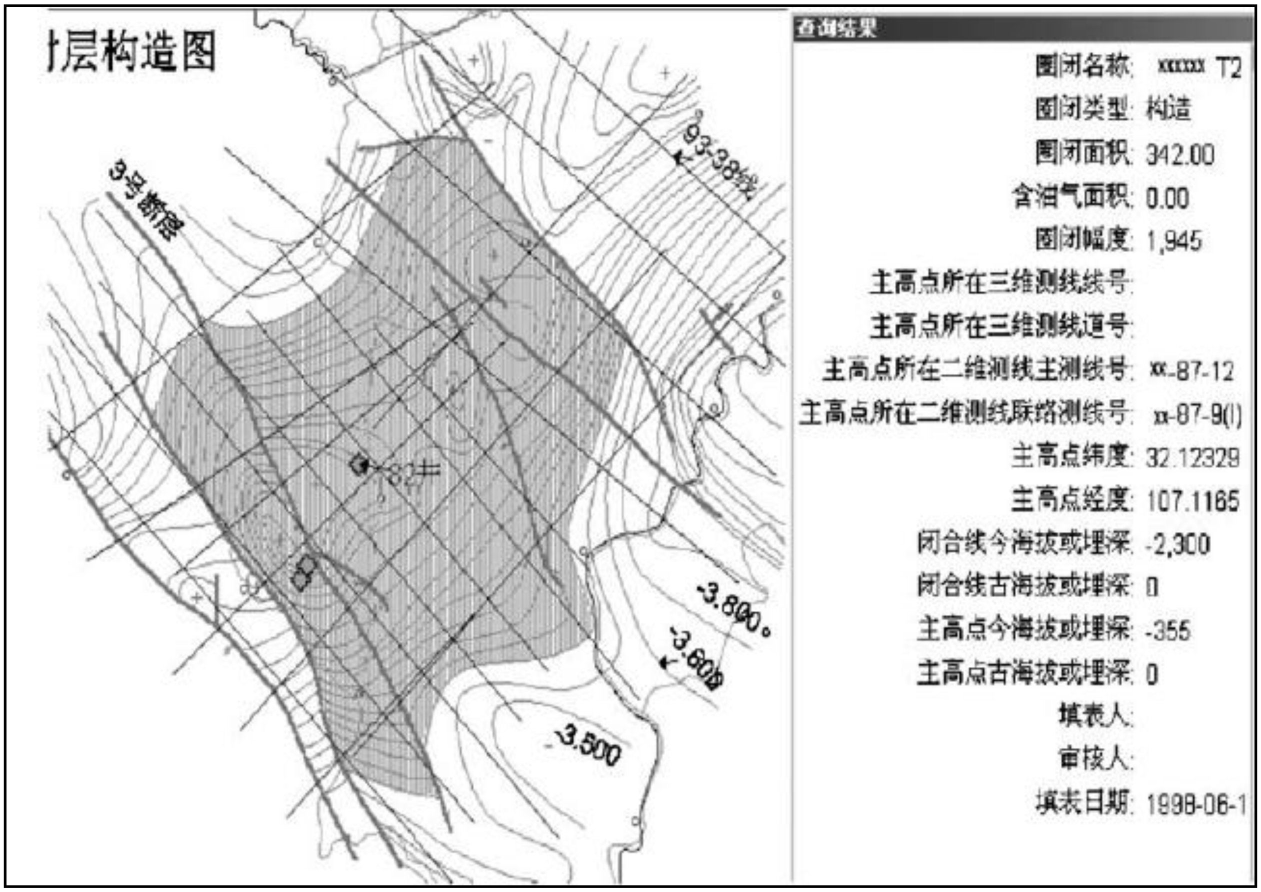


Figure 12: *Results of trap query. (after W. Chuan, P. Suping, 2003)*

Statistical analysis:

In addition to the ability to information query, the system can also perform statistical analyses of trap information, such as distribution of traps type in the whole regions, trap geometry, depth and horizons, statistics about size, degree of exploration, potential reserves, and success ratio *(Figure 13)*. These statistical results are vital matter for prospected exploration, and would be very critical to evaluate the development stages of basin life.

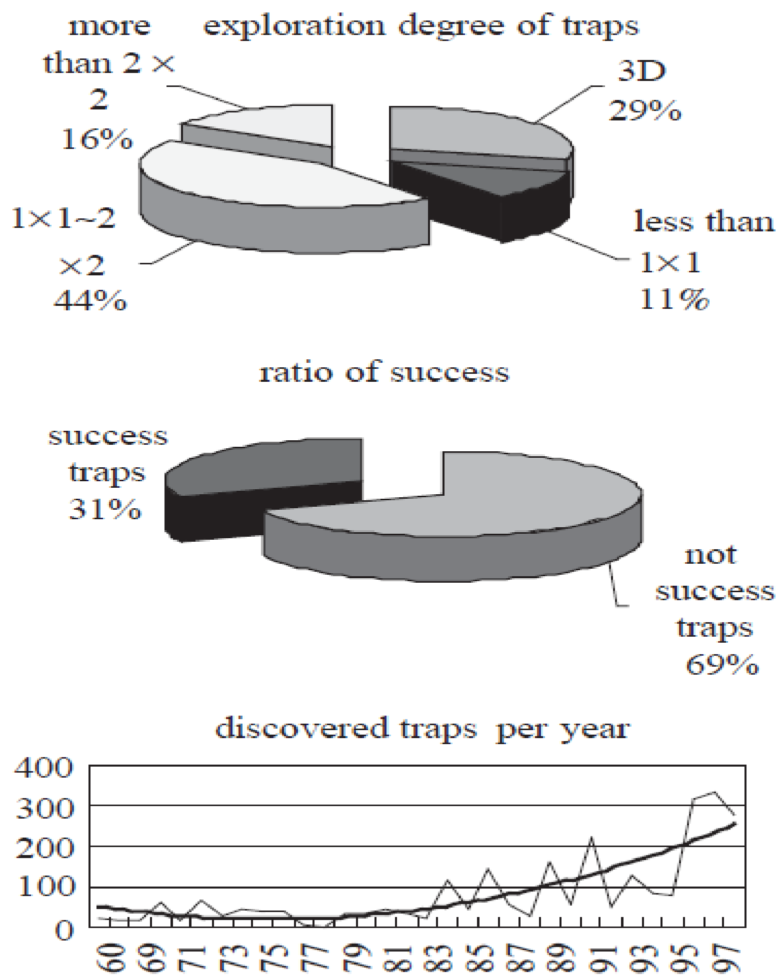


Figure 13: *Some statistics of traps information (after W. Chuan, P. Suping, 2003).*

Conclusion:

This study talked about the GIS application in petroleum exploration taking as examples; two case studies about different applications, run in two different sites, the first case study introduced a GIS based model for migration simulation of natural gas in Songliao basin, north east China using definite modeling algorithms which took into consideration the nature of the upward migration of gas, because the shortage of data, these models based only on the top surface geometry of member-4, Denglouku Formation, although migration pathways modeling needs a lot factors and data such as burial depth, capillary pressure, permeability but this study enhance feasibility of GIS-based modeling in such studies even in a new petroleum fields as its carried out on an already productive field and the results showed an agreement with existing, an important factor to delineate migration pathways in many basin is faults distribution, which act either as pathways or seals (barriers) of petroleum migration wasn’t considered in this study because there are no faults found crossing and affecting cap rocks. The second separate case study is somehow related to an advanced step in hydrocarbon exploration as it displayed the ability to establish a trap information system based on GIS, the system framework included two databases and eight modules to summarize a series of conventional procedures regarding data query, statistical analysis and even decision making the matter which save a lot of effort and time.

Finally I highly recommend benefiting from GIS technology in petroleum exploration and other sections in petroleum industry as a tool that saves money and time with ability to expand the input database to cover all factors that affect on exploration success.

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