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UNITED NATIONS UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME

KenGen
Kenya Electricity Generating Co., Ltd.

3D VISUALIZATION OF GEOTHERMAL WELLS DIRECTIONAL SURVEYS AND INTEGRATION WITH DIGITAL ELEVATION MODEL (DEM)

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ABSTRACT

High spatial resolution topographic data is essential to assist volcanic field work, for volcano morphology analyses, and for hazard modelling of volcanic flow processes. The stereoscopic capability of ASTER data provides the opportunity to derive DEMs at a spatial resolution of 15 m for the many regions lacking accurate topographic maps. For visualization, a three dimensional model DEM of the geothermal field with the directional wells and other geographical phenomena were incorporated into the GIS program. The three dimensional model viewers were used with directional geothermal well featuring in the Greater Olkaria geothermal field.

The three dimensional modelling of geothermal wells was done using the deviation surveys data by linear referencing. The tool was developed in an excel based program developed using a Visual Basic for Application (VBA) procedures (macros) which is the excel visual Basic Editor (VBE).
Geographic Information System (GIS) technology was used to model geothermal well directional survey data. This aids in visualizations suggesting interrelationships between well bore productivity. Running these data through a model in ArcGIS, 3D maps can be created showing where well bores corkscrew their way down through the earth's crust. This phenomenon is difficult to see on a two-dimensional map or cross-section view. The 3D map is more intuitive to KenGen's team in exploration and production who are accustomed to thinking in three dimensions. This model is of interest to potential drillers because it shows that a well bore went down this way. With respect to this model, geological rock units can be incorporated in the model thus showing the rock unit penetrated by a particular geothermal well bore.

1. INTRODUCTION

A directional survey is a series of measured depths points down the well path with corresponding hole inclination and direction. From these points, the spatial position of the well path needs to be calculated.

A map showing directional well surveys and how the engineering/survey data behaves is required. A two- or three-dimensional view of the directional survey is necessary. The three dimensional view aids in the geophysical visualization and interpretation leading to the discovery of new geothermal reservoirs. A map helps determine the volumetrics to calculate reserves, and a map view of proposed drilling helps avoid intersecting an existing geothermal well.

Digital Elevation Model (DEM) can be extracted and integrated in visualization GIS environments for landscape representation and further analysis. This paper focuses on the extraction of DEM from ASTER DEM generation for visualization of calculated directional well survey data as well as modeling of surface processes of Olkaria geothermal field. Directional survey data were extracted using the ArcInfo GIS software such as elevation, aspect, slope angle, vertical curvature, and tangential curvature.

2. VIEW OF GEOTHERMAL WELL DIRECTIONAL SURVEYS

The directional data survey (actual depth, the inclination and azimuth) was input in an excel based program developed using a Visual Basic for Application (VBA) procedures (macros) in Figure 1 which is the excel visual Basic Editor (VBE).

When drilling a well, the possibility exists that the well may not be perfectly vertical. Depending on the drilling technique used and the geological formations that were encountered during the drilling process, a well may deviate from the intended vertical direction. The amount of deviation from vertical measured in degrees will affect the True Vertical Depth (TVD) of the well. If the inclination of the well is determined, then the true vertical depth (TVD) can be calculated (IHS, 2007).

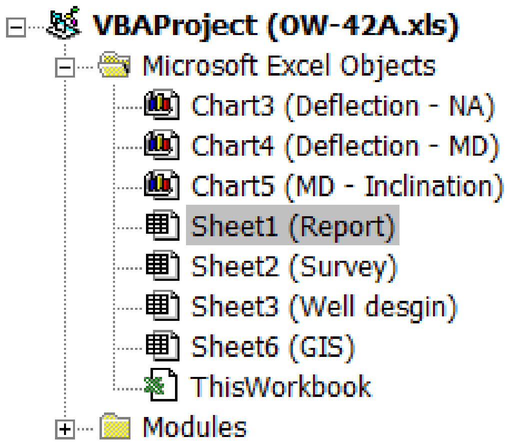

FIGURE 1: A Visual Basic Application Project for directional well data (OW-42A)

The information about a particular well e.g. OW-42 from the directional well survey data was generated as shown in Figure 2 below:

KenGen | NE Field OW-42A | Generate report | 7/16/2012

MD [m]	TVD [m]	Inclination [°]	Azimuth [°]	Northing [m]	Easting [m]	Deflection [m]	X	Y	Z
0	0.0	0.00	0.0	0.0	0.0	0.00	200284.0	9902917.9	2000.4
0	0.0	0.00	0.0	0.0	0.0	0.00	200284.0	9902917.9	2000.4
385	385.0	0.59	244.0	-1.7	-3.6	3.96	200280.5	9902916.2	2385.3
399	399.0	0.87	314.8	-1.6	-3.7	4.04	200283.9	9902916.3	2399.3
414	414.0	1.20	320.4	-1.3	-3.9	4.14	200283.8	9902916.6	2414.3
434	433.9	2.91	322.7	-0.5	-4.5	4.56	200283.4	9902917.4	2434.3
453	452.9	4.76	330.5	0.8	-5.3	5.37	200283.3	9902918.8	2453.2
473	472.7	6.88	333.7	3.0	-6.4	7.03	200283.0	9902920.9	2473.1
492	491.5	9.10	343.6	5.9	-7.2	9.30	200283.2	9902923.8	2491.9
511	510.2	11.01	354.9	9.5	-7.5	12.11	200283.7	9902927.4	2510.5
531	529.6	13.45	2.2	14.1	-7.4	15.93	200284.2	9902932.1	2530.0
550	547.8	16.79	6.2	19.6	-6.8	20.72	200284.6	9902937.5	2548.1
570	566.4	21.48	6.3	26.9	-6.0	27.52	200284.8	9902944.8	2566.8
745	711.9	33.74	7.6	123.2	6.9	123.40	200296.9	9903041.1	2712.3
826	781.0	31.55	10.3	164.9	14.5	165.54	200291.6	9903082.8	2781.3

FIGURE 1: A form showing the report about OW-42 in the NE geothermal field

where:
- TVD- True vertical Depth
- MD- Measured Depth

The result of the this VBA project is X,Y,Z and well name data which are then exported to GIS to create shapefiles. Table containing X coordinates (Longitude) and Y coordinates (Latitude) is brought into ArcMap and converted to a shapefile or geodatabase feature class taking into consideration the correct spatial reference

X	Y	Z	Well
200284.04	9902917.93	2000.35	OW-42A
200284.04	9902917.93	2000.35	OW-42A
200280.48	9902916.19	2385.33	OW-42A
200283.89	9902916.34	2399.33	OW-42A
200283.84	9902916.58	2414.32	OW-42A
200283.43	9902917.39	2434.30	OW-42A
200283.26	9902918.76	2453.23	OW-42A
200282.98	9902920.91	2473.09	OW-42A

FIGURE 3: X,Y,Z and well name to be exported to GIS for the generation of shapefiles

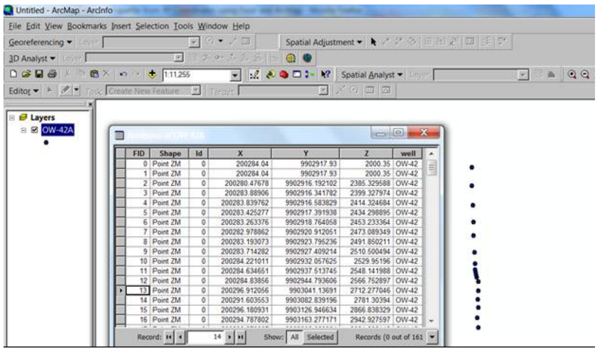

FIGURE 4: A map directional well surveys and the converted engineering/survey data to GIS format for display on a map.

The data consist the creation of 3D model which was done in ArcInfo with 3D Analyst tool extension. However, 3-D modelling of directional geothermal wells requires more steps. It deals with linear features and elements located along them. These features assume any direction and orientation in a 3-dimensional space. The available application tools that could allow precise generation of 3D lines from XYZ coordinates were utilized.

The 3D directional geothermal wells were generated from XYZ coordinates of the vertices which were extracted from the deviation survey data. The shapefile generated were then transformed into 3D points in ArcInfo. This process was performed for each well. The heights from an ASTER DEM were utilized in ArcScene and a vertical exaggeration set to enhance 3D visualization.

A map provides a two- or three-dimensional view of the directional survey, which aids in the geophysical visualization and interpretation that leads to the discovery of new geothermal reservoirs (Kenez, 2008). A map helps determine the volumetrics to calculate reserves, and a map view of proposed drilling helps avoid intersecting an existing well. The map in Figure 4 above shows directional well surveys and the converted engineering/survey data to GIS format for display on a map.

3. 3D MODELING OF OLKARIA GEOTHERMAL FIELD TERRAIN

Viewing data in three dimensions gives new perspectives about the derived data, adding insights that would not be readily apparent from a planimetric view. Having multiple viewpoints of the data guarantees to have a first raw exploration of their quality. The ASTER-DEM was imported into the ArScene for 3D visualization. GIS, and in particular ArcScene, allows the management and visualization of geographic data, for interactive fly-through of user-defined flight paths. The geographical phenomena can also be draped multiple GIS layers and raster data, even if some aliasing effects are present in the produced video animations (Poli, Remondino and Dolci, 2004).

Digital Elevation Models (DEMs) from ASTER are a type of raster GIS layer. Raster GIS represents the world to be a regular arrangement of positions. In a DEM, each pixel has a value corresponding to its elevation (Cote, 2010). The fact that spatial locations are arranged regularly allows the raster GIS to infer many interesting associations among locations: Which cells are upstream from other cells? Which locations are visible from a given point? Where are the steep slopes? One of the most powerful applications of DEMs is adding synthetic hillshading to maps so that the map reader may see the relationship between terrain and other features that may be mapped as in Figure 5.

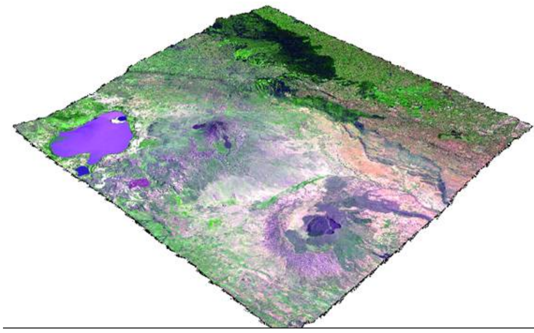

FIGURE 4a: 3D view of Olkaria volcano Digital Elevation Model (Baseheights are obtained from ASTER DEM)

ASTER consists of 3 down looking sub-systems. The Visible and Near-infrared (VNIR) has three bands covering the wavelength range 0.52-0.86µm (green, red, near-infrared), with a spatial resolution of 15m; the ShortWave Infrared (SWIR) has 6 bands in the range 1.6-2.4µm, with a spatial resolution of 30m; the Termal InfraRed (TIR) has 5 bands in the range 8.1-11.3µm, with a ground resolution of 90m.This was developed jointly by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). The ASTERGDEM shown in Figure 6 was georeferenced in ArcMap using the metadata provided in (The Ministry of Economy, Trade and Industry of Japan (METI), & Spacesystems, 2008).

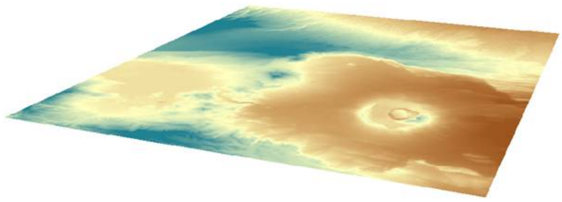

FIGURE 4b: An ASTER DEM that is registered in GIS

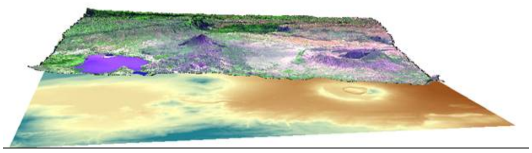

FIGURE 4c: LANDSAT Image draped on an ASTER DEM for Olkaria Volcano

The 3D model of Olkaria geothermal field was generated from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) for 2008. The Advanced Spaceborne

Thermal Emission and Reflection Radiometer (ASTER) is one of the instruments carried on the EOS-AM1 platform, launched on December 18, 1999.The ASTER instrument covers a wide spectral region

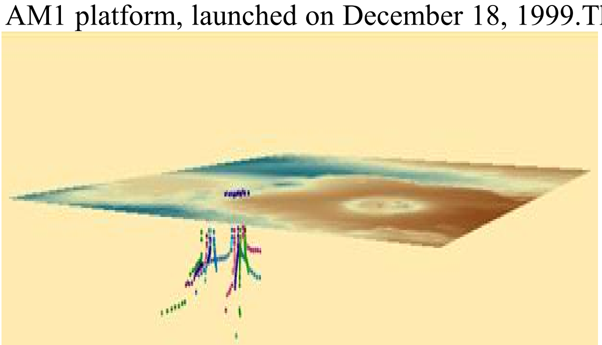

FIGURE 2a: ASTER DEM model of Olkaria geothermal field showing 3D view of geothermal directional wells.

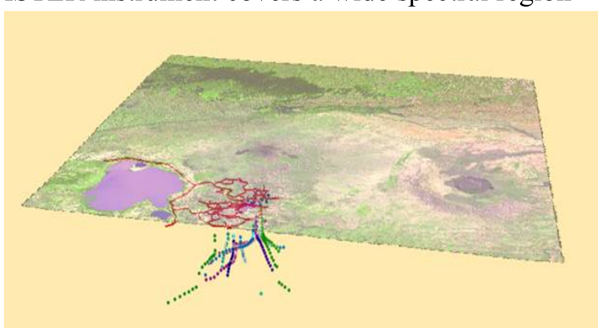

FIGURE 5b: 3D view of the geothermal directional wells, road network in a LANDSAT image. The base heights were from ASTER DEM shown in Figure 6.

with 14 bands from the visible to the thermal infrared with high spatial, spectral and radiometric resolution. An additional backward looking near-infrared band provides stereo coverage.The ASTERGDEM was georeferenced in ArcMap using the metadata.

4. DISCUSSION AND CONCLUSION

This paper demonstrates the power of developing a VB model for geothermal well directional survey computation. This study focused as well on the usefulness of building a 3-D digital elevation model to visualize directional geothermal wells in a GIS environment. This aids in the geophysical visualization and interpretation that leads to the discovery of new geothermal reservoirs. This model could now be used as basis for many exploration investigations.

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