STATE OF THE ART IN GEOTHERMAL FIELD VISUALISATION

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SUMMARY – FieldGL, a graphical three-dimensional (3D) interface for the GDManager integrated geothermal database system is presented. The interface allows the user to interactively view and explore wells, data related to wells, and other subsurface information. It can also be used to view and graphically modify a computer model and then to view the results of a simulation. The interface is written with Borland Delphi and utilises the accelerated graphics rendering tools available in standard GLScene and OpenGL graphical libraries. As the interface library is object orientated it is readily extendable and has since been incorporated into the Automated Well Test and Analysis System (AWTAS) and WELLSIM softwares developed conjointly by PB Power, Genzl Division and UniServices. This library is an attractive alternative to existing 3D packages for displaying information within a geothermal field.

1. INTRODUCTION

The GDManager integrated geothermal database system has progressed from a MS-DOS based system (Barnett et al., 1987; Anderson and Ussher, 1992; Anderson et al., 1995) to having a sophisticated Windows interface (Anderson et al, 2000). GDManager is presently used by some 15 government agencies and private power producers for the management of more than 40 fields in 10 countries.

GDManager now stores practically all of the geothermal resource data collected on a geothermal project fi-om the initial exploration, through to exploitation of the resource.

The critical importance of data collection and maintenance in a geothermal field is well established (Anderson et al., 2000). A geothermal resource, under exploration, is a four dimensional entity (x,y,z,t). In the context of mathematical modelling it is essential that the location of each element of data is accurately known and stored. To this end AWTAS (O'Sullivan et al., 2000) was developed using a subset of GDManager database tables as a means of constructing mathematical models based on validated well locations and geometries.

Wells are a major source of data within a geothermal field. Details about a well's location, deviation trace, casing details, associated feed-zones, and lithology provide much well information to the geothermal engineer.

Traditional means of comparing properties on a well-by-well basis involved exporting data to an external package such as SURFER © (Golden Software Inc., USA). There are shortcomings with this approach, however, as the graphical results are plotted as a cross-section or elevation. Furthermore this plotting procedure has no capability for feedback and as such cannot be used as a pre- or post-processor for mathematical modelling.

1.1 Existing Visualisation Packages

One goal of sophisticated data management packages is to provide true 3D visualisation (Anderson et al., 2000). Sophisticated 3D graphics packages have been developed for fields such as petroleum reservoir engineering, finite element analysis, and computational fluid dynamics. One such visualisation package, used for groundwater applications, is the Visual MODFLOW 3D-Explorer (Accent Software, 1999).

Unfortunately these products are typically expensive, require expensive hardware, and are customised for the associated modelling software. In some cases the interface is a separate application where results from a numerical simulation are read and then displayed (Bullivant et al., 1995). This paradigm can be unwieldy and is contrary to the philosophy of GDManager as a central repository of geothermal data.

1.2 Aims of this Interface

The main goal is to provide a graphical interface integrated into GDManager that allows for a certain amount of user interaction where appropriate. Of perhaps equal importance is to allow for extensibility so that it is available for other software that uses a GDManager database as the field descriptor. A useful geothermal 3D graphical interface for GDManager has the following aims:

- Render geometry of GDManager spatial data
- Selection, translation, and zoom
- "Well-centric" design
- Integration/extensibility with application
- Mathematical model pre- and post-processor

• Runs on IBM-compatible PCs
• User-friendliness

This paper describes an interface (called FieldGL) that goes some way in satisfying the above aims. The interface is based on Borland Delphi's Visual Component Library (VCL) (Cantu 1999) philosophy allowing the interface to be used in all "GDManager-aware" softwares. This provides an obvious benefit of a consistent behaviour for all applications and this aids in user-friendliness.

2. DATA OBJECTS

FieldGL makes the distinction between two different types of data objects:

• Data stored in a GDManager database
• Data used to represent a mathematical model

These object types are now discussed in turn.

2.1 GDManager Database Tables

The GDManager database structure represents a normalised data model of the information that is stored (Barnett et al., 1987). Links between the database tables embody logical relationships within the information stored. For example, well location and deviation is maintained in the well and well deviation tables, while geological and temperature data collected fi-om wells is stored in separate, but related tables (Barnett et al., 1987). FieldGL uses these relationships to calculate the spatial location geometry of observed data. It currently accesses a subset of tables fiom a GDManager database as follows:

Well
Specifies the well name, wellhead location and elevation, casing depth, major feed-zone depth and total measured depth.

Well Deviation
Specifies the well deviation, in terms of measured depth, vertical depth and deviation east and north of the wellhead at surveyed points down the well. A simple linear interpolation is assumed between the surveyed points.

Well **Casings**
Specifies all casings in terms of sections specified in start and finish depths, casing type and date.

Production Zones
Specifies the top and bottom of feed-zones in the well together with the interpretation method (e.g. 'spinner **log'**, 'water circulation loss') and relative importance (e.g., low, medium, high).

Gravity (Surface Surveys)
Specifies the location, elevation, and observed gravity of points occupied in a gravity survey.

Well Stratigraphy
Specifies the measured stratigraphy **from** a well in terms of formation type and top and bottom depths.

All depths in the property tables, that is well casings, production zones, and stratigraphy, are specified in measured depths. In combination with the well deviation a property location in global 'xyz' co-ordinates can be obtained.

2.2 Mathematical Model Data

Mathematical models of a well and/or reservoir feed-zones are typically formulated based on the physical layout of wells and production zones identified during testing. It is advantageous to "overlay" a finite volume grid with the well data **from** the GDManager database for example and use FieldGL as a simulation post-processor.

A well bore finite volume grid can be considered simply as a collection of cylindrical blocks aligned along the well trace with diameters fitting the selected casing configuration. The structure of the grid might be **known** prior to simulation such as the case of a transient well-reservoir model for example. Alternatively the blocks may be constructed on the fly. This is useful for examining the step-wise iteration procedure used in WELLSIM (Gunn, 1992). In both cases the scalar numerical variables (e.g. pressure, temperature, two-phase flow regime) may be shown graphically on a block-by-block **basis.**

A radial feed-zone can be considered as a collection of concentric annuli centred about the sand-face (well-reservoir connection). Changes in pressure and temperature gradient are greatest about the well so the grid there is fine with increasing block size towards the outer boundary of the zone. The blocks themselves are children **of** their layer enabling efficient object management within the interface. In this way the user **may** click and drag any block in a layer and the entire radial feed-zone model can be moved along the well trace as desired.

Well and reservoir **grids** are added to the scene as appropriate by the application via public methods in FieldGL. Additional model information, such as the start and end points for a **WELLSIM** simulation, may be displayed in a similar fashion.

3. COMPONENT STRUCTURE

3.1 Introduction

The OpenGL library is an open standard for 3D visualisation developed by Silicon Graphics Inc. OpenGL is a low-level specification, which provides a set of geometric primitives (points, lines, polygons) to describe a particular scene of interest. OpenGL **is** either implemented **via** software or, more commonly now, on hardware-accelerated display adapters.

The GLScene (Grange, 2000) library is a set **of** open source "wrapper" classes to OpenGL, available under the Mozilla Public Licence (MPL, 2000). This library combines the use of Delphi's VCL to give higher-level management of the 3D scene. GLScene provides a hierarchical object structure, movement functions, and procedural objects to provide a generic 3D engine.

The FieldGL interface discussed in this paper provides an additional layer between an application (e.g. GDManager) and the generic 3D classes provided with GLScene. This relationship is shown in Figure 1.

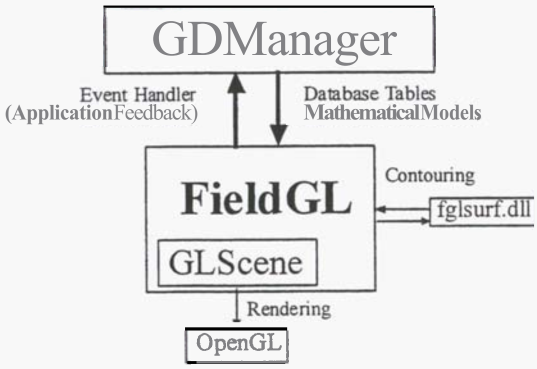

Figure 1- Schematic of the graphical interface FieldGL as used by GDManager.

The GLScene library will automatically provide OpenGL hardware acceleration where available. Such hardware acceleration is the norm with new computer systems at present and this allows an entire field to be displayed at once. FieldGL has been designed such that most object types can be toggled. This allows the interface to be used with software rendering on modest systems that do not support OpenGL rendering in hardware.

A dynamic link library (fglsurf.dll), written in Fortran90, was developed. This library includes a basic scattered data-fitting algorithm (CSHEP2D) (Renka, **1999)** that can be used directly from FieldGL for contouring purposes.

3.2 Controls and Event Handlers

The GLScene library (encapsulated within FieldGL) provides a sophisticated camera-target viewing concept. Once the target (the focal point of the camera) has been set, all movement is relative to this point. Internally, the camera is specified as a "child" of the target. This has the advantage of making the translation and selection operations a simple placement of the focal point. Using the camera-target concepts FieldGL can be used in any one of three "modes":

- Selection of an object
- Movement of camera andor target
- Movement of object to new position

Any object on the field scene may be selected. Selecting an object has the effect of relocating the camera focal point to the new position. Having the ability to select any object of the field is useful, especially in the case of a long narrow field. Fixed focal point options were investigated in early versions of the interface, however this approach was found to be overly restrictive.

There are three basic movement options available and shown in Figure **2.**

- Pitch/yaw rotation (roll is disabled)
- Zooming camera to/from focal point
- Translating camera/target in XY and XZ planes

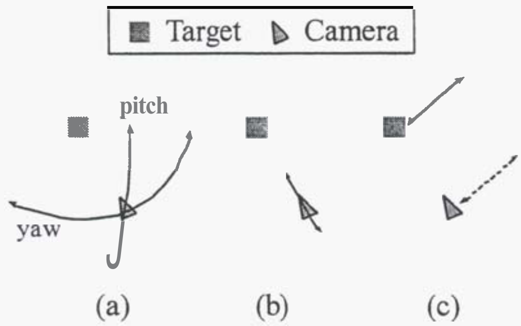

Figure **2-** Camera-Target Movement in FieldGL: (a) Rotation, (b) Zoom, (c) Translation

Navigation around the reservoir is performed through the use of either the mouse or keyboard. The camera-target concepts allow the user to quickly and easily select an appropriate focal point (typically a well, measurement tool, or production zone) and then select a viewpoint based on this perspective.

An object movement mode is available. This has been designed as a means of allowing the user to adjust the position **of** mathematical model objects interactively. To date the moveable objects are 'well-centric' such as a radial feed-zone or WELLSIM simulation start and finish points.

An event-handler (extensible function call) allows the FieldGL interface to be used interactively by the user as both a pre- and post-processor. The object movement mode allows the user to adjust the position of the object along the well deviation trace bounded by the top and bottom. Here the new position is available to the application where the underlying mathematical model is adjusted.

3.3 Hierarchical Well Tree

The data **from** a GDManager database and mathematical models are largely well-centric and are organised internally as such in a hierarchical tree structure. This .logically mirrors both the normalised structure of the GDManager tables and the hierarchical tree of primitive objects in the underlying GLScene library. A particular option can be toggled globally by sweeping through the tree and setting the appropriate option on a well-by-well basis.

3.4 Field Objects

Certain measured objects are not related to a particular well. These include the gravity sample points and the sea level plane. Any object not associated with a well is managed separately fiom the hierarchical tree.

4. APPLICATIONS

4.1 Displaying a GDManager Field

The basic application is to display a field from a GDManager database. Figure 3 shows the Atlantis field (a generic test field) with deviation traces. The sea level (elevation = 0m) is shown as an alpha-blended transparent plane. The camera target is focused on a group of wells in the south east of the field.

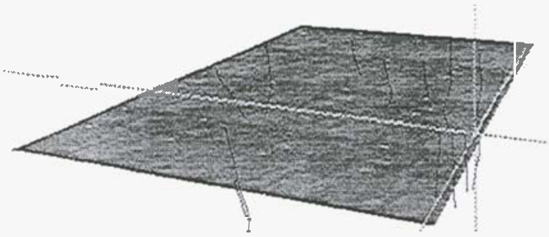

Figure 3- Deviation traces in Atlantis field.

The camera-target interface can provide a view of the field at different scales ranging from a field wide view to examining a subset of wells in detail. Figure 4 displays a subset of wells in Atlantis (the group of wells in the south east of Figure 3) with the casing and production zone display options enabled. The casing diameters have been scaled for clarity.

As has been mentioned the production zone table has records specifying the interpretation type and relative importance of the feed-zone. The relative size of a zone gives an indication of the importance whereas the colour represents the interpretation type. At any time the user can obtain a detailed "tool-tip" or "hint" by pointing at a zone. By displaying groups of wells the reservoir engineer can gain a qualitative insight on where to locate a reservoir feed-zone for example.

A similar field overview can be obtained fiom a display of stratigraphy interpretations for a group of wells. An example is shown in Figure 5. Different types of stratigraphy interpretation (e.g. SUMMARY, DETAILED) may be selected.

One of the main strengths of the interface is the ability to concurrently display several well properties. For example, interpreted production zones may be overlayed with stratigraphy. This may provide a quick field wide view of any underlying correlation between the two properties.

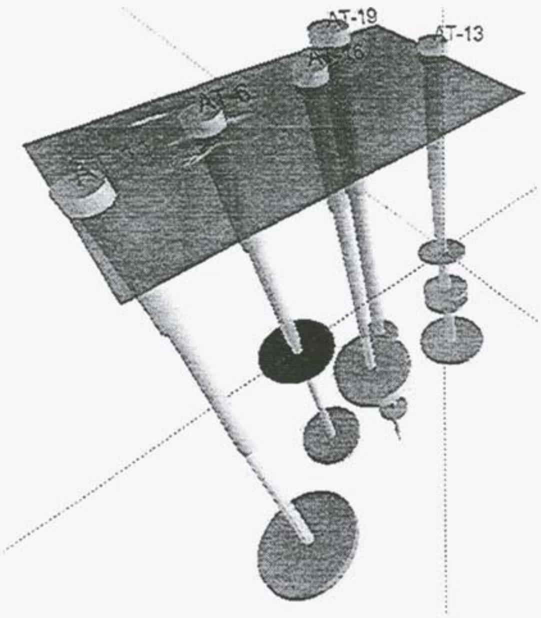

Figure 4- Subset of the Atlantis field with casing, and production zones enabled.

Figure 5- Display of well stratigraphy.

A preliminary contouring routine, CSHEP2D (Renka, 1999) is currently used to generate a contour of the field topography based on the wellhead and gravity survey measurements. An example of a generated topographical surface is given in Figure 6.

The contouring capabilities are "proof-of-concept" at present. It is envisaged in the future that this could be extended to create isothermic and isobaric surfaces fiom interpreted "spot" temperatures and pressures in geothermal wells. These measured variables are also managed in the GDManager database.

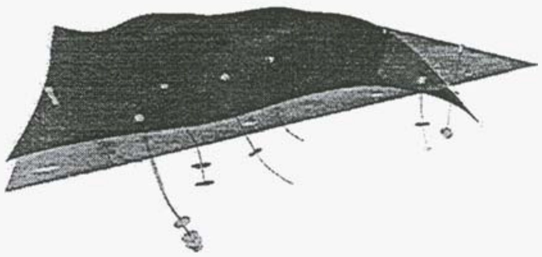

Figure *6*- Surface contour of Atlantis field based on wellhead elevations.

4.2 Setting up an AWTAS test

AWTAS (O'Sullivan et. al., 2000) uses a concept of pumping wells and observation tools to help describe a well test analysis problem. FieldGL can highlight the pumping well and display the positions of the measurement instruments.

4.3 WELLSIM Post-Processing

A WELLSIM (Gunn, **1992)** discharge test model produces a table of fluid property steady-state results along the well. In the presence of two-phase flow texture bitmaps are applied to the finite volume well block objects. This gives visual details on the flow regimes present during discharge. An example, given in Figure 7, shows the transitions fiom single phase liquid to an annular two-phase flow regime.

After a simulation is performed the user may click on a well block and this will highlight the current record in the table of WELLSIM results. This feature is implemented using a FieldGL event-handler ("OnSelectWellBlock"). The interface for selecting a block is defined in FieldGL and the specific implementation is located in the application (WELLSIM).

In GDManager the effect of clicking a well block might in the future provide a list of all measured profiles surveyed at that point. This functionality is easily achievable by writing a new implementation of the "OnSelectWellBlock" method in GDManager.

4.4 Coupled Well-Reservoir Models

The FieldGL component has application in displaying a reservoir grid in the GDManager "well-space". This is of particular benefit in deciding an appropriate elevation to locate a radial feed-zone model as shown in Figure 8. Furthermore simple transient animations of scalar block properties (e.g. temperature, pressure) in the model can be constructed by setting each block "material" property at each discrete time step of a numerical simulation.

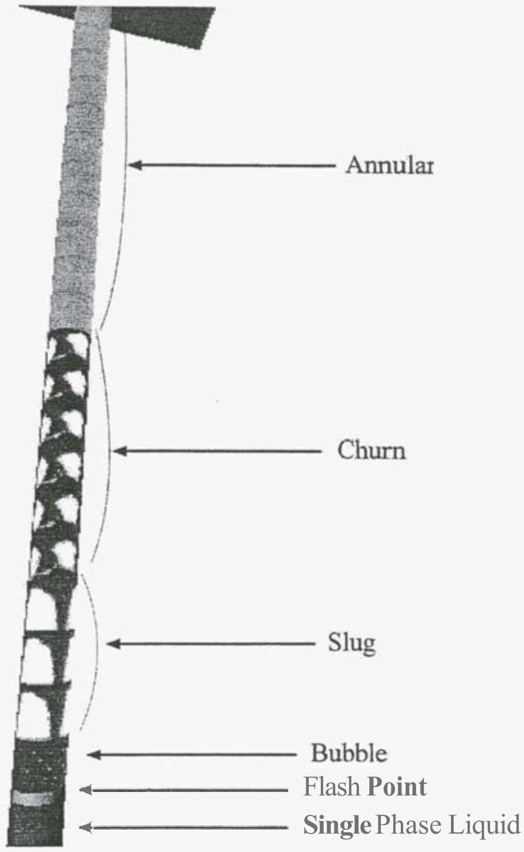

Figure **7**- Flow regime interpretation fiom WELLSIM discharge test.

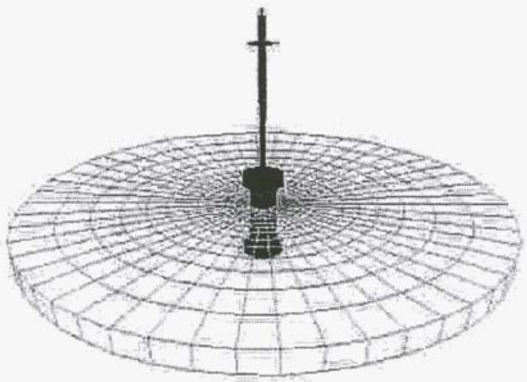

Figure **8**- Display of a well with casing, production zones, and radial feed zone model.

5. FUTURE DIRECTIONS

5.1 Display of Additional Well Properties

In addition to the well-centric properties mentioned above (casings, production zones, lithology) a GDManager database stores other properties including down-hole resistivity and PTS (pressure-temperature-spinner) logs. In the future these data sets will become viewable.

5.2 Integration with GDManager

It is useful to be able to produce these **3D** visualisations directly from the live field data in

GDManager. This eliminates the export, import, and processing steps needed in many packages. Merely opening the FieldGL component would produce the (user definable) default visualisation that proves most useful for the data types currently selected. The visualisation parameters and data selections could then be modified on the fly, if necessary, directly within FieldGL.

In addition to the sea level plane, and field terrain contouring already present, we could use FieldGL to generate contours directly from selected live field data. In practice, however, actual field data is often too sparse to generate acceptable contours without pre-processing and smoothing. As there are tools within GDManager to create well-behaved SURFER © (Golden Software Inc., USA) grid files for most data sets, it would be advantageous to use these files directly to present data on the well space.

The most useful parameters to present three-dimensionally would be variations with elevation, such as – "Elevation of 200°C Isotherm", "Elevation of First Appearance of Epidote" and "Water Level in Monitor Wells". If multiple, related, contours are available (isotherms at 200°C, 190°C, 180°C, etc...) it may be interesting to display these contours in sequence over time to create an animated surface. Other parameters could include 'Boundary of Conductive Layer', "Bouguer Anomaly" and various chemical concentrations fiom discharging wells.

GDManager has functions to enter and store simple TETRAD/ASTRO or MULKOM/TOUGH style grids and then assign feed-zones in wells given the reservoir layers (Anderson et. al., 2000). The FieldGL interface could be used in the future to display a simulation grid in GDManager well space to visually aid in the assignment procedure. An example is given in Figure 9.

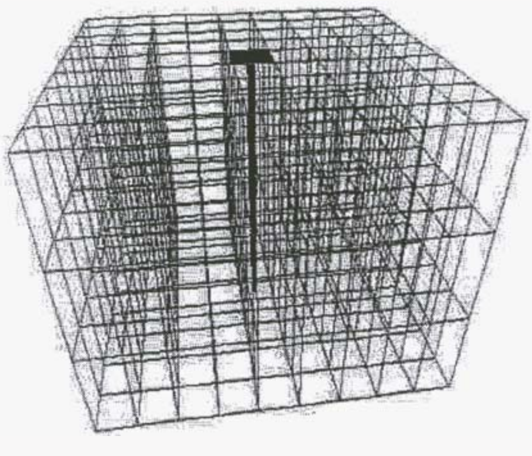

Figure 9- Simple structured TOUGH style finite volume grid overlayed on the GDManager well space.

6. CONCLUSIONS

The graphical interface presented here is comparable to the sophisticated 3D packages available in terms of both functionality and ease of use. The level of functionality coupled with its integrated object-orientated Delphi architecture, extendibility, and open-source foundations makes the FieldGL interface an attractive and promising means of visualising geothermal field data.

7. REFERENCES

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