Using GMS as a pre- and post-processor for TOUGH2

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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 grid 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 TT2M (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

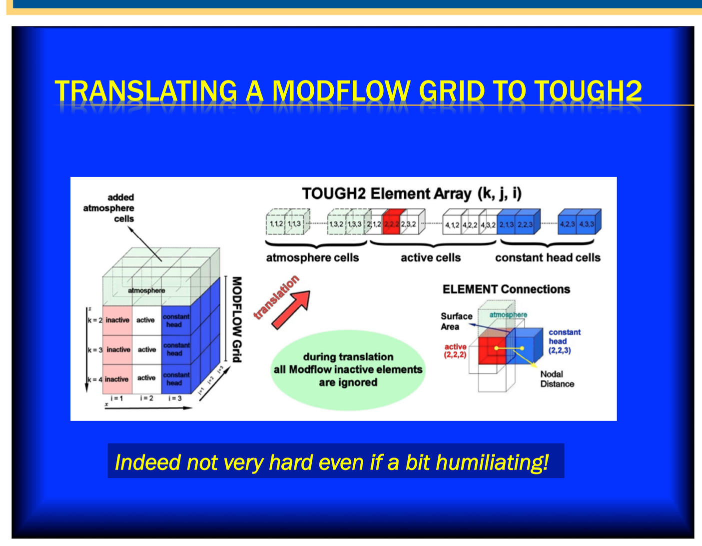
- Observational point data are represented by
  - 2D scatter point data sets, i.e., values of a variable with (x, y) coordinates;
  - 3D scatter point data sets, i.e., values of a variable with (x, y, z) coordinates.
- 3D scatter point data sets are the format to import the TOUGH2 output data.

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

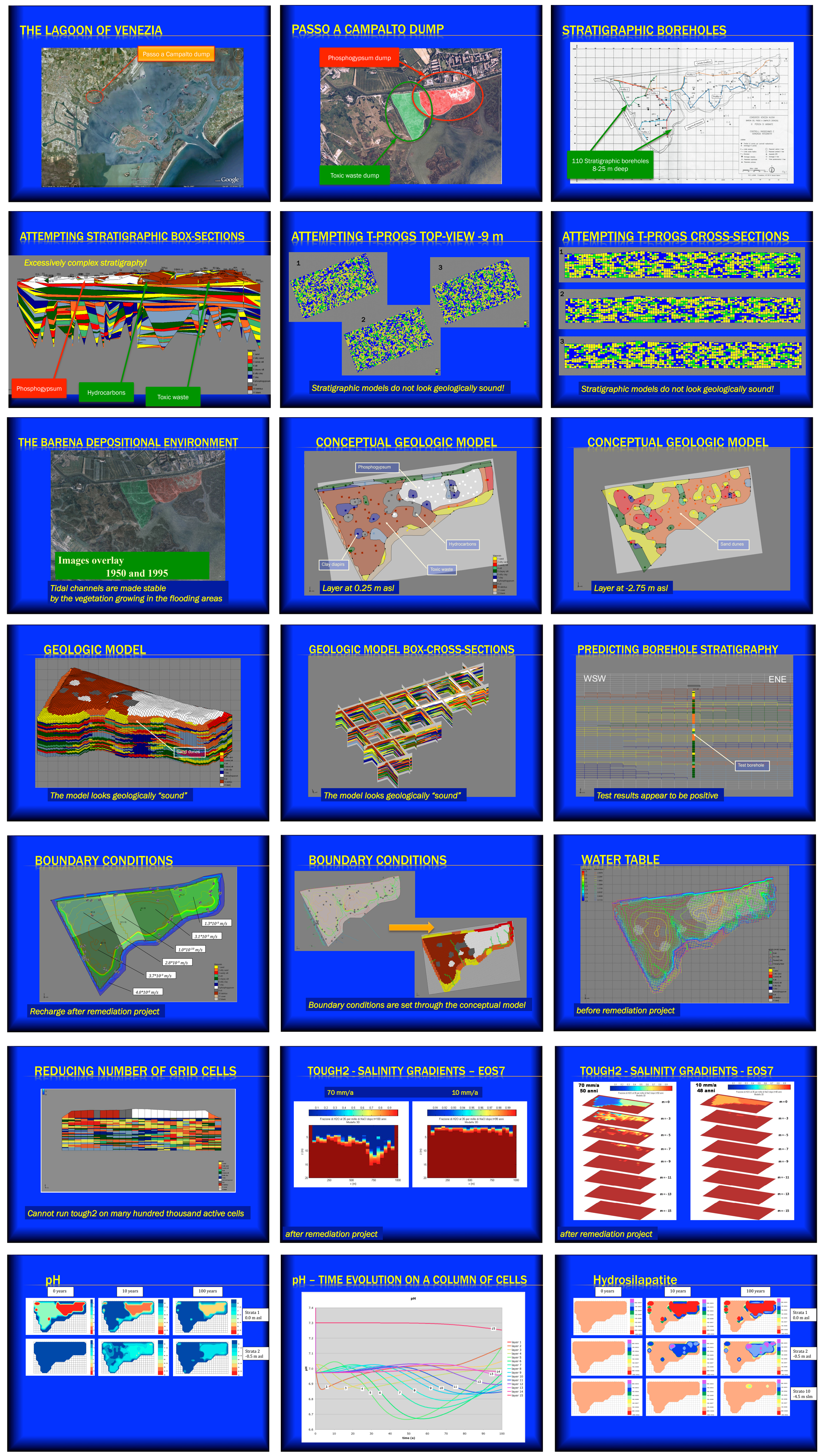


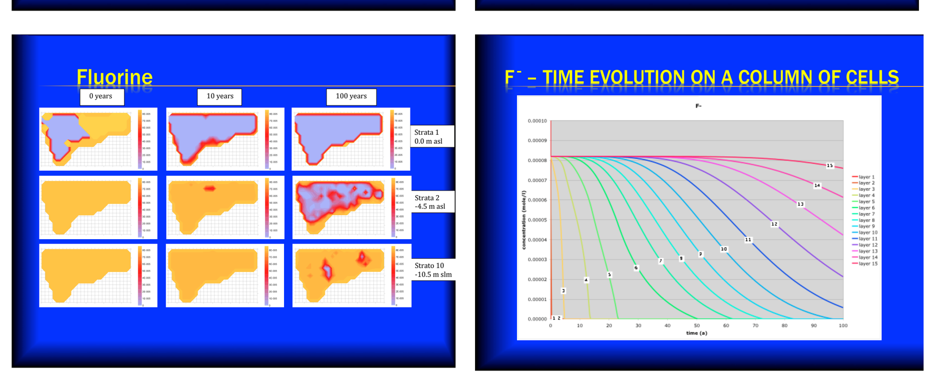
Additional advantages

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.

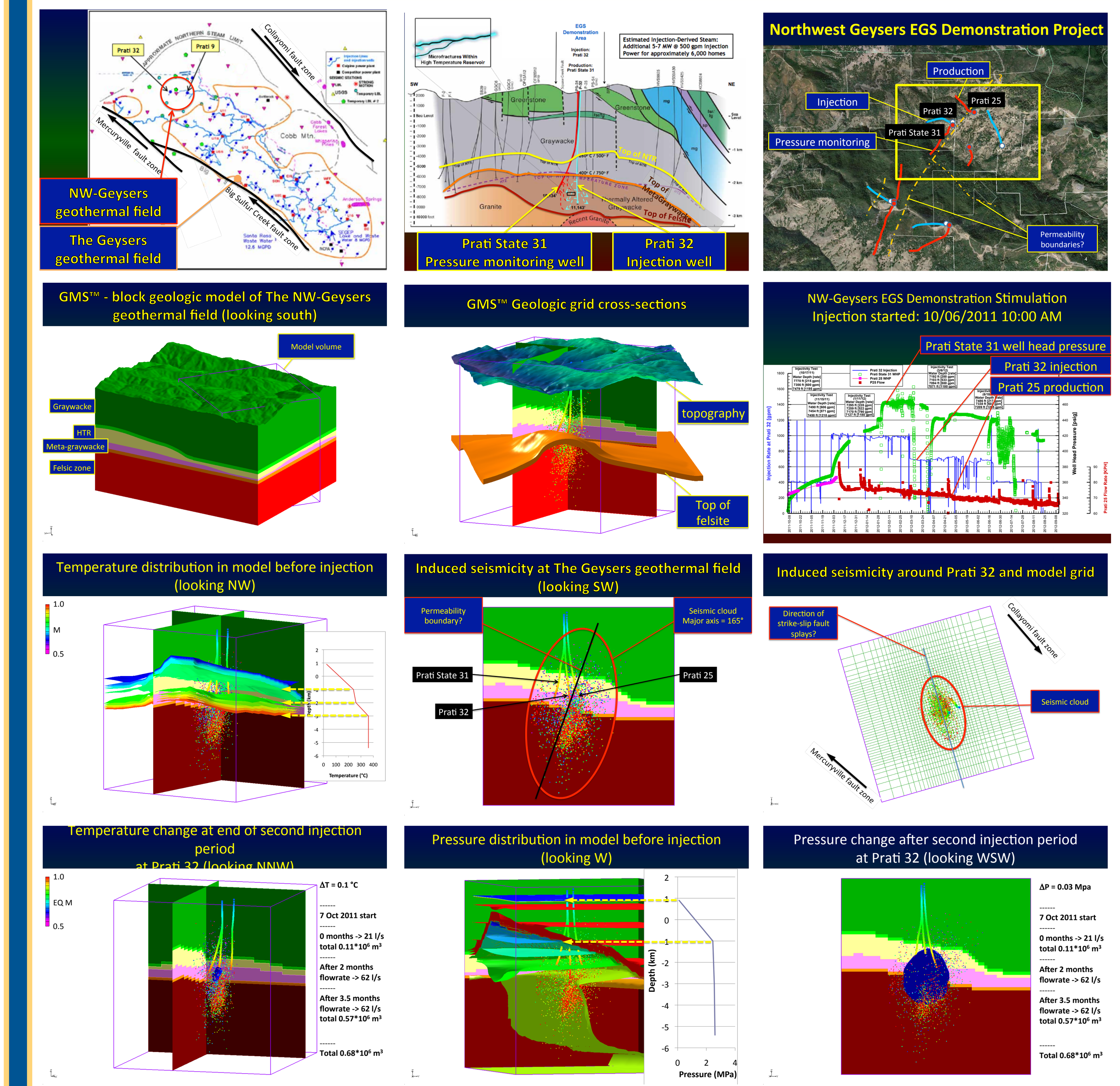
Example: A Venitian Lagoon Phosphogypsum land fill[1, 2]

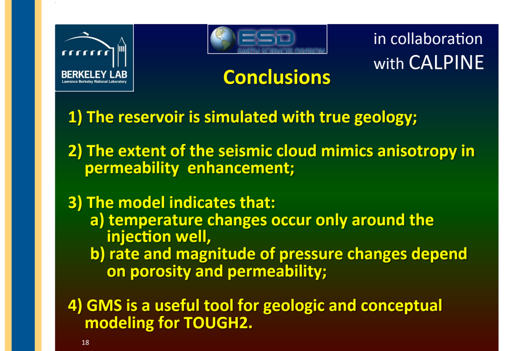




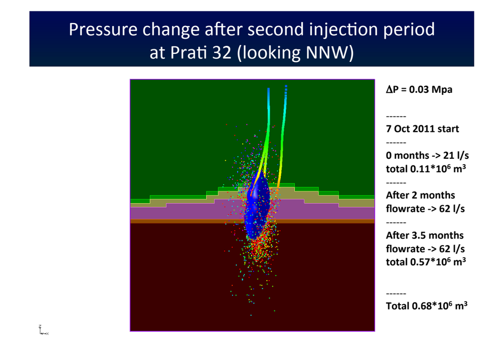
This is a case in which it would have been very hard to use TOUGH2 without a good geologic and conceptual modeling interface that allows preparing input files and visualizing results.

Example: The Geysers Geothermal field[3]

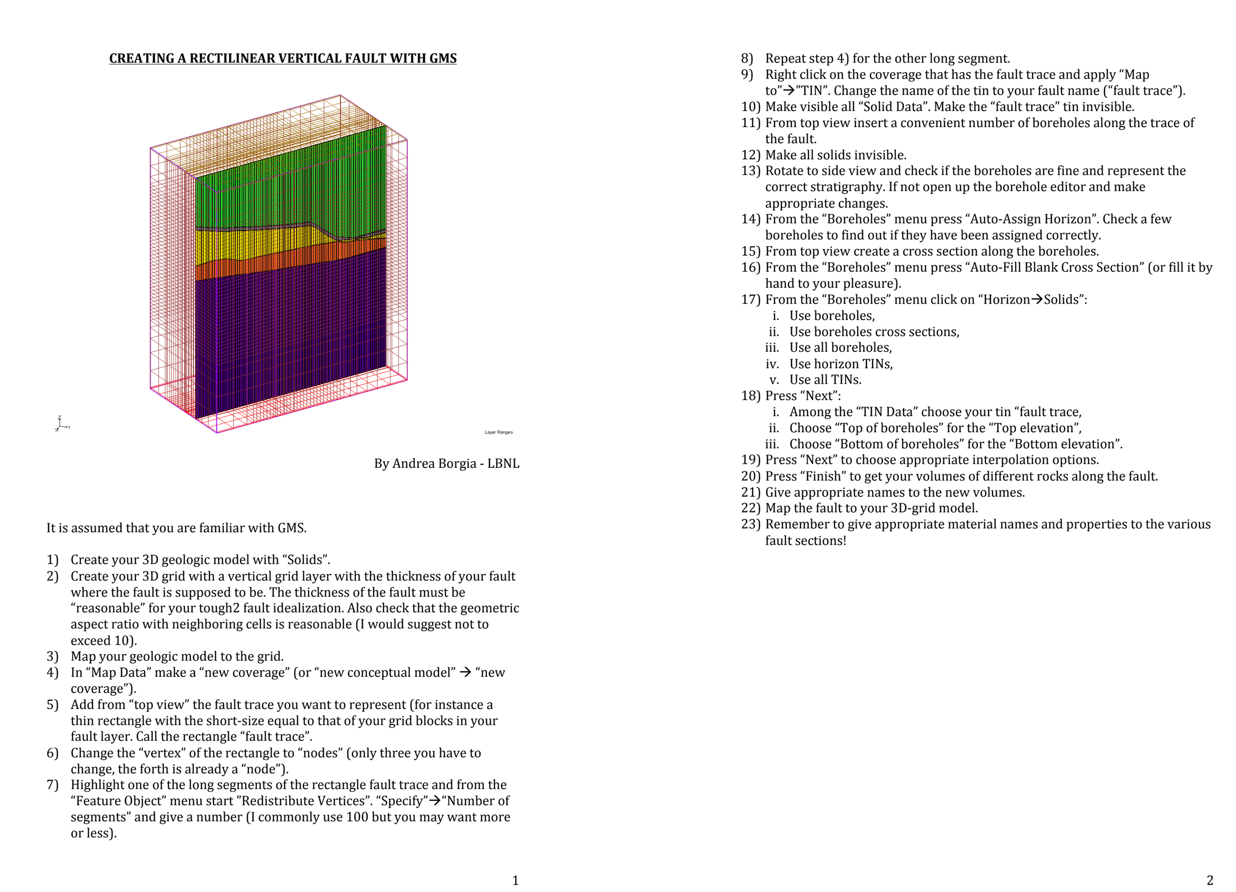




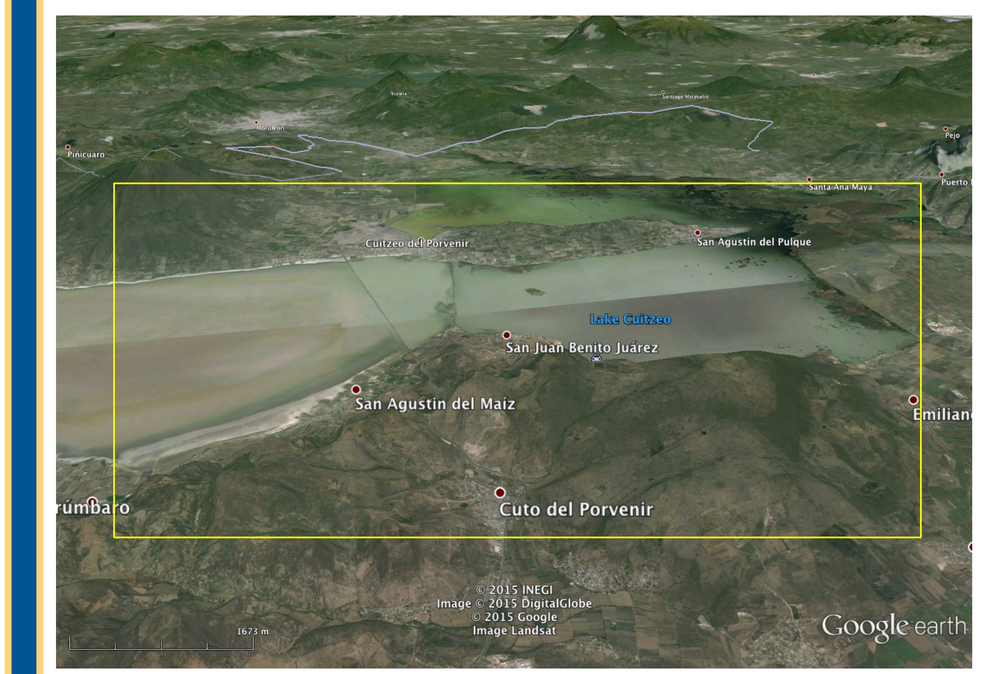
Geologic modeling for preparing TOUGH2 input files and TOUGH2-results visualization in one single environment is very important for optimizing work and understanding physical conditions and model results.



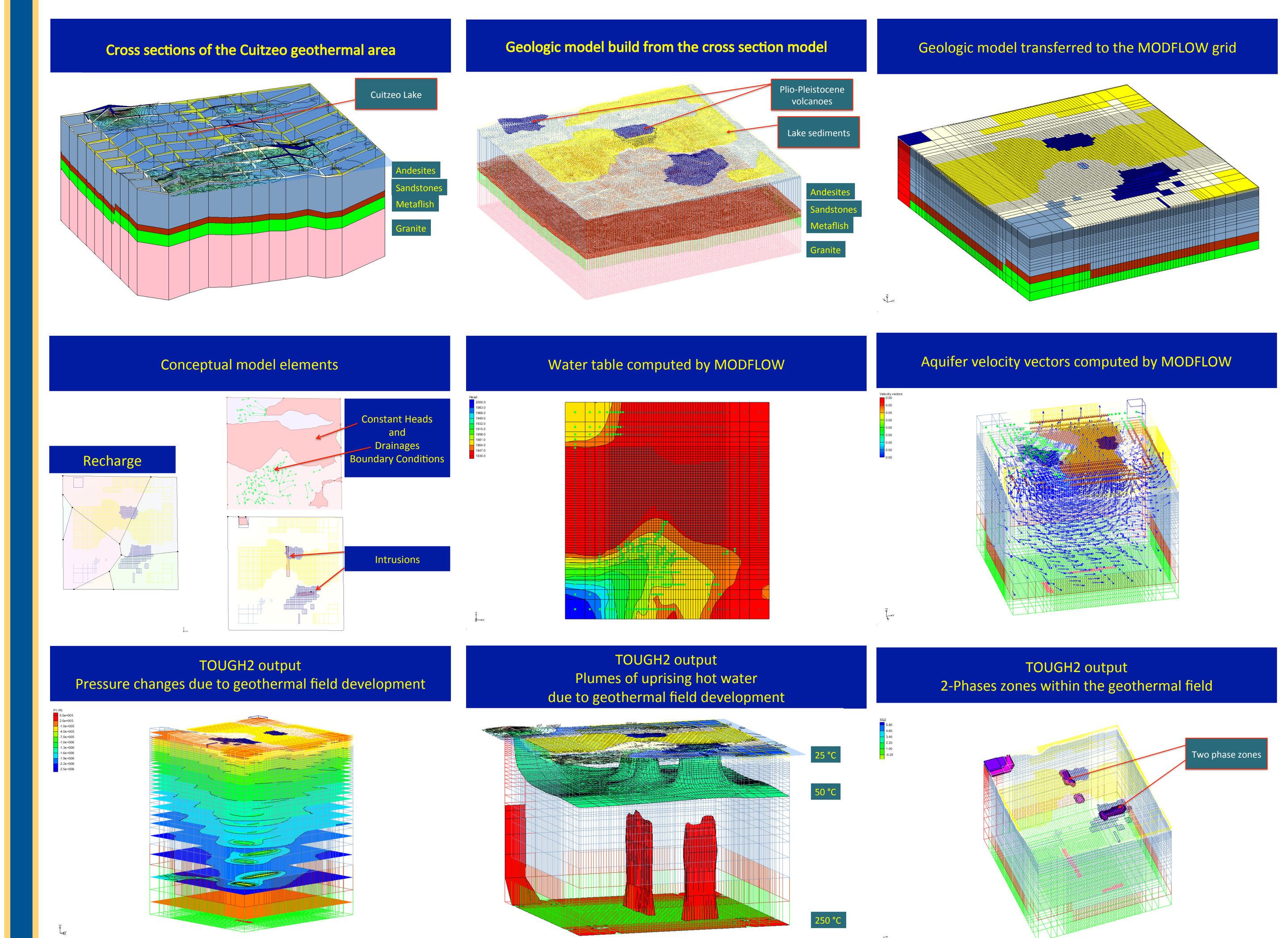
Example: Modeling faults



Example: The Cuitzeo (Mexico) Geothermal field[4]



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

[1] Borgia A., Cattaneo L., Marconi D., Delcroix C., Rossi E.L., Clemente G., Amoroso C.G., Lo Re F., Tozzato E., 2010. Using a MODFLOW grid, generated with GMS, to solve transport problem with TOUGH2 with complex geological environments: the intertidal deposits of the Venetian Lagoon. TOUGH 2009. Computer & Geosciences, doi 10.1016/j.cageo.2010.11.007.

[2] Calcara M., Borgia A., Cattaneo L., Bartolo S., Clemente G., Amoroso G., Lo Re F., Tozzato E., 2013. Modelling reactive transport in a phosphogypsum dump, Venezia, Italia. EGU General Assembly 2013, held 7-12 April, 2013 in Vienna, Austria, p. 13125.

[3] Borgia A., Rutqvist J., Oldenburg C.M., Hutchings L., Garcia J., Walters, M., Hartline, C., Jeanne P., Dobson P., 2013. Three-dimensional numerical reservoir simulation of the EGS Demonstration Project at The Geysers geothermal field. XI Congreso de Geología de América Central. Panama City, Panama.

[4] Borgia A., Garduño Monroy V.H., Osti S., Fumagalli L., Mazzoldi A., 2015. Modeling the mid-enthalpy Cuitzeo geothermal field, Mexico. In preparation.

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