Tucson Office
3031 West Ina Road
Tucson, AZ 85741
Tel 520.297.7723 Fax 520.297.7724
www.tetratech.com

Technical Memorandum

To:	Kathy Arnold	**From:**	Grady O'Brien, Project Manager
Company:	Rosemont Copper Company	**Date:**	July 09, 2010
Re:	Hydrogeologic Framework Model	**Doc #:**	170/10-320874-5.3
CC:	David Krizek, P.E. (Tetra Tech)		

Tetra Tech's groundwater flow modeling team has prepared a three-dimensional hydrogeologic framework model to support development of our regional groundwater flow models. The following technical memorandum describes the process for constructing the framework model.

1.0 Introduction

Rosemont Copper Company (Rosemont) is planning the development of an open pit mining and mineral processing operation known as the Rosemont Copper Project (Project) on the east side of the Santa Rita Mountains, approximately 30 miles southeast of Tucson, Arizona in Pima, County. As part of the mining operation, dewatering of the Open Pit will continue throughout the 20-25 years of operation and cease at closure. When mining ceases and dewatering is discontinued, the pit will naturally refill with water from groundwater, surface-water, and precipitation contributions and a pit lake will form. It is expected that the pit will remain a perpetual hydraulic sink at a stabilized, equilibrium condition due to the high evaporation rate of the Rosemont area. This implies that groundwater will perpetually flow into the Open Pit, although at a much lower rate than during the active dewatering process.

Rosemont has contracted Tetra Tech to develop regional groundwater flow models for the Project. These flow models will represent pre-mining steady state conditions, active mining conditions, and post-closure mining conditions. Tetra Tech has undertaken several tasks to support development of these groundwater flow models. These tasks include development of a Davidson Canyon conceptual model, hydrogeologic framework model, recharge distribution, steady-state water levels and potentiometric surface, evaluation of aquifer testing and hydraulic properties, evapotranspiration distribution, and streamflow conditions. Upon completion of the groundwater flow models, Tetra Tech will document the model construction process, calibration results, flow model predictions, and sensitivity analyses.

This technical memorandum documents the tasks completed to develop a 3-dimensional hydrogeologic framework model from the 2-dimensional horizontal hydrogeologic data provided by Montgomery & Associates (M&A). This 3-dimensional hydrogeologic framework model will be incorporated into the regional groundwater flow models being developed by Tetra Tech.

1.1 Task Objectives and Scope

The objective of this task was to develop a 3-dimensional representation showing the extent and geometry of the hydrogeologic units for Tetra Tech's regional groundwater flow model of the Rosemont Copper Project. The hydrogeologic framework model is a necessary step toward creating this geologically-based flow model. This technical memorandum describes the processes, logical structure, and software used to develop the hydrogeologic framework model.

The hydrogeologic framework model scope is limited to the original M&A flow model domain (M&A, 2009b) and the existing horizontal hydrogeologic slices developed by M&A (M&A, 2009a and M&A, 2009b). No additional field investigation or geologic interpretation was completed as part of this task.

2.0 Approach

This hydrogeologic framework model was constructed using the Mining Visualization System (MVS) software package (C Tech, 2010). The framework model was created using hydrogeologic data at 200 feet intervals between altitudes between 5,400 and 2,400 feet above mean sea level (amsl). These horizontal slices, or 2-dimensional layers, represent the subsurface hydrogeologic units and were developed by Montgomery & Associates (M&A, 2009a). The hydrogeologic slices were created from a combination of publically available surface geology maps, borehole lithology data, and cross sections. Rosemont geologists initially developed several detailed geologic cross sections in the proposed Open Pit area based on mineral exploration borehole data. M&A reviewed these sections and modified them based on hydrologic boreholes completed by M&A. The detailed geologic cross sections were then extended to create the hydrogeologic cross sections presented in M&A (2009a) and M&A (2009b). The geologic formations were grouped into ten (10) hydrogeologic units (HGU) based on their age and material properties. These HGUs were not modified for this framework modeling effort (Table 1).

Table 1 Hydrogeologic Units used in the Hydrogeologic Framework Model

Unit Abbreviation	Description
Qal	Quaternary and Recent alluvium
QTg	Late Tertiary to Early Quaternary basin-fill deposits - higher permeability
QTg1	Late Tertiary to Early Quaternary basin-fill deposits - lower permeability
QTg2	Late Tertiary to Early Quaternary basin-fill deposits - lowest permeability
Tsp	Early to Mid-Tertiary sedimentary and volcanic units (Pantano Formation)
KTi	Upper Cretaceous and Early Tertiary intrusive rocks
Kv	Upper Cretaceous volcanic rocks
Ksd	Lower Cretaceous sedimentary units (Bisbee Group)
Pz	Paleozoic sedimentary and metamorphic formations
pCb	Precambrian igneous and metamorphic crystalline formations

3.0 Framework Modeling Process

The process utilized to transform the two-dimensional data sets into the three-dimensional block model consisted of three (3) steps:

Step 1. Data sampling - Convert horizontal slices from GIS shapefile polygon format to simulated horizontal boreholes in Pre-geology file format (.pgf) with approximately 400-meter horizontal spacing.

Step 2. Hydrogeologic Unit Interpolation - Utilize MVS's *Indicator Kriging* and *Interp_Cell_Data* statistical modules to populate a pre-determined model grid based on the .pgf file.

Step 3. Consistency Check - Perform Quality Assurance/Quality Control check of resulting model framework in Groundwater Vistas software package (Rumbaugh and Rumbaugh, 2007) to ensure consistency with the source horizontal layers and correcting places where statistical interpolation resulted in conceptually inconsistent rock types.

3.1 Data Sampling

The conceptual hydrogeologic model developed by M&A was created in the form of 2-dimensional horizontal hydrogeologic slices. These slices were provided in polygon-format GIS shapefiles, one shapefile for each of the 16 horizontal slices at elevations from 5,400 to 2,400 feet amsl with a 200-foot vertical spacing. The bottom of the proposed pit is at an elevation of 3,050 feet amsl. The geologic model was extended to an elevation of 1,000 feet amsl to allow simulation of deep groundwater flow in the regional model. Two (2) additional horizontal slices were created at elevations of 2,000 and 1,600 feet amsl. These slices were constructed to be conceptually consistent with the existing 2,400 feet amsl layer by continuing previous trends to a depth of 1,000 feet amsl. However, there are no vertical boreholes at these depths to verify the interpolated geology.

A custom FORTRAN program was written to generate simulated horizontal “boreholes”, in the same plane as the hydrogeologic slices. These simulated boreholes were spaced 400 meters apart on an East-West and North-South grid. Simulated borehole logs were created by selecting the hydrogeologic contacts encountered at the hydrogeologic unit edges, represented by polygons in the shapefiles. This sampling grid was selected to produce sufficient data density to minimize the extent of spatial statistical interpolation used to identify the most probable rock type (see Step 2). The simulated borehole data were converted into the MVS pre-geology file format (.pgf), which represents the 3-dimensional boring logs used by MVS. A comparison between the simulated boreholes and the source geologic layers from an elevation of 3,600 feet amsl is shown on Figure 1. The grid of simulated boreholes appears to capture the scale of features necessary to produce a 3-dimensional block model, including most major HGU features. Exceptions include areas where the scale of the feature is smaller than the 400 meter spacing, such as the crystalline intrusive unit (KTi) near the pit. This KTi unit was manually refined in the framework model.

3.2 Hydrogeologic Unit Interpolation

Prior to creation of the geologic framework model, the numerical grid for the groundwater flow model was defined. A flow model grid telescoping from a cell width of 800 feet at the model domain edges to a cell width of 200 feet in the vicinity of the pit was selected to define model cells in plan view. Vertically, the grid was constructed using horizontal model layers with consistent thickness. Flow model layers intersecting the pit were assigned a cell thickness of approximately 150 feet and model cells above and below the pit were assigned thicknesses between 200 and 430 feet. The uppermost elevation of the flow model was placed at an elevation of 5,500 feet amsl, and the base of the model at an elevation of 1,000 feet amsl. The top was selected to be 100 feet above the uppermost horizontal geologic slice. In this way, the slice geology is then representative of the geologic structure of the approximate center of the flow model layer. The elevation for the bottom of the flow model was chosen to be significantly below the anticipated bottom of the pit so that hydraulic stresses would not encounter boundary conditions as they propagated through the model. Elevations and thicknesses for the flow model layers are shown below in Table 2. The bottom of the lowest flow model layer intersecting the pit (layer 15) was assigned to the anticipated bottom elevation of the pit itself (3,050 feet amsl). Figure 2 shows the horizontal and vertical flow model grid discretization. This grid information was provided to the MVS module *Krig_3D_Geology*, and was used as the matrix to be populated with the geologic framework data from Step 1.

Table 2. Flow Model Layer Elevations and Thicknesses

Flow Model Layer	Top Elevation (feet amsl)	Layer Thickness (feet)
1	5,500	250
2	5,250	200
3	5,050	150
4	4,900	150
5	4,750	150
6	4,600	150
7	4,450	150
8	4,300	150
9	4,150	150
10	4,000	150
11	3,850	150
12	3,700	150
13	3,550	150
14	3,400	150
15	3,250	200
16	3,050	330
17	2,720	430
18	2,290	430
19	1,860	430
20	1,430	430

Using a process that C Tech describes as Geologic Indicator Kriging (GIK), the MVS module *Indicator_Geology* uses the statistical kriging routine to follow a probabilistic approach to geologic structure modeling in which the probability for each material is computed for every cell in a grid. By kriging on material probability, instead of a spatial field such as elevation, the material having the highest probability (for an individual cell) is assigned to the cell. For example, if a cell has a QTg probability of 0.55 and a Ksd probability of 0.45, the cell is assigned to be QTg. *Indicator_Geology* was used to process the .pgf borehole file created in Step 1 to create a geologic model with a finer vertical resolution (approximate 100 foot thick layers) than the final flow model grid defined in *Krig_3D_Geology,* but on the same horizontal grid as defined in *Krig_3D_Geology.* This framework model was then processed using the interpolation module *Interp_Cell_Data* to populate the final variable-thickness flow model grid produced in *Krig_3D_Geology.*

The *Interp_Cell_Data* module interpolates cell data from one (1) field to another using a Nearest Neighbor interpolation. Typical uses of this module are mapping of cell data from a 3-dimensional mesh onto a geologic surface or a 2-dimensional fence section. In these applications, the 2-dimensional surface(s) simply provide the new geometry (mesh) onto which the adjacent cell material types are statistically interpolated. For use in the Rosemont regional groundwater flow model, the grid-mesh from *Krig_3D_Geology* was populated with the geologic model data from *Indicator_Geology* using this module, thereby creating a final hydrogeologic framework model with the resolution desired for use in the groundwater flow model.

3.3 Consistency Check

The hydrogeologic framework model was exported directly from MVS into Groundwater Vistas and examined for consistency with the conceptual hydrogeologic model provided by M&A. Inconsistencies are typically the result of scale issues or transitions between hydrogeologic units. The 400-meter spaced horizontal simulated boreholes could not capture small-scale, detailed features when the spacing was larger than the feature. The transition between steeply dipping materials in two (2) horizontal hydrogeologic slices, or where the geology in one (1) slice was significantly different from the geology in the slices above or below it, typically results in alternating materials near the contact. The issues that would significantly impact the flow model results were corrected, but other minor discrepancies were not edited. The final hydrogeologic framework model, after correcting significant inconsistencies, is shown on Figure 3. The primary corrections included refining the crystalline intrusive unit present to the north of the pit and refining the distribution of the Quaternary alluvium (Qal) where the flow model layers intersect the land surface.

A set of hydrogeologic sections in the form of a fence diagram was created to illustrate the internal hydrogeologic framework (Figure 4). Geologic sections A-A' and B-B' from the M&A Groundwater Flow Modeling Report (M&A, 2009) are compared to sections at the same locations in the hydrogeologic framework model (Figures 5 and 6). A horizontal grey line was added to the MVS sections to denote the maximum depth of the M&A hydrogeologic slices. Interpolation was performed below this elevation to extend the hydrogeologic model to an elevation of 1,000 feet amsl.

The MVS hydrogeologic sections agree well with the M&A sections. However, there are areas where the M&A section lines intersect a small portion of an HGU that was not manually drawn on the sections. Examples of these areas are illustrated on Figures 5 and 6.

4.0 References

Ferguson, C.A. (2009). *Bedrock Geologic Map of the Northern Part of the Empire Ranch 7 ½' Quadrangle, Pima County, Arizona*: Arizona Geological Survey Open-File Report OFR-09-05, scale 1:24,000.

Ferguson, C.A., Youberg, A., Gilbert, W.G., Orr, T.R., Richard, S.M. and Spencer, J. (2001). *Geologic Map of the Mount Fagan 7.5' Quadrangle, Eastern Pima County, Arizona*. Arizona Geological Survey Digital Geologic Map 11. November 2001.

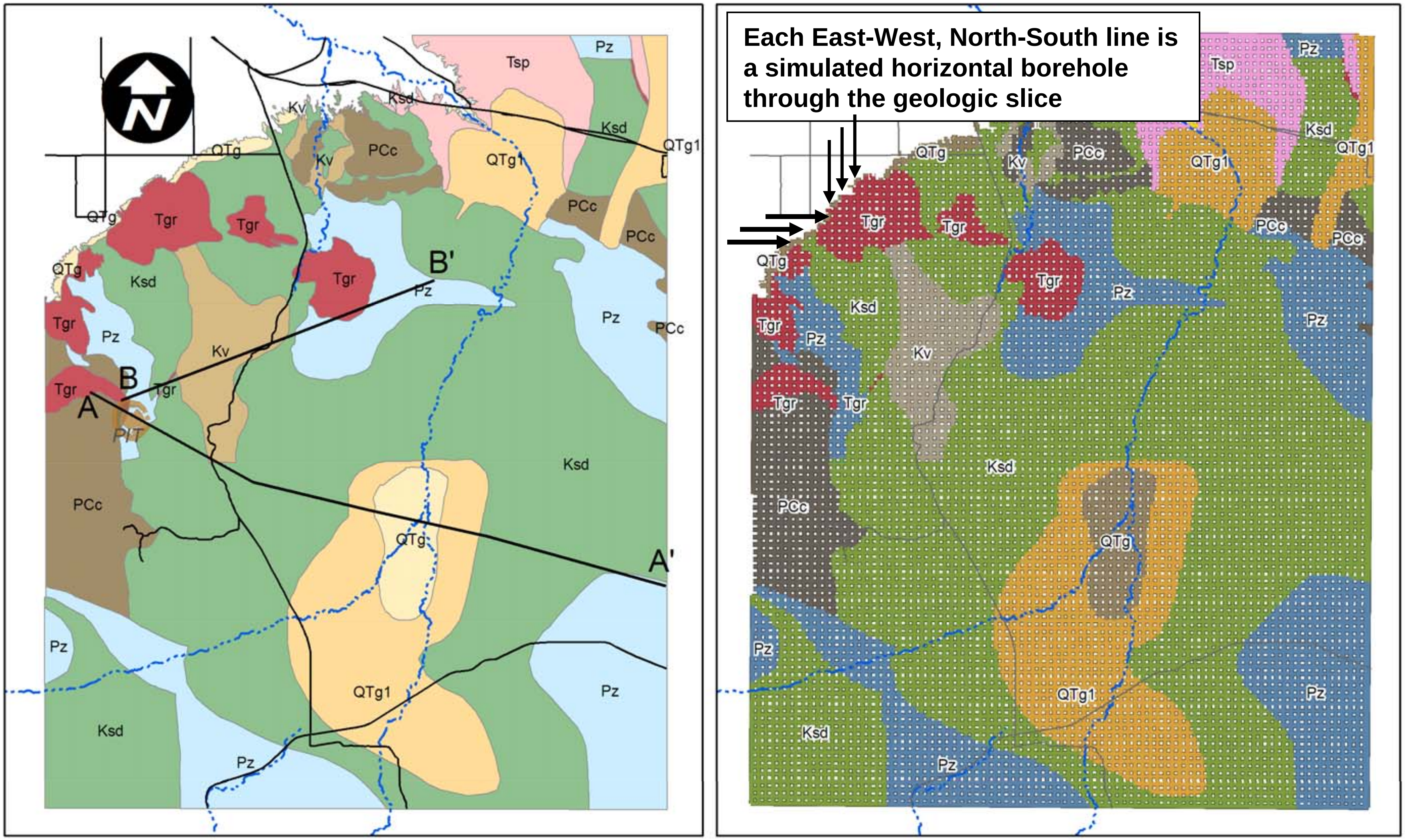
Fetter, C.W. (1994). *Applied Hydrogeology*. Prentice Hall, New Jersey. 691p.

Montgomery & Associates, Inc. (M&A) (2009a). *Results of Phase 2 Hydrogeologic Investigations and Monitoring Program, Rosemont Project, Pima County, Arizona*. Prepared for Rosemont Copper Company. Report dated February 26, 2009.

M&A (2009b). *Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closure*. Prepared for Rosemont Copper Company. Report dated October 28, 2009.

Rumbaugh, J.O and Rumbaugh, D.B. (2007). *Groundwater Vistas, Version 5*, Environmental Simulations, Inc., Reinholds, PA. (http://www.groundwatermodels.com)

FIGURES



Geologic Slice at 3,600 ft Elevation

0 2.5 5 10 15 Miles

Pre-Geology Boreholes at 3,600 ft Elevation

Project No: 114-320874

July 2010

Figure 1
Comparison of Horizontal Geologic Slice with Pre-Geology Boreholes

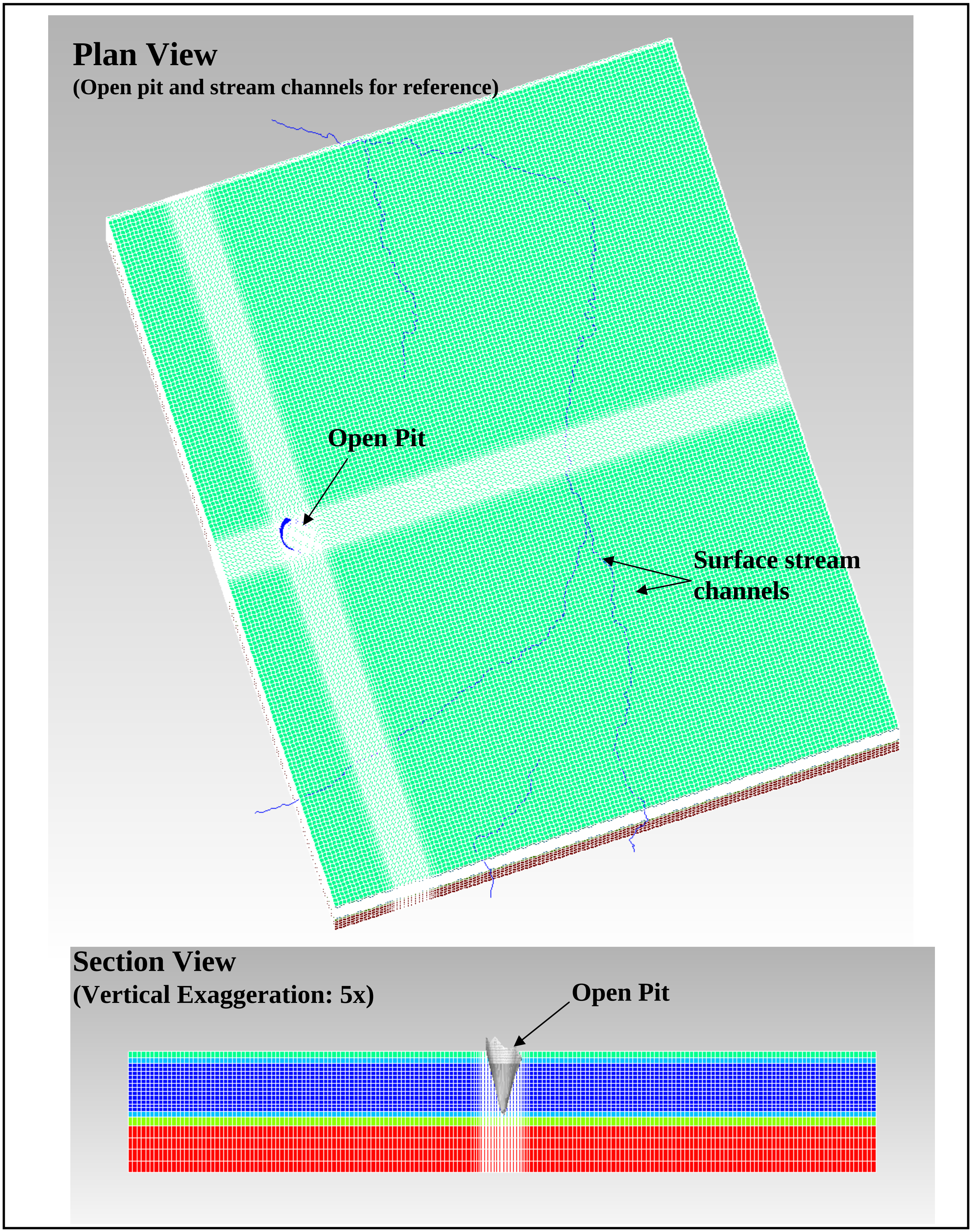


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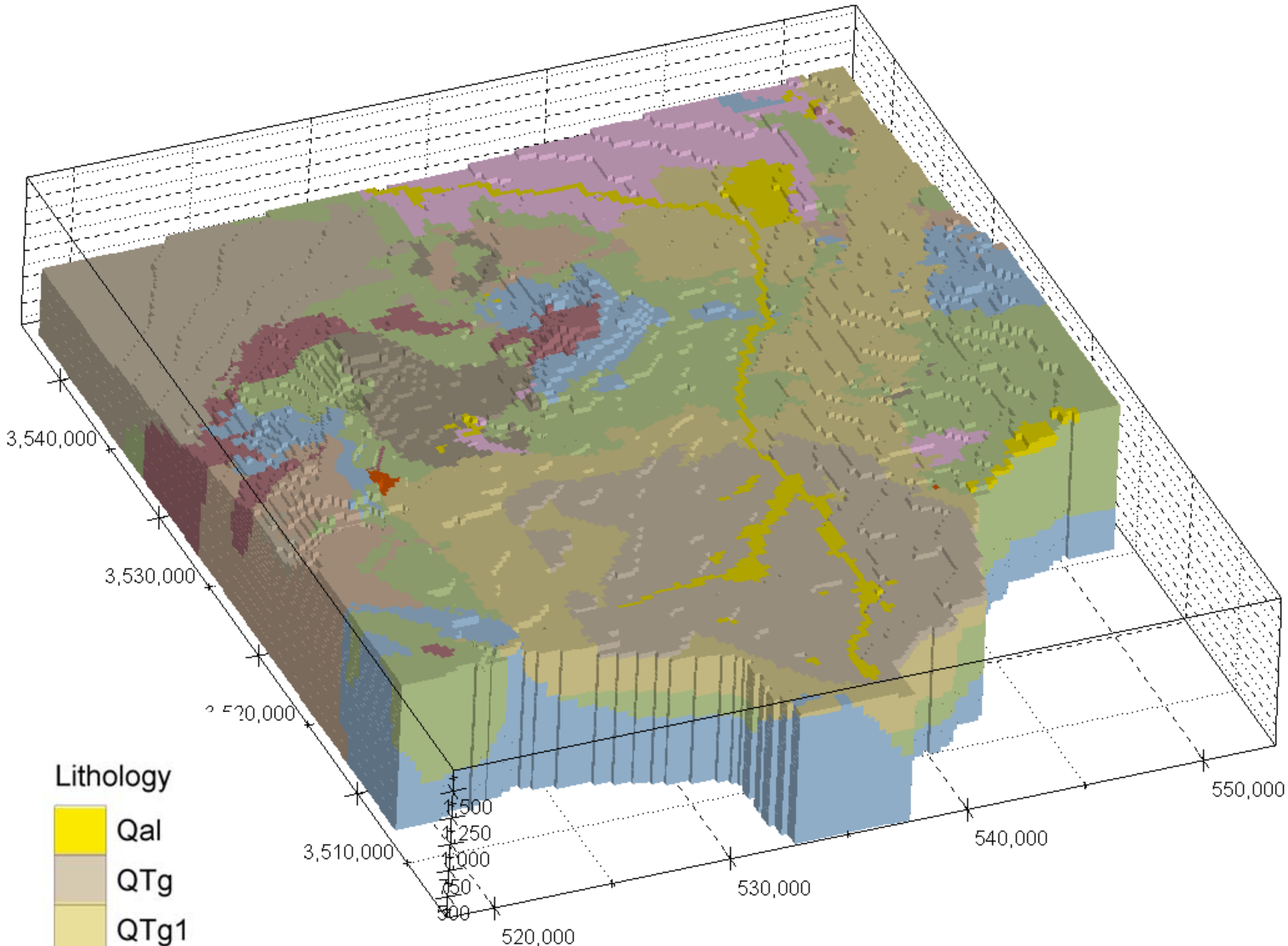
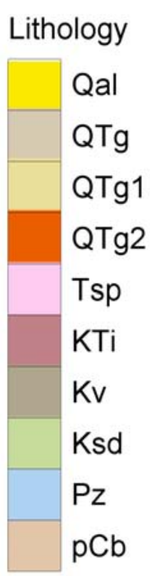
Figure 2
Model Grid Discretization

Vertical Exaggeration: 5x
All units are shown in meters





Abbreviation	Description
Qal	Quaternary and Recent alluvium
QTg	Late Tertiary to Early Quaternary basin-fill deposits - higher permeability
QTg1	. Late Tertiary to Early Quaternary basin-fill deposits - lower permeability
QTg2	Late Tertiary to Early Quaternary basin-fill deposits - lowest permeability
Tsp	Early to Mid-Tertiary sedimentary and volcanic units (Pantano Formation)
KTi	Upper Cretaceous and Early Tertiary intrusive rocks
Kv	Upper Cretaceous volcanic rocks
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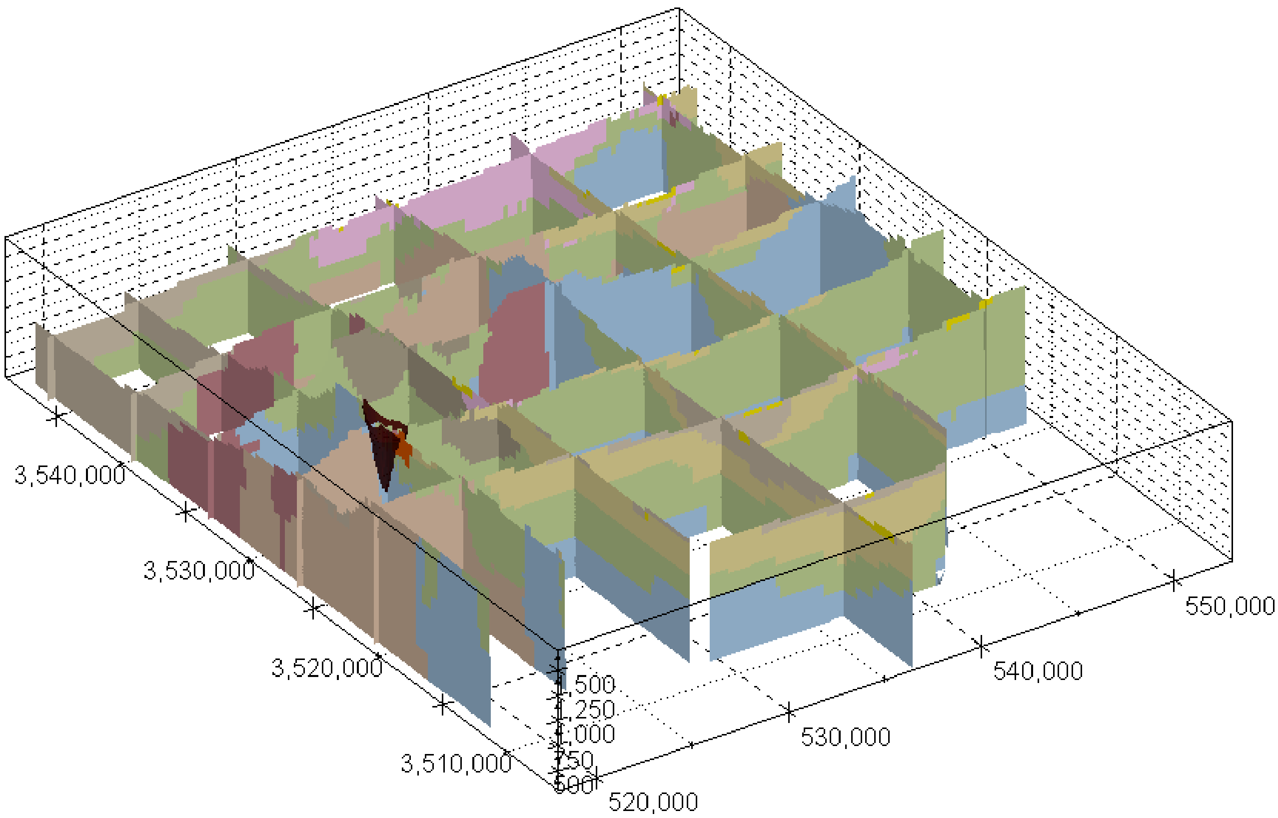
Figure 3
Geologic Framework Model Block



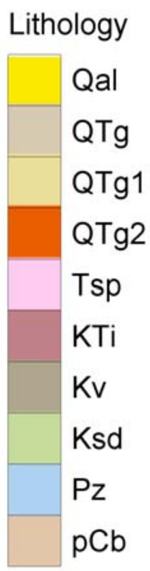


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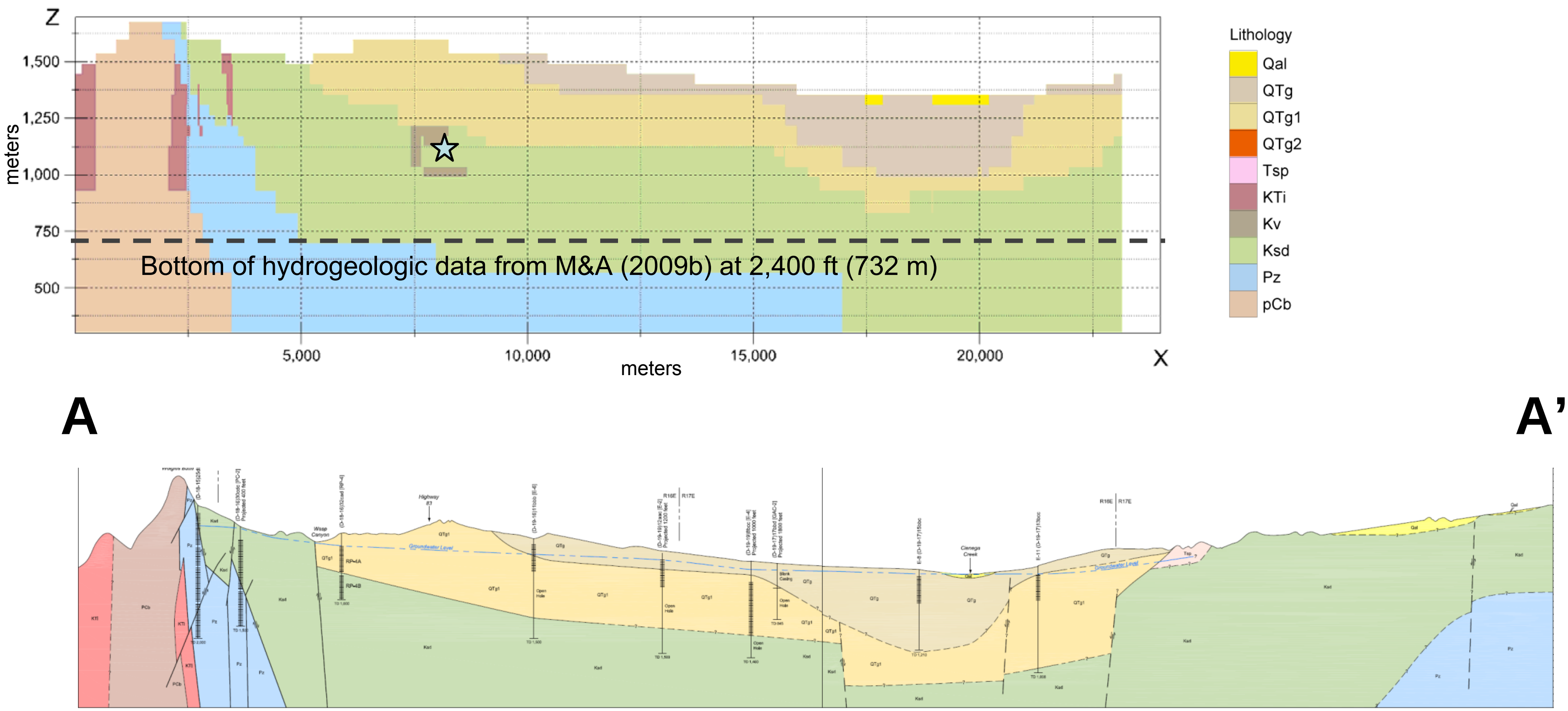
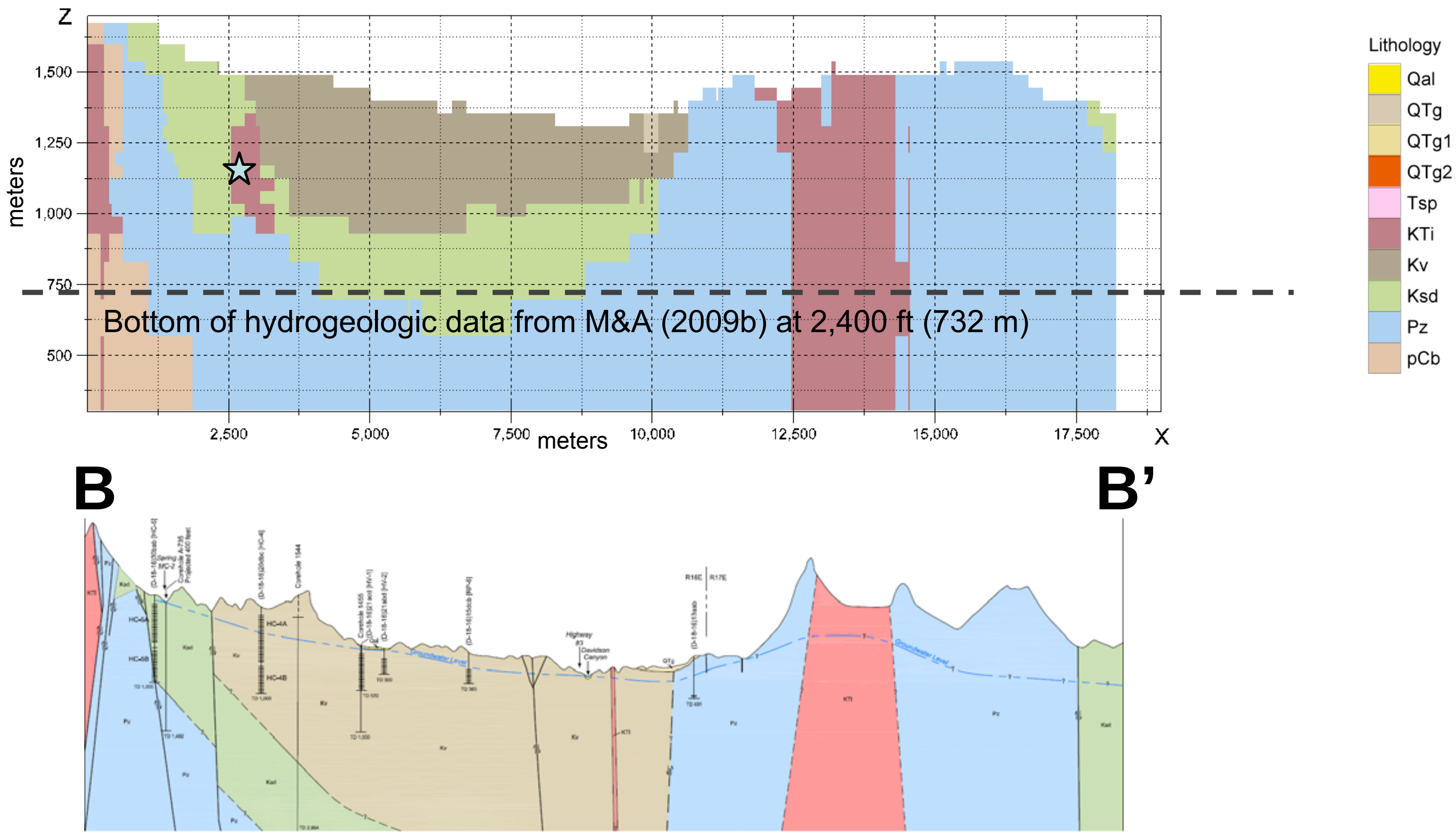
Figure 4
Geologic Block Displayed In Section



Note:
☆ Kv is included on the kriged framework model section, but was omitted on the manually drawn M&A Geologic Section A-A'.
See Figure 1 for section-line location.

Figure 5
Comparison of Geologic Section A - A'
with Flow Model Geologic Block



Note:
☆ KTi is included on the kriged framework model section, but was omitted on the manually drawn M&A Geologic Section B-B'.
See Figure 1 for section-line location.

Figure 6
Comparison of Geologic Section B – B' with Flow Model Geologic Block

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Memorandum

To: Beverly Everson

Cc: Tom Furgason

From: Kathy Arnold

Doc #: 025/10 – 15.3.2

Subject: **Transmittal of Tetra Tech Groundwater Memoranda**

Date: July 9, 2010

Rosemont is pleased to transmit the following technical memorandums related to the groundwater modeling work that has been undertaken by Tetra Tech:

- *Hydraulic Property Estimates,* Tetra Tech, July 2010
- *Hydrogeologic Framework Model*, Tetra Tech, July 2010

Rosemont is providing three hardcopies and two disk copies for the Forest and two hardcopies and one disk copy for SWCA.