

SUMMARY OF OBJECTIVES

Do you need or like to work with:

- complex geology?
- conceptual modeling?
- statistical analysis?
- original TOUGH2 files format?

GMS → TOUGH2 → GMS

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Scope

- In some instances there is the need to:
 - use TOUGH2 in complex geological systems, with both surface and underground geological data from geophysical techniques and boreholes; amount of data may increase in time and the geological model have to be updated;
 - test different conceptual models or elaborate on specific ones;
 - change grid sizes or orientations, cell spacing and distribution;
 - visualize input and output data in 3D;
 - use standard statistical analysis on output data.

IN THESE CASES TOUGH2 MAY BE FOUND TO BE A NIGHTMARE! PARTICULARLY FOR BEGINNERS!

One possible solution

- Use Groundwater Modeling System (GMS™) as a TOUGH2 pre- and post-processor <<http://www.aquaveo.com>>

Preprocessing:

- Build a:
 - 3D Geologic Model;
 - Conceptual Model;
 - 2D and 3D scatter-point sets (observations);
 - grid.
- Exchange data between these four categories.

Postprocessing:

- Visualize model output variables with geology, in space (3D) and time (movies).
- Analyze output variables with statistical package.

GMS – TOUGH2 simulations workflow

- Create a model;
- Interpolate the model to a MODFLOW and run it in "steady state";
- Save the GMS-MODFLOW model as original modflow file format;
- Use the Fortran code TMT2 (Translating MODFLOW to TOUGH2 – downloadable for free from the TOUGH2 webpage) to generate MESH (with ELEME and CONNE blocks) and INCON files;
- Use the MESH and INCON files to solve your TOUGH2 problem;
- Use the Fortran code T2M (Translating TOUGH2 to MODFLOW – only a preliminary version available – ask me), or any other self-made code, to generate 3D scatter point data sets of the values of TOUGH2 output variables at each grid-block center;
- Read the 3D scatter point data set into GMS;
- Interpolate the 3D scatter point data set to the grid;
- Analyze results with visualization and statistical analysis tools.

3D Geologic model

<http://www.xmswiki.com/xms/GMS/GMS>

Build your 3D geologic model through:

- materials (lithological units);
- tins (2D geologic surfaces);
- boreholes (used to make stratigraphic horizons);
- cross sections – this is the way you may implement faults;
- solids (rock "bodies" of specific lithologies).

Save the geologic model and change it whenever you need without interfering with the rest of the model.

Conceptual model

http://www.xmswiki.com/xms/GMS/Map_Module

Build your conceptual model through:

- map module, with tools that are a GIS-based, abstract, simplified description of natural systems;
- coverages, that contain all information needed to be transferred to specific grid volumes;
- frame of model grid.

Build many different conceptual models to test different thesis.

2D and 3D scatter-point sets

http://www.xmswiki.com/xms/GMS/2D_Scatter_Point_Module
http://www.xmswiki.com/xms/GMS/3D_Scatter_Point_Module

Observational point data are represented by

- 2D scatter point data sets, i.e., values of a variable with (x, y) coordinates;
- 3D scatter point data sets, i.e., values of a variable with (x, y, z) coordinates.

3D scatter point data sets are the format to import the TOUGH2 output data.

Grid

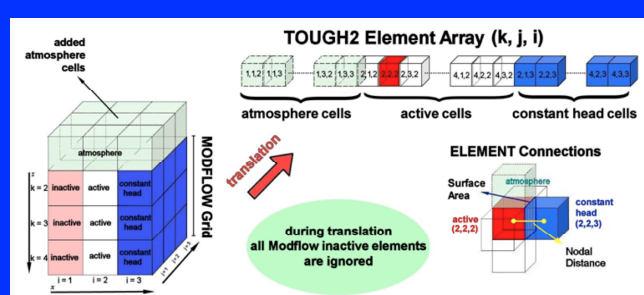
http://www.xmswiki.com/xms/GMS/3D_Grid_Module

Build your model grid by making a MODFLOW-like grid (a rectangular structured grid)

- This is perhaps the weak part of the process:
 - only this type of grid is allowed;
 - only one grid per model is allowed.

HOW IT WORKS

TRANSLATING A MODFLOW GRID TO TOUGH2

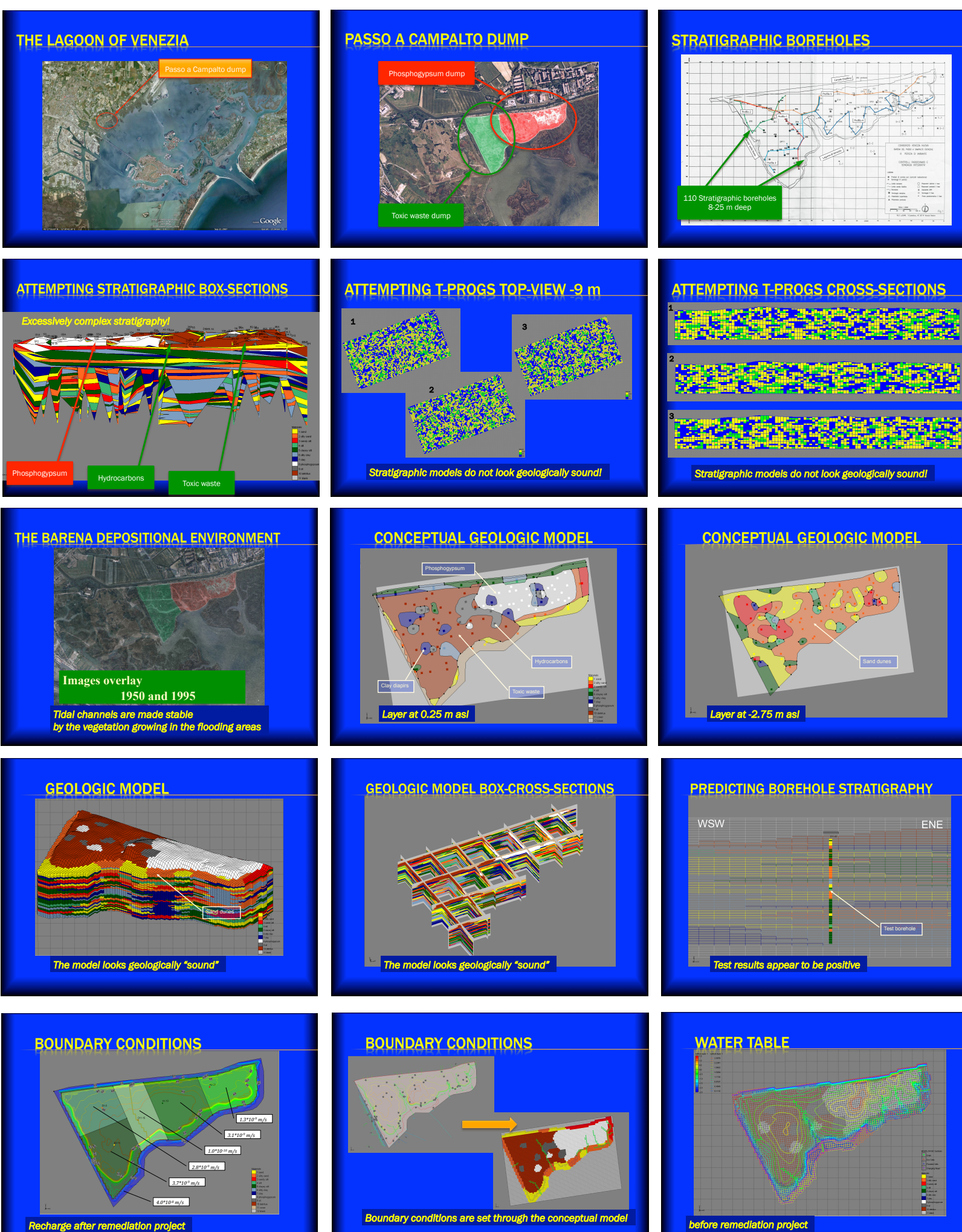


Additional advantages

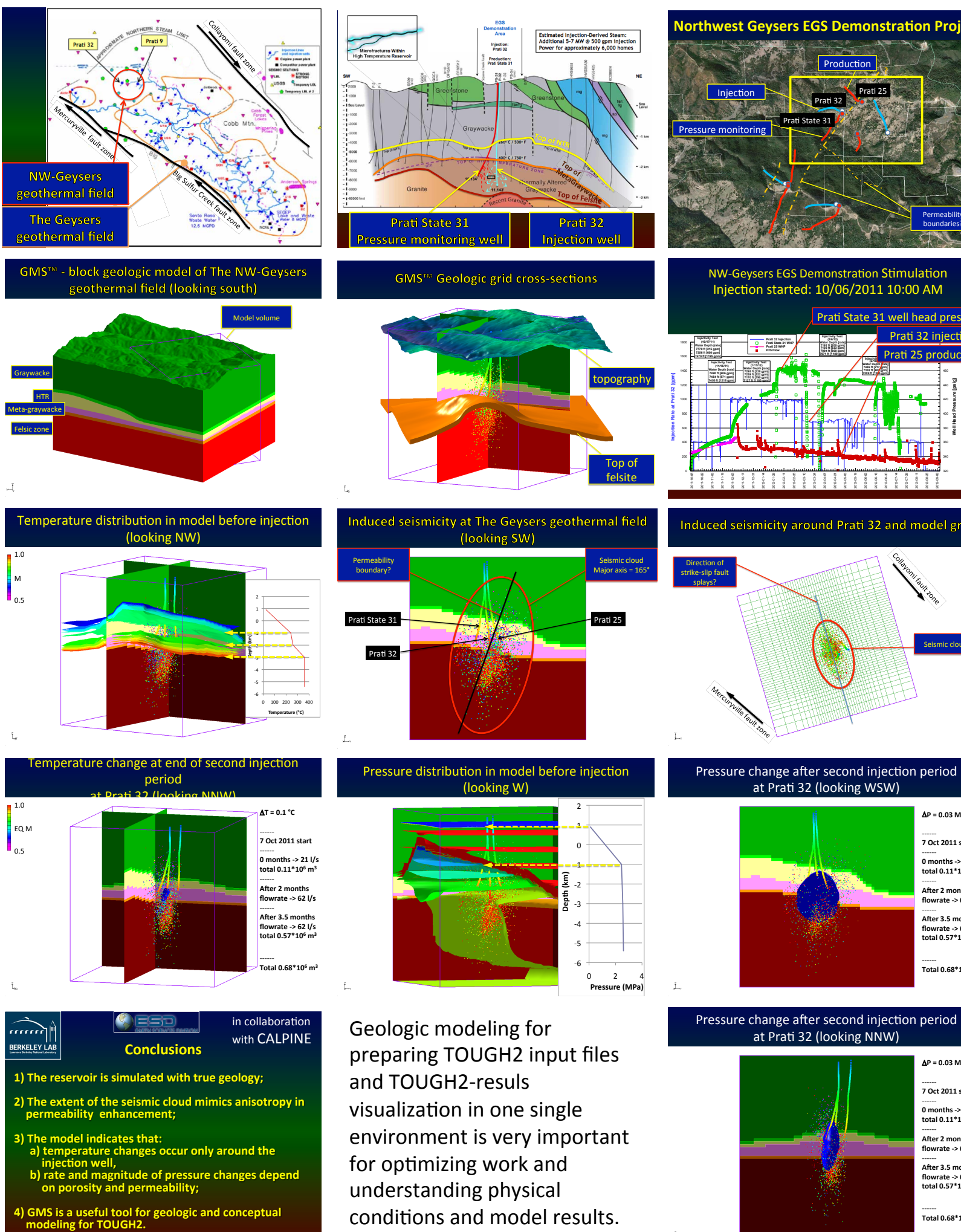
Facility to interface solutions found in MODFLOW and other codes with TOUGH2.

For instance, since the topography of the water table strongly influences the hydrothermal flow topology, you can use the water table calculated and calibrated in MODFLOW as the top fully-saturated, constant-head, pressure boundary condition for TOUGH2.

Example: A Venetian Lagoon Phosphogypsum land fill^{1, 2}

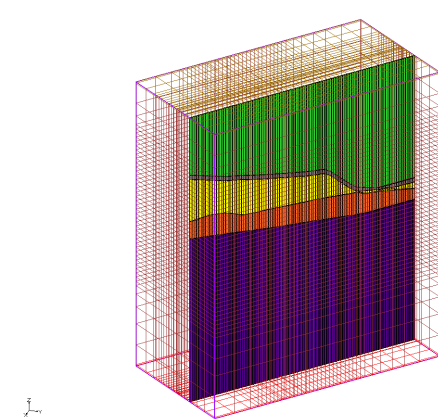


Example: The Geysers Geothermal field³



Example: Modeling faults

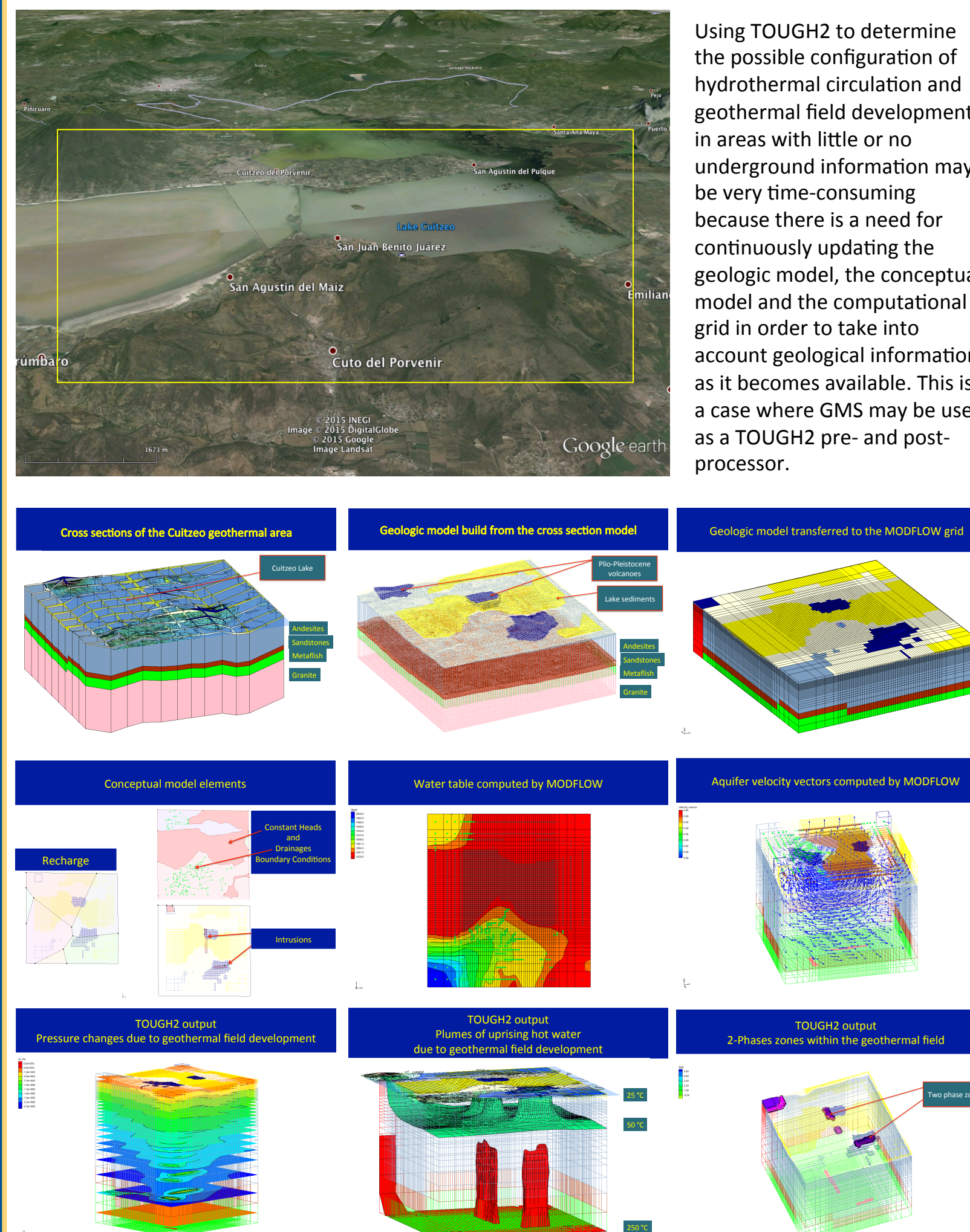
CREATING A RECTILINEAR VERTICAL FAULT WITH GMS



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- 1) Create your 3D geologic model with "Solids".
- 2) Create your 3D grid with a vertical grid layer with the thickness of your fault where the fault is supposed to be. The thickness of the fault must be "reasonable" for your TOUGH2 fault idealization. Also check that the geometric aspect ratio with neighboring cells is reasonable (I would suggest not to exceed 10).
- 3) Map your geologic model to the grid.
- 4) In "Map Data" make a "new coverage" (or "new conceptual model" → "new coverage").
- 5) Add from "top view" the fault trace you want to represent (for instance a thin rectangle with the short-size equal to that of your grid blocks in your fault-layer. Call the rectangle "Fault trace").
- 6) Change the "vertices" of the rectangle to "nodes" (only three you have to change, the fourth is already a "node").
- 7) Highlight one of the long segments of the rectangle fault trace and from the "Feature Object" menu start "Redistribute Vertices" → "Specify" → "Number of segments" and give a number (I commonly use 100 but you may want more or less).
- 8) Repeat step 4) for the other long segment.
- 9) Right-click on the coverage that has the fault trace and apply "Map to TIN". Change the name of the tin to your fault name ("Fault trace").
- 10) Make visible all "Solid Data". Make the "Fault trace" tin invisible.
- 11) From top view insert a convenient number of boreholes along the trace of the fault.
- 12) Make all solids invisible.
- 13) Rotate to side view and check if the boreholes are fine and represent the correct stratigraphy. If not open up the borehole editor and make appropriate changes.
- 14) From the "Boreholes" menu press "Auto-Assign Horizons". Check a few boreholes to find out if they have been assigned correctly.
- 15) From top view create a cross section along the boreholes.
- 16) From the "Boreholes" menu press "Auto-Fill Blank Cross Section" (or fill it by hand to your pleasure).
- 17) From the "Boreholes" menu click on "Horizon → Solids":
 - i. Use boreholes.
 - ii. Use boreholes cross sections.
 - iii. Use all boreholes.
 - iv. Use horizon TIN.
 - v. Use all TINs.
- 18) Press "Next":
 - i. Among the "TIN Data" choose your tin "Fault trace".
 - ii. Choose "Top of boreholes" for the "Top elevation".
 - iii. Choose "Bottom of boreholes" for the "Bottom elevation".
- 19) Press "Next" to choose appropriate interpolation options.
- 20) Press "Finish" to get your volumes of different rocks along the fault.
- 21) Give appropriate names to the new volumes.
- 22) Map the fault to your 3D-grid model.
- 23) Remember to give appropriate material names and properties to the various fault segments.

Example: The Cuitzeo (Mexico) Geothermal field⁴



Using TOUGH2 to determine the possible configuration of hydrothermal circulation and geothermal field development in areas with little or no underground information may be very time-consuming because there is a need for continuously updating the geologic model, the conceptual model and the computational grid in order to take into account geological information as it becomes available. This is a case where GMS may be used as a TOUGH2 pre- and post-processor.

REFERENCES

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ACKNOWLEDGMENTS

This work was originally funded by the TOUGH Development Grant through the U.S. Dept. of Energy under Contract No. DE-AC02-05CH11231. Financial contribution and GMS support was provided by Acquaveo. Financial contribution and logistical support was also provided by EDRA.