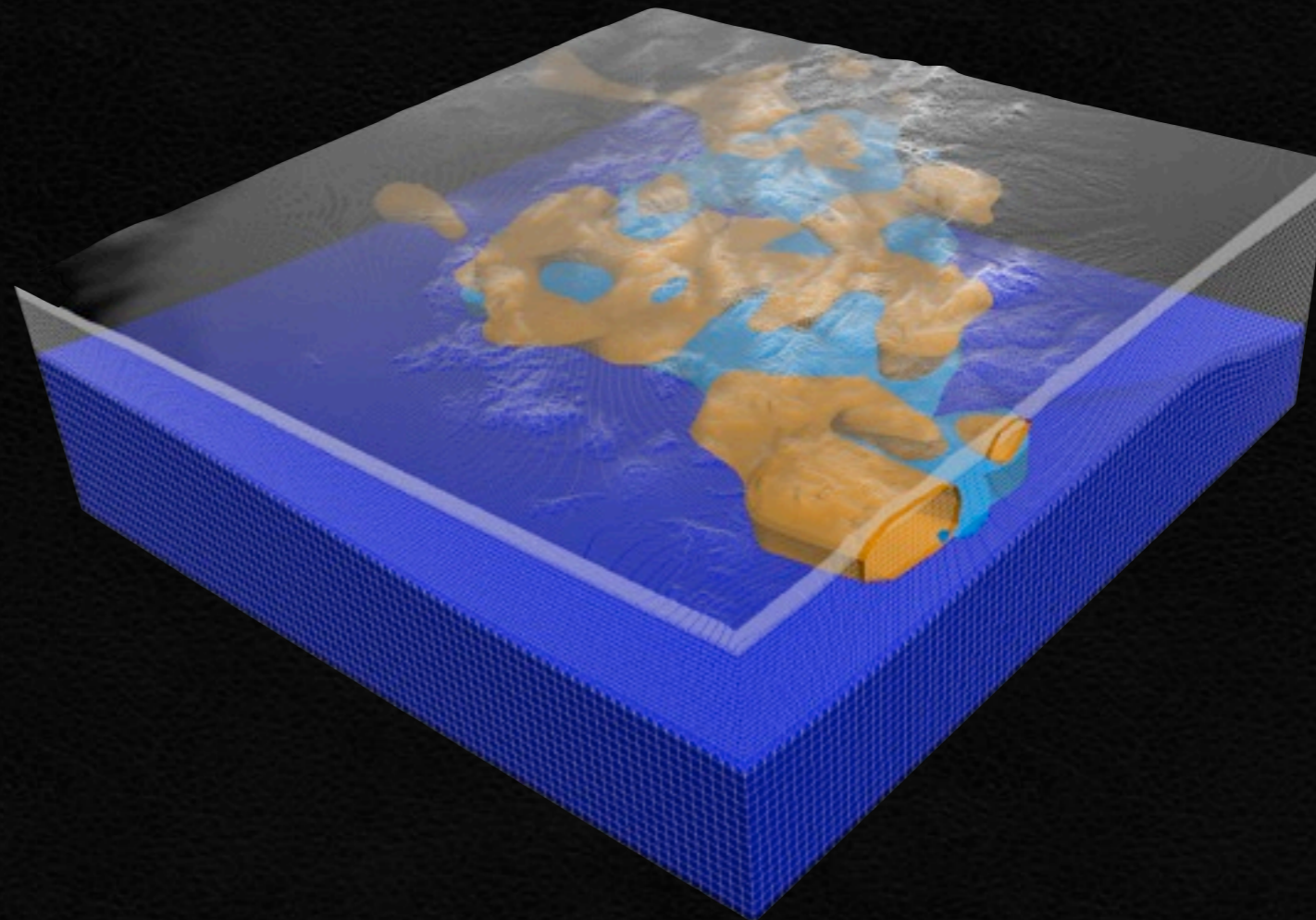




15.7.2013
CIG-QUEST-IRIS
workshop

Seismic Imaging
of structure
and source

Univ. of Alaska
Fairbanks



Hex meshing 101



Emanuele Casarotti
Istituto Nazionale di Geofisica e Vulcanologia

HEX Meshing



courtesy of Walt Disney

SPECTRAL ELEMENT METHOD (SPECFEM3D)

Full complexity

Exponential **ACCURACY** of high-order methods

Suitable for implementation in parallel architectures

Mechanical properties can vary inside each element

Low Number of elements for wavelength

EFFICIENCY!!!! (Diagonal Mass Matrix - Explicit time scheme)

SPECTRAL ELEMENT METHOD (SPECFEM3D)

Full complexity

Exponential **ACCURACY**

Suitable for imple

Mechanical prop

Low Number of e



HEX

EFFICIENCY!!!! (Diagonal Mass Matrix - Explicit time scheme)

MESH: features

$$\Delta h = v_{min} T_o \frac{N + 1}{f(N)}$$

$$\Delta t < C_{max} \frac{v_{min}}{v_{max}} T_o \frac{N + 1}{f(N)}$$

Seismic velocity can vary inside the volume

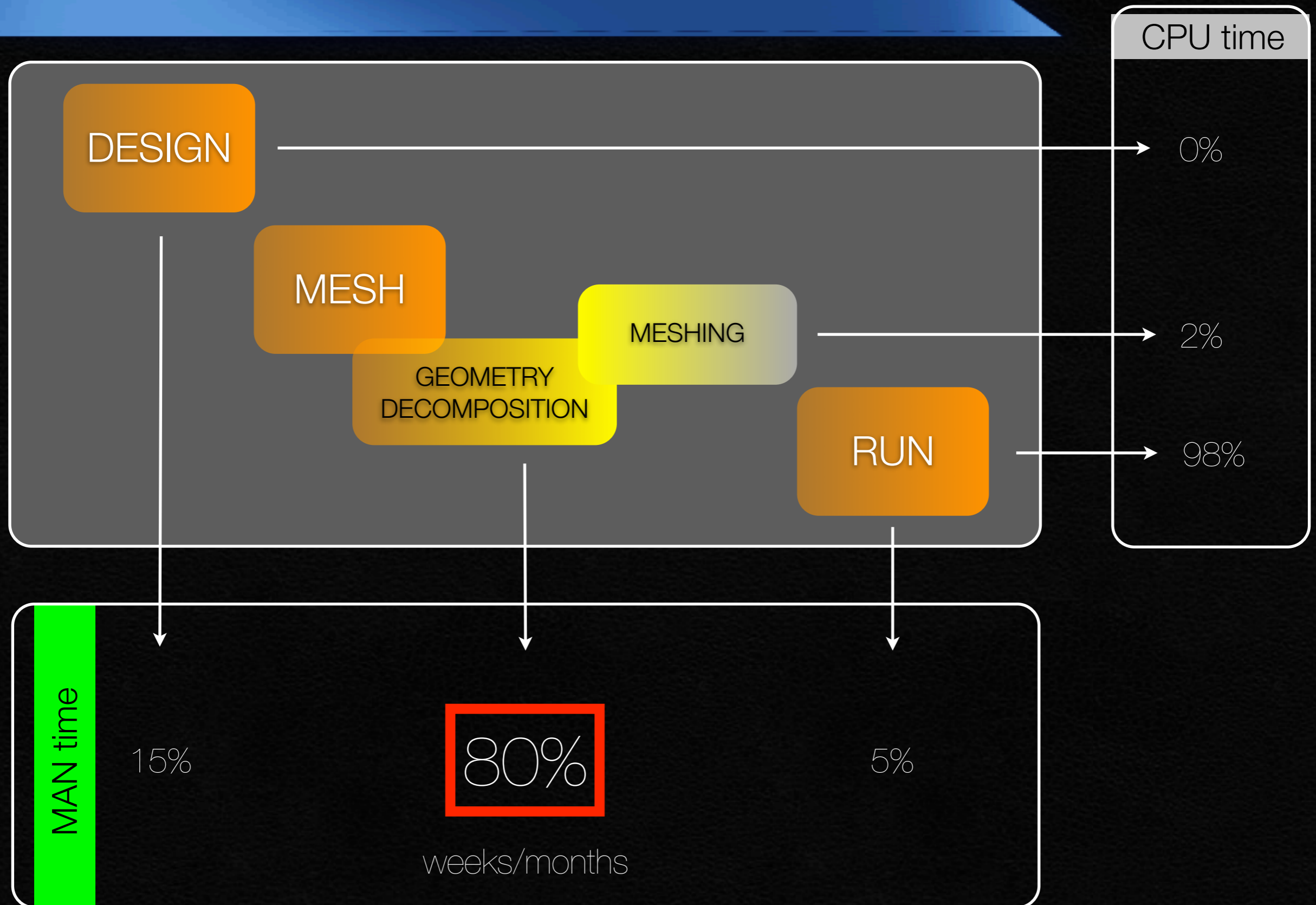


UNSTRUCTURED - ANISOTROPIC - CONFORMAL
(honoring the geology) (usually the dimension of the elements increase with depth)

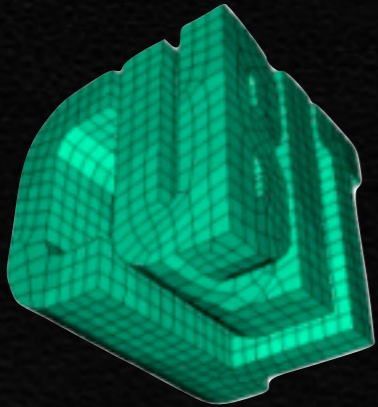
MESH: parallelism

	Little volume (10x10x10 km)	Huge volume (300x300x100 km)
Long period	~ 1 million	~ 1/5 millions
Short period	~ 5/10 millions	~ 0.5/10 billions (Earth ~ 20 Ghex)

MESH: no automatic solution



MESHER: CUBIT



The CUBIT Geometry and Mesh Generation Toolkit

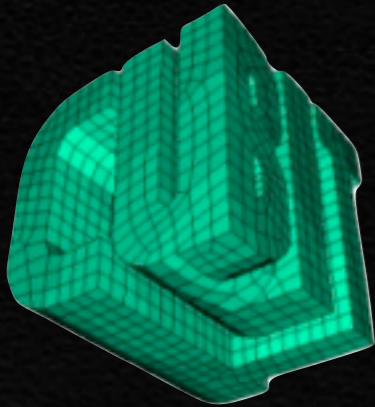
FREE for academic

(300\$ distribution fee for institution, you can share with your colleagues inside the institution, fairly)

2D/3D solid-modeler mesher:

- Geometry preparation
- Automatic meshing algorithms
- Quality analysis
- Hexahedra/Tetrahedra

MESHER: CUBIT



The CUBIT Geometry and Mesh Generation Toolkit

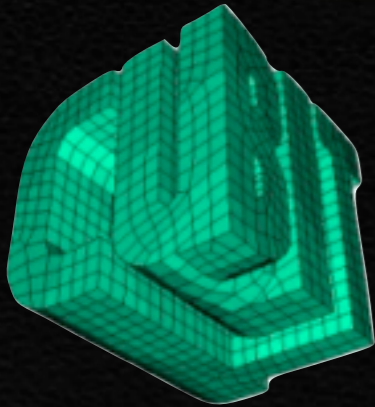
FREE for academic
(300\$ distribution fee for non-academic use, you can share with your colleagues inside the institution, fairly)



2D/3D solid-modeler mesher:

- Geometry preparation
- Automatic meshing algorithms
- Quality analysis
- Hexahedra/Tetrahedra

MESHER: CUBIT



The CUBIT Geometry and Mesh Generation Toolkit

US national lab: cubit.sandia.gov (free)



Trelis

Academic: csimsoft.com (300\$-1250\$)

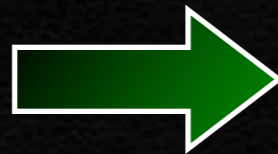
2D/3D solid-modeler mesher:

- Geometry preparation
- Automatic meshing algorithms
- Quality analysis
- Hexahedra/Tetrahedra

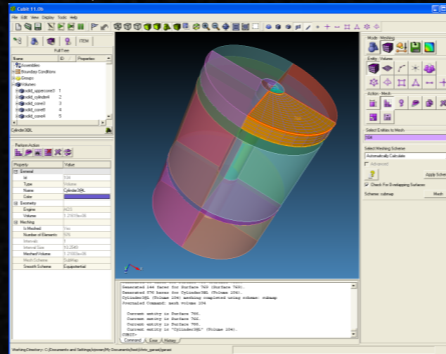
MESHER: CUBIT

CAD

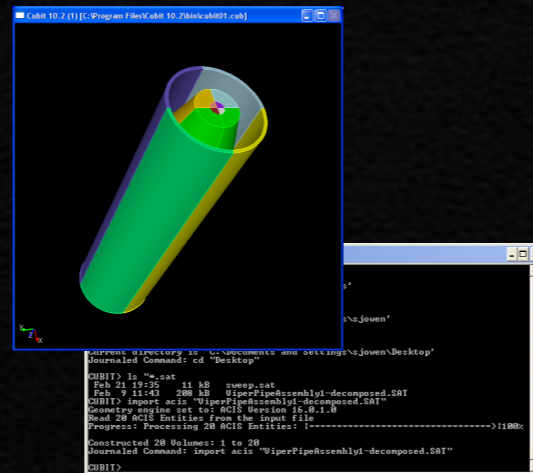
ACIS (CUBIT, Autocad)
STEP
IGES (Rhinoceros)
Facets (GOCAD)
STL
ExodusII



Graphical Interface



Command line

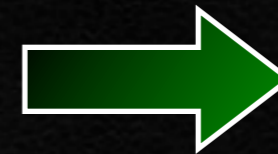


Python API

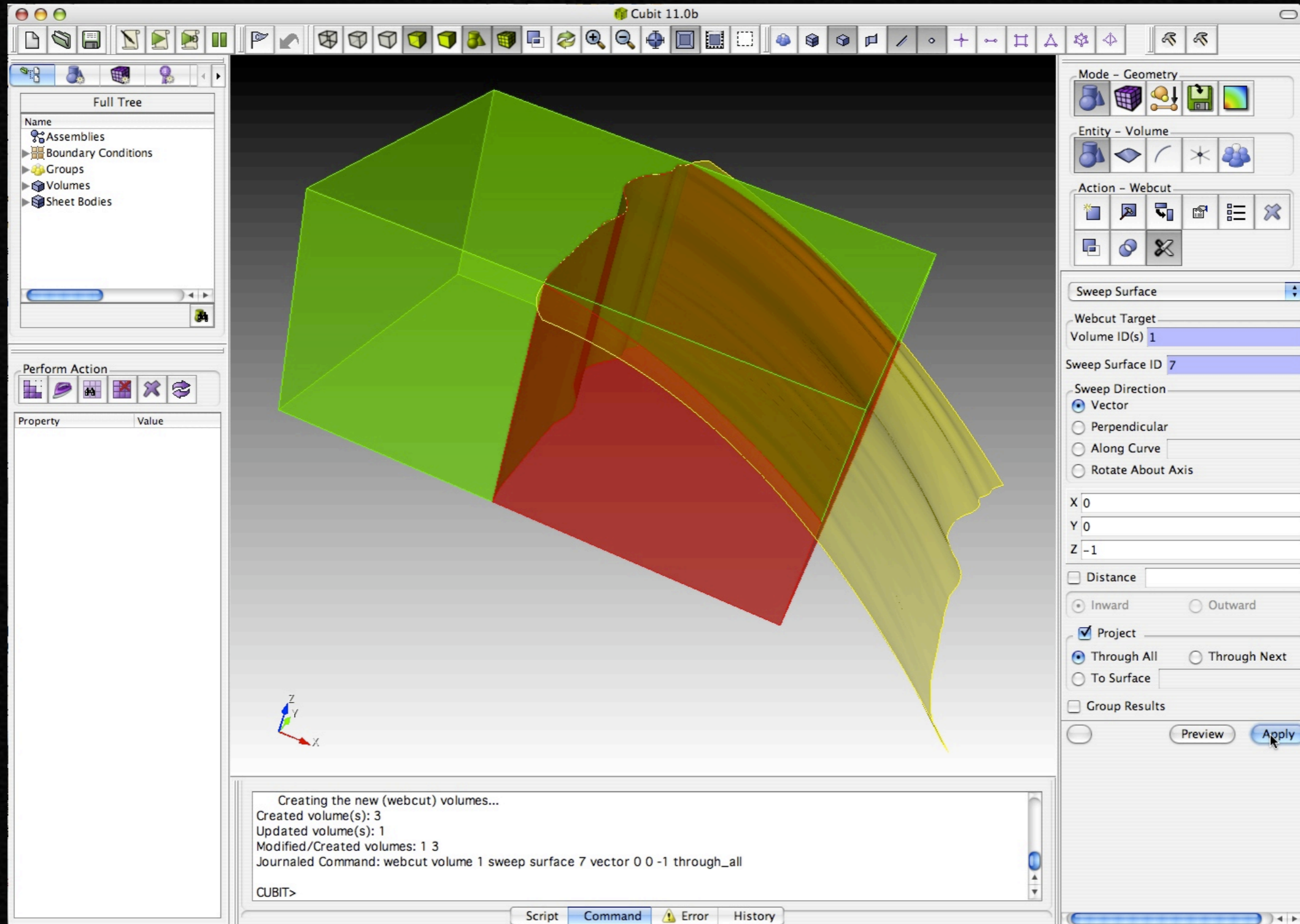


MESH

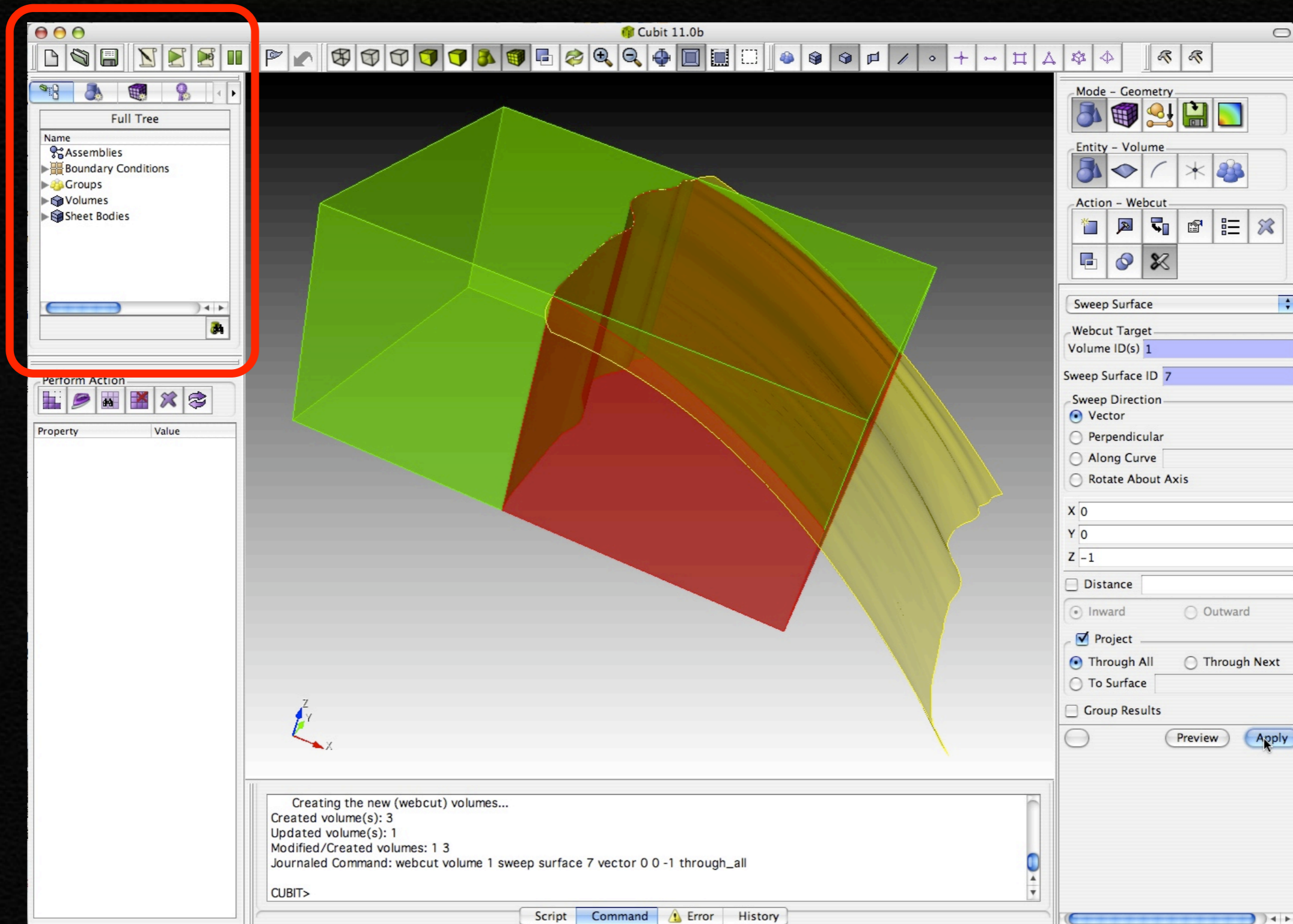
Abaqus (ASCII)
IDEAS
NASTRAN
Petran
LS-Dyna
ExodusII (NETCDF)



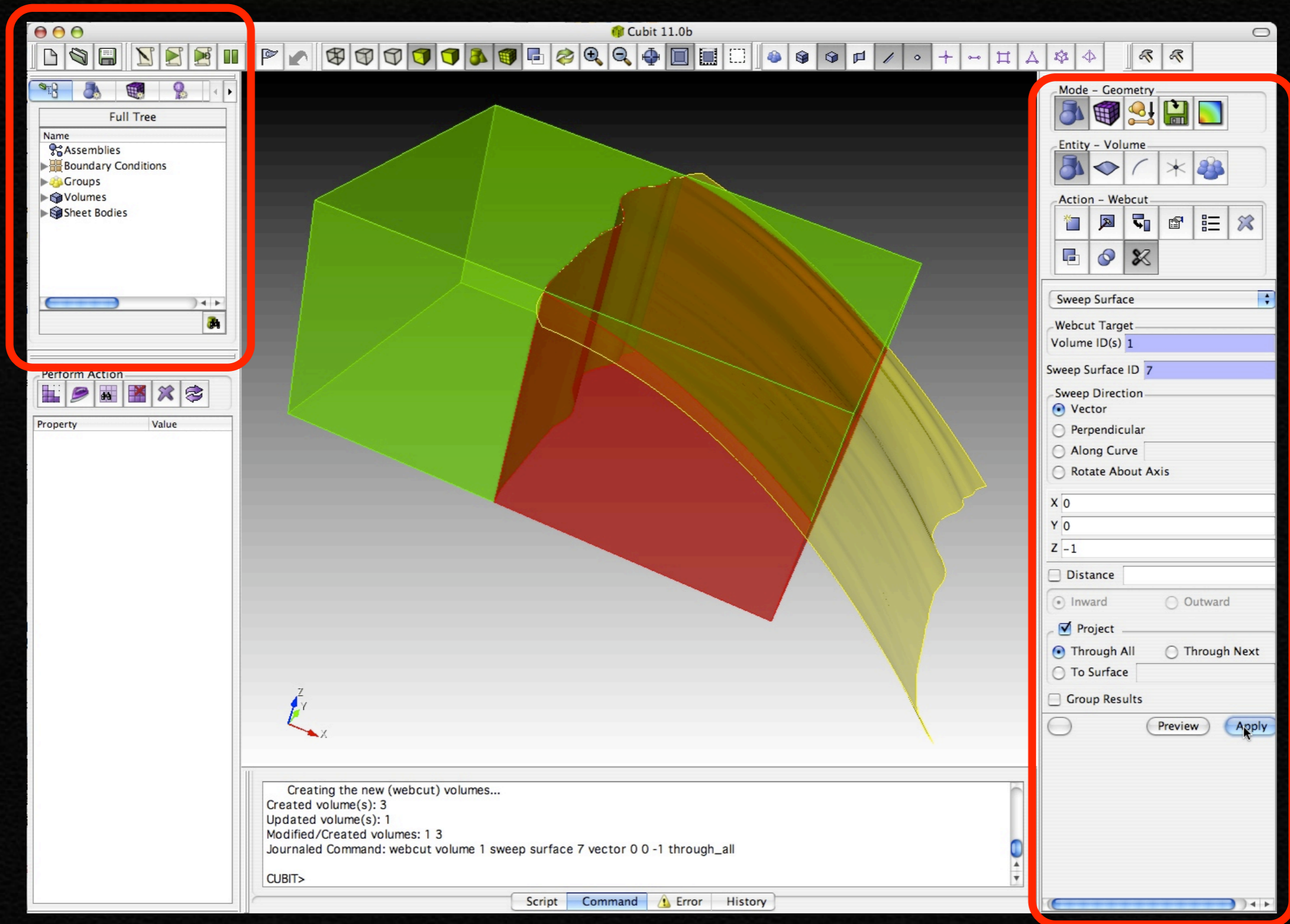
MESHER: CUBIT



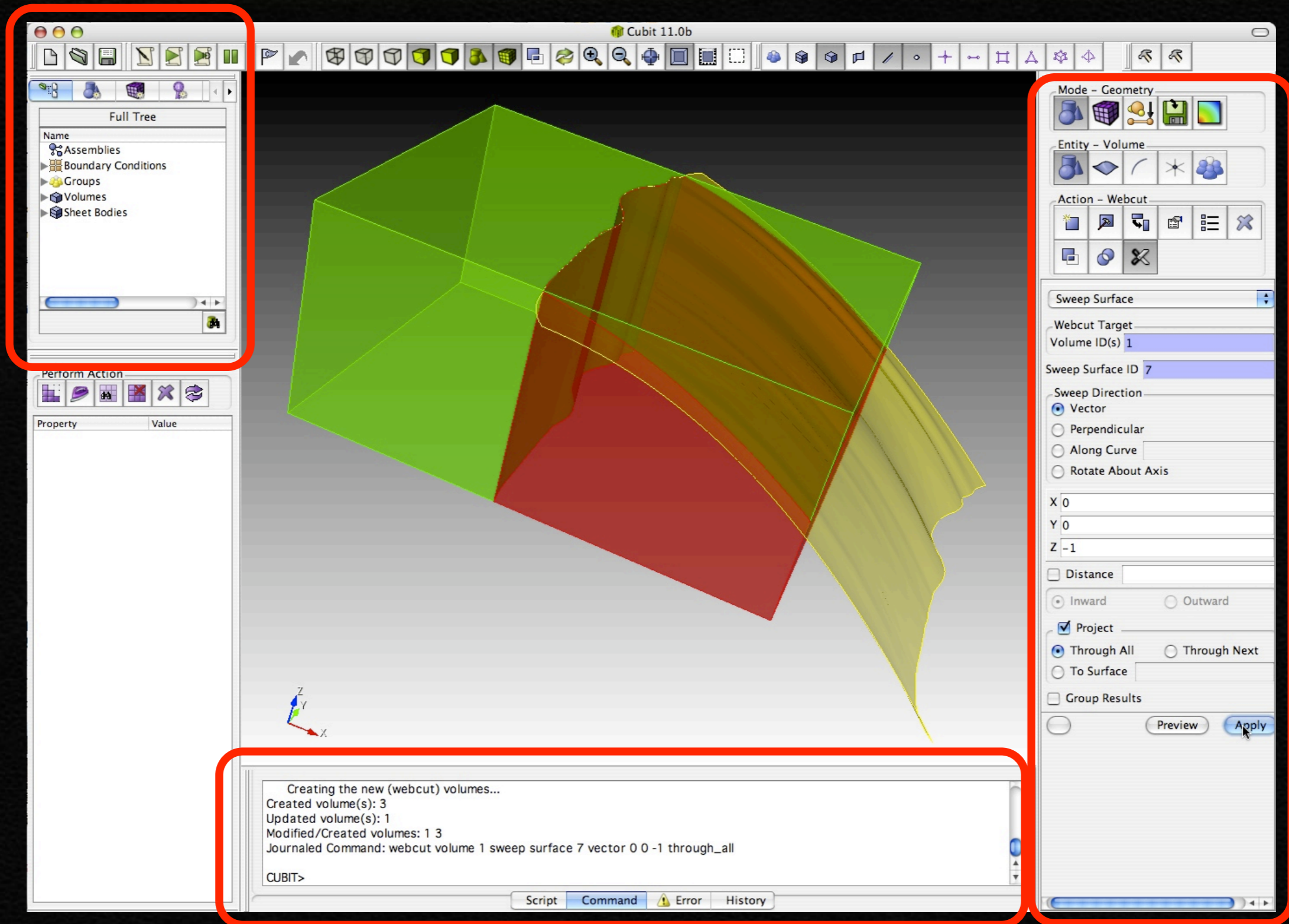
MESHER: CUBIT



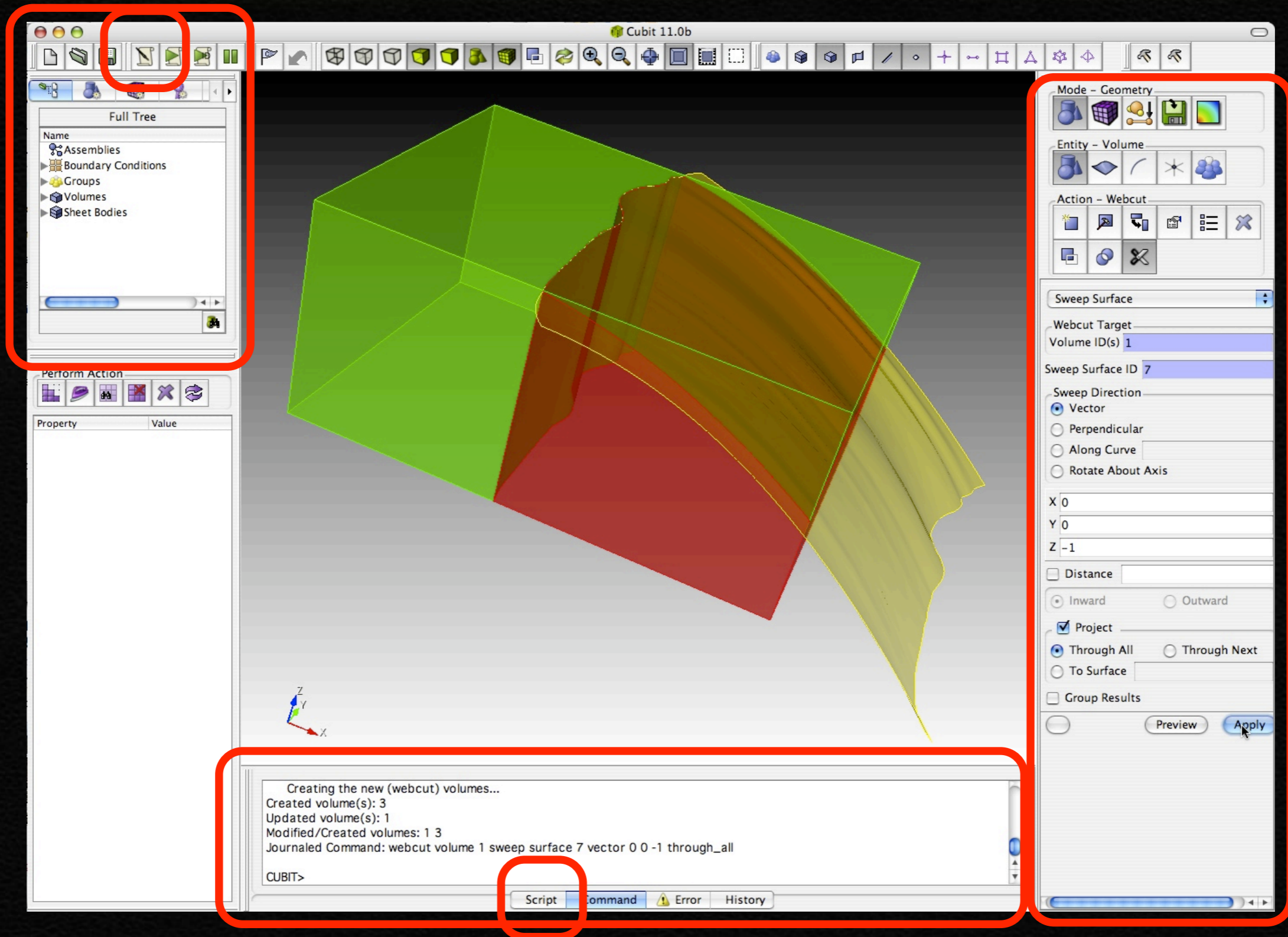
MESHER: CUBIT



MESHER: CUBIT



MESHER: CUBIT



MESHER: CUBIT

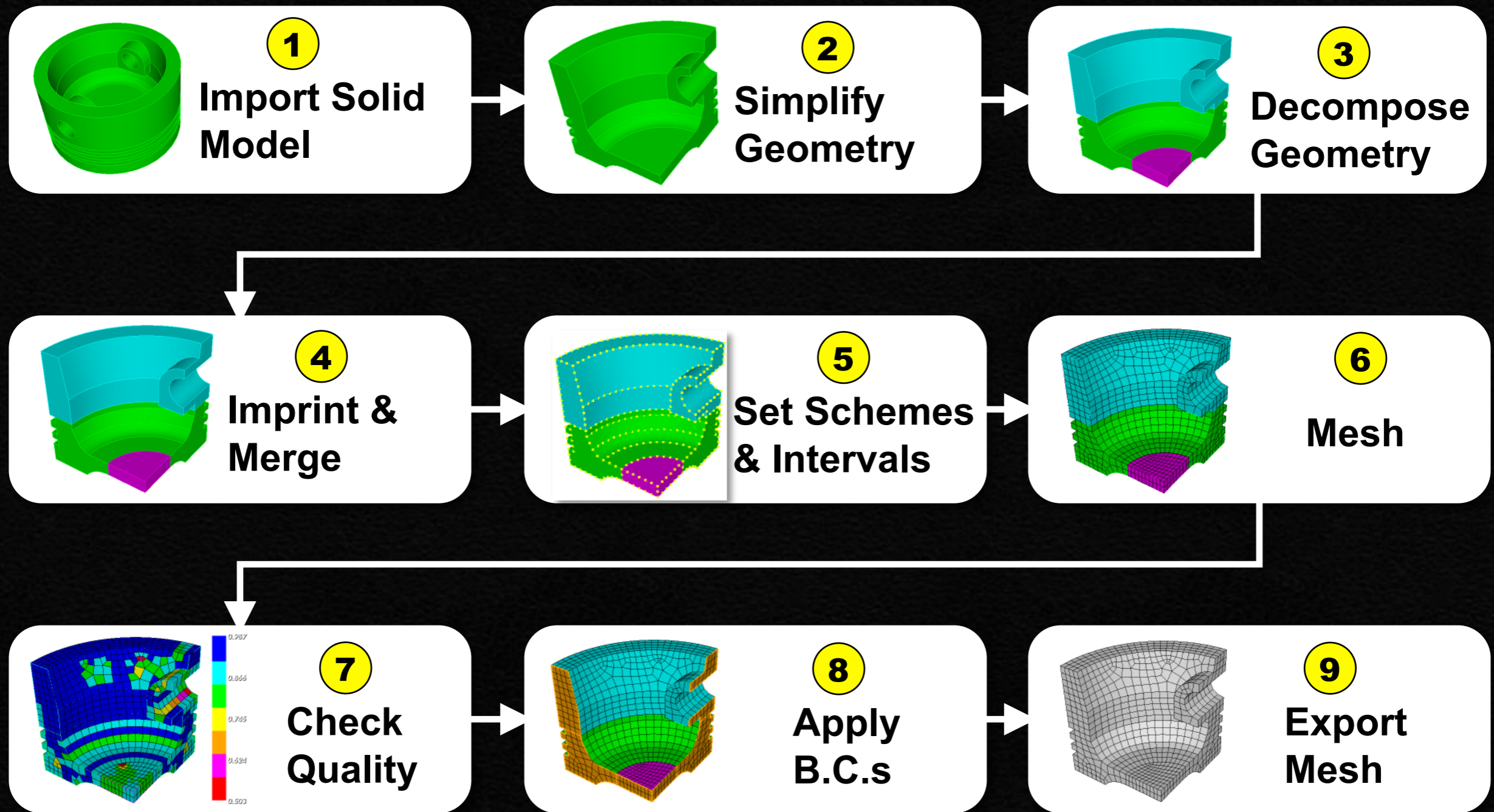
The screenshot displays the Cubit 11.0b software interface. The main window shows a 3D model of a meshed object. The interface is divided into several panels:

- Full Tree (Left):** A hierarchical tree view showing the model's structure, including Assemblies, Boundary Conditions, Groups, Volumes, and Sheet Bodies.
- Journal Editor (Center):** A text editor window containing a script for creating a sweep surface. The script includes commands for setting parameters, importing a grid file, and defining a sweep surface.
- Mode - Geometry (Right):** A panel for configuring the sweep surface operation. It includes options for Sweep Surface, Webcut Target, Sweep Surface ID, Sweep Direction, and Project settings.
- Status Bar (Bottom):** A bar at the bottom of the window showing the current command and status. The 'Script' button is highlighted.

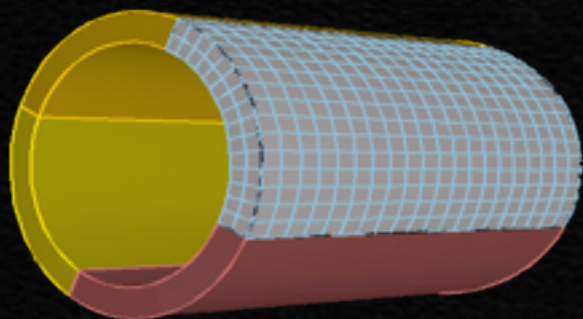
```
name='/Users/emanuele/Desktop/stromboli/stromboli.xyz'  
xstep=10  
ystep=10  
nx=246  
ny=246  
#command = "reset"  
cubit.cmd(command)  
import os  
command = "set echo off"  
cubit.cmd(command)  
command = "set journal off"  
cubit.cmd(command)  
def create_line(n,step,grdfile):  
    last_curve_store=cubit.get_last_id("curve")  
    command="create curve spline "  
    for i in range(0,n):  
        record=grdfile.readline()  
        if i%step == 0:  
            x,y,z=record.split()  
            txt=" Position " + x +' '+ y +' '+ z  
            command=command+txt  
            #print command  
            cubit.silent_cmd(command)  
            last_curve=cubit.get_last_id("curve")  
            if last_curve != last_curve_store:  
                return last_curve  
            else:  
                return 0  
def skip_line(n,grdfile):  
    for i in range(0,n):  
        record=grdfile.readline()  
u_curve=[]
```

Creating the new (webcut) volumes...
Created volume(s): 3
Updated volume(s): 1
Modified/Created volumes: 1 3
Journaled Command: webcut volume 1 sweep surface 7 vector 0 0 -1 through_all
CUBIT>

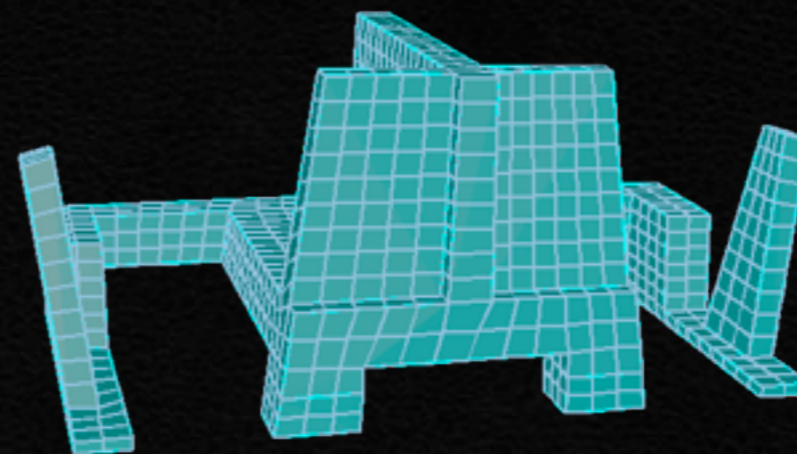
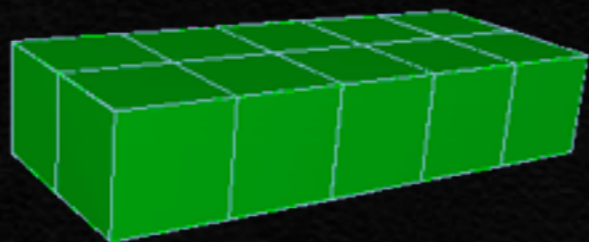
THE MESHING PROCESS



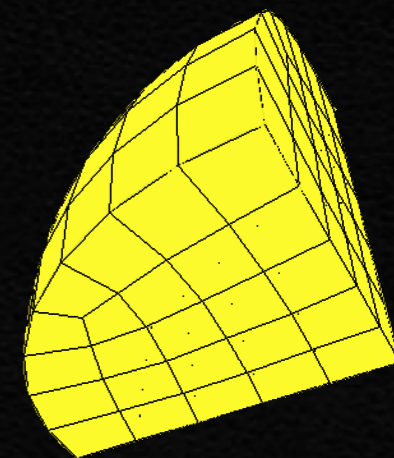
THE MESHING PROCESS



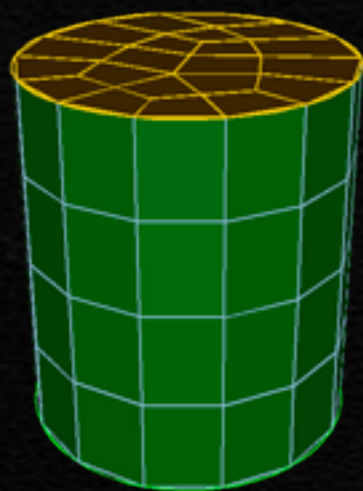
Map



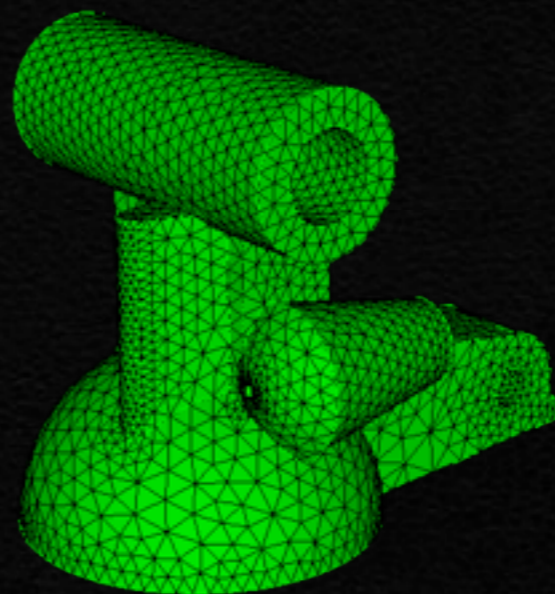
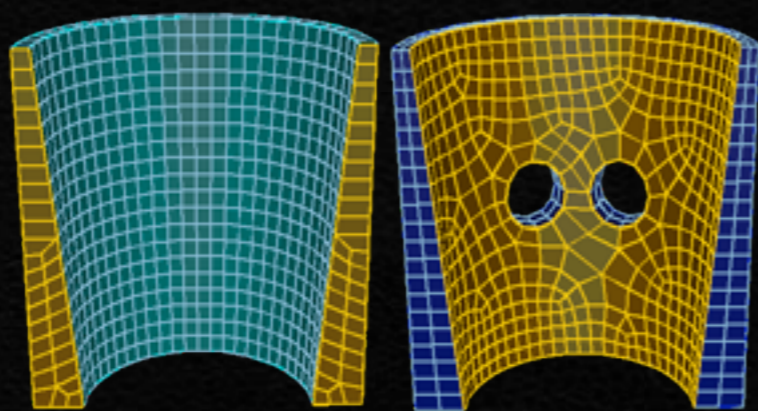
Sub-map



Triprimitive



Sweep

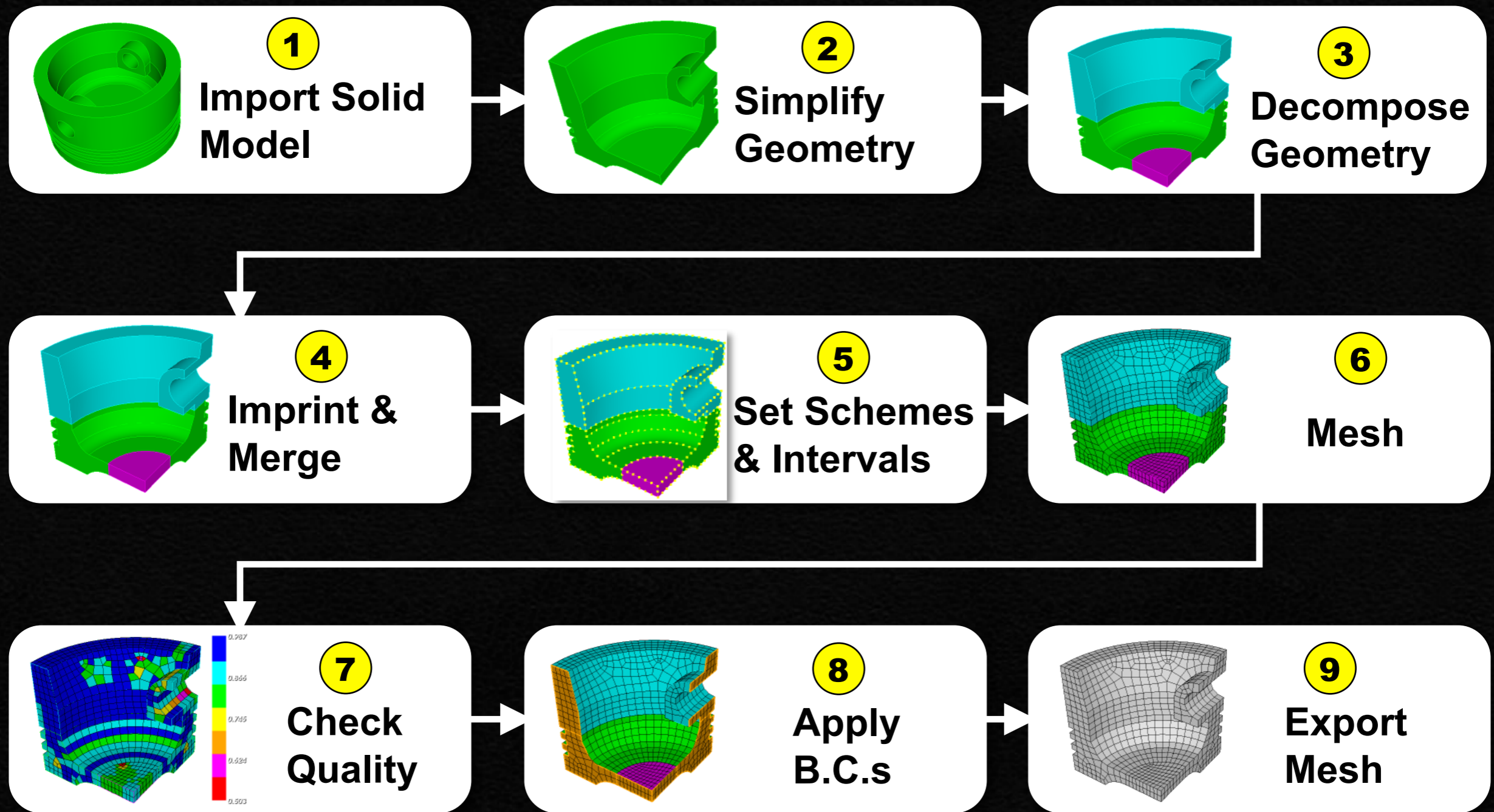


Tetmesh



THEX

THE MESHING PROCESS



THE MESHING PROCESS

- I - Construction of the geometry
- II - Meshing the geometry
- III - Boundary condition + Export the mesh

THE MESHING PROCESS

CUBIT FILE: geometry layer + meshing layer

ACIS:

Nurbs

- > Main engine
- > All the features of CUBIT are available (cleanup tool, imprinting,...)
- > Perfect for mechanical object (CAD...)
- > **Heavy usage of memory**
- > **ACIS/Nurbs are not common in geoframeworks** (Rhynoceros)
- > Best option for us: creating the geometry in CUBIT

FACET:

Triangulate surfaces

- > secondary engine
- > **NOT all the features of CUBIT are available**
- > good for **GOCAD**
- > Much less usage of memory
- > Triangulate surfaces are everywhere in geophysics
- > Best option for us: creating and decomposing the model not in CUBIT

THE MESHING PROCESS

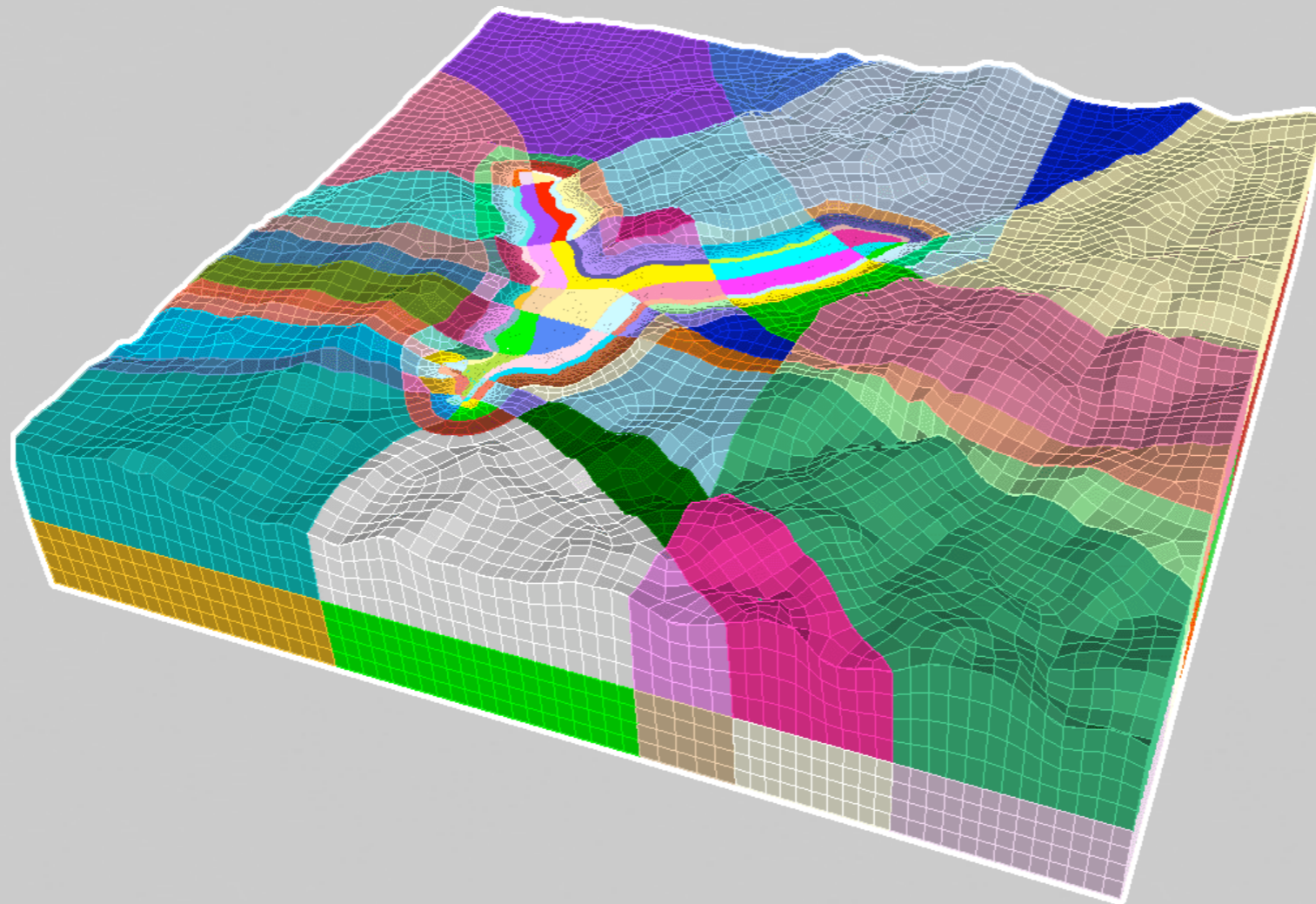
- I - Construction of the geometry
- II - Meshing the geometry
- III - Boundary condition + Export the mesh

THE MESHING PROCESS

- 0 - Define purpose and resolution of mesh
- I - Construction of the geometry
- II - Meshing the geometry
- III - Boundary condition + Export the mesh

MESHING STRATEGIES

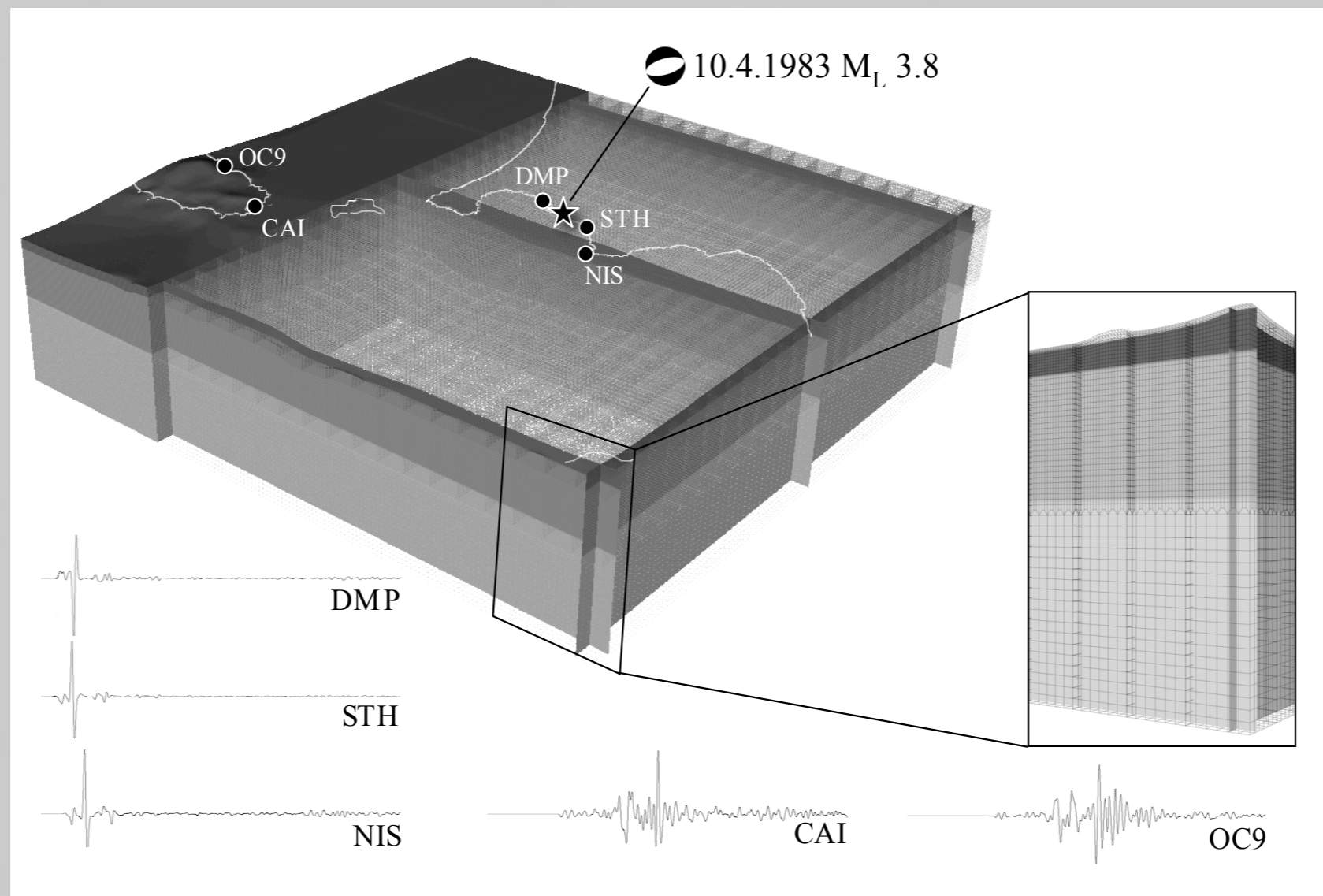
a) brutal (by hand in cubit)



MESHING STRATEGIES

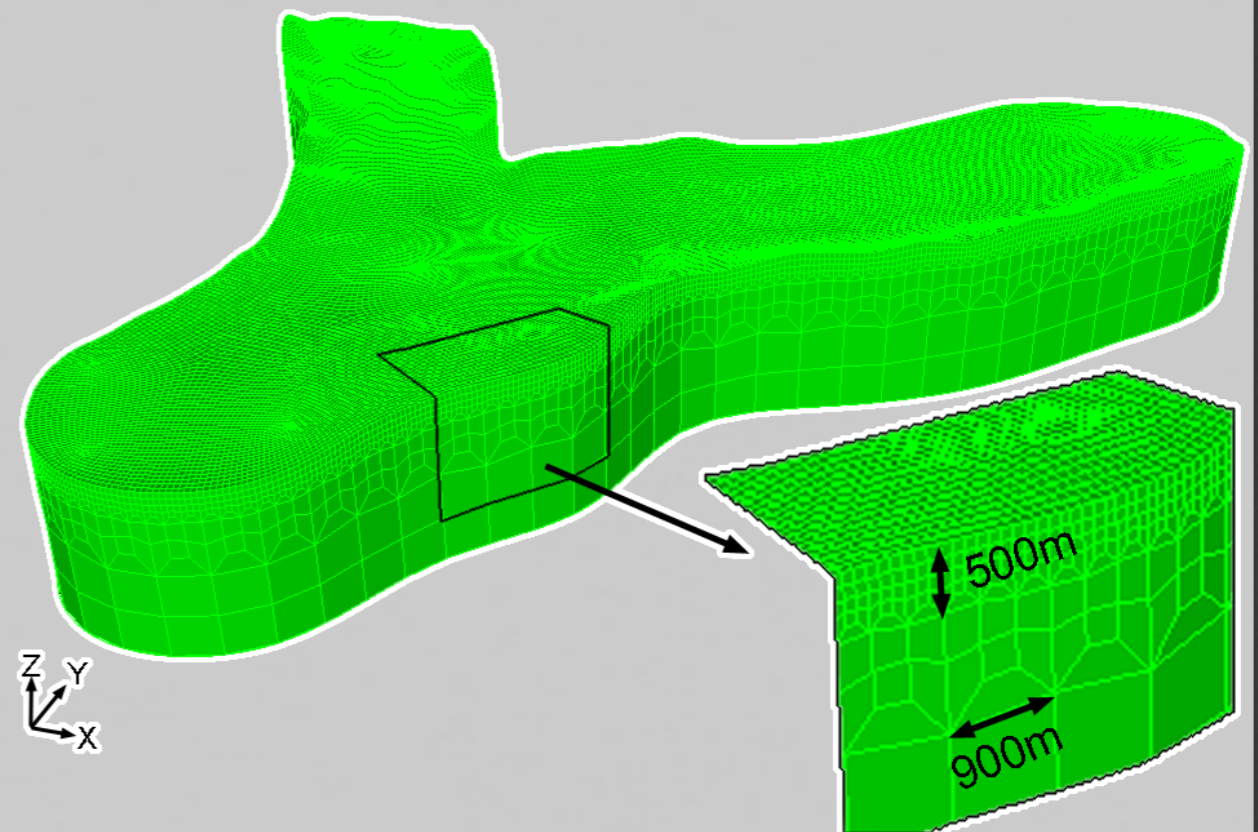
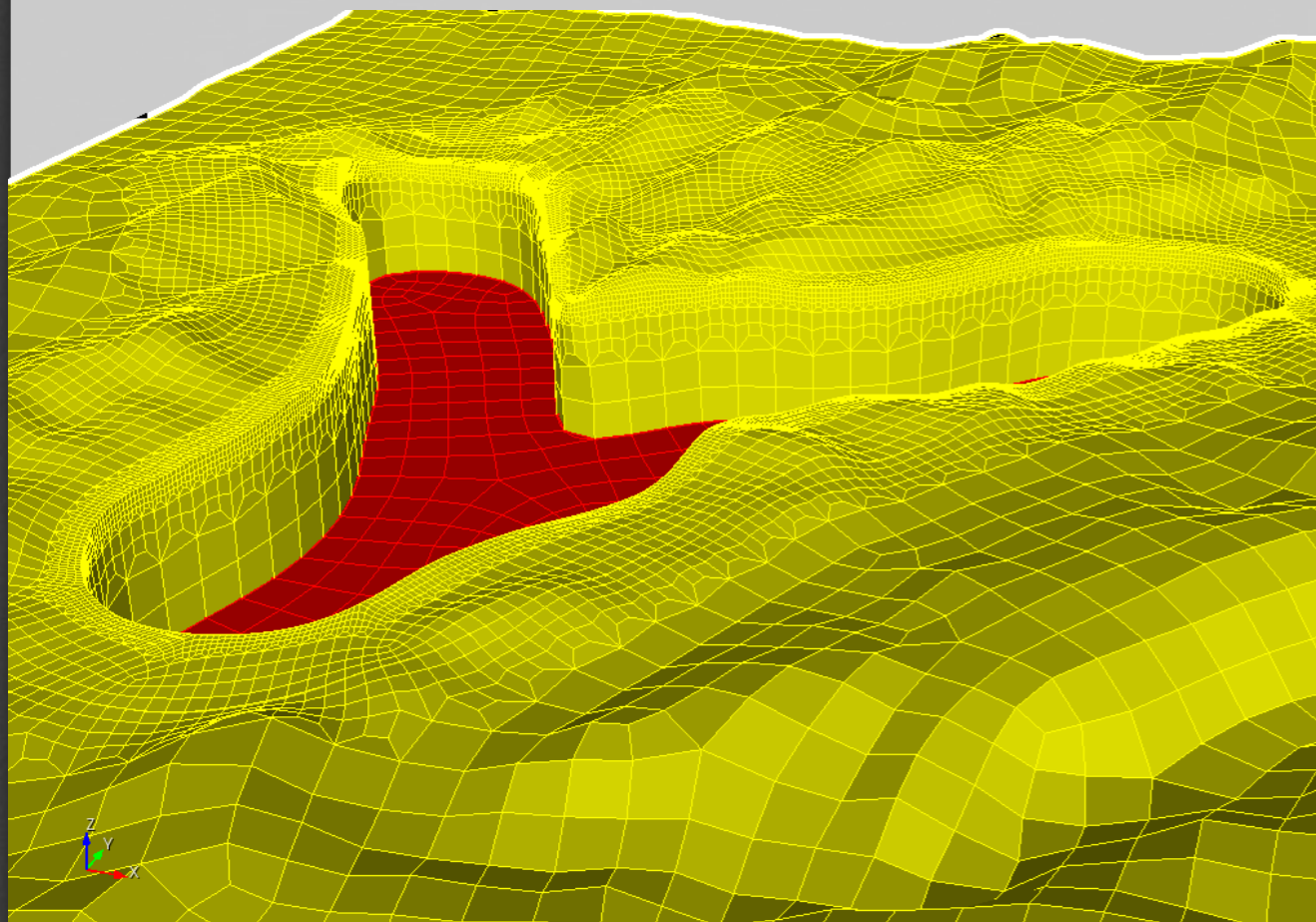
a) brutal (by hand in cubit)

b) GEOcubit (scripting)

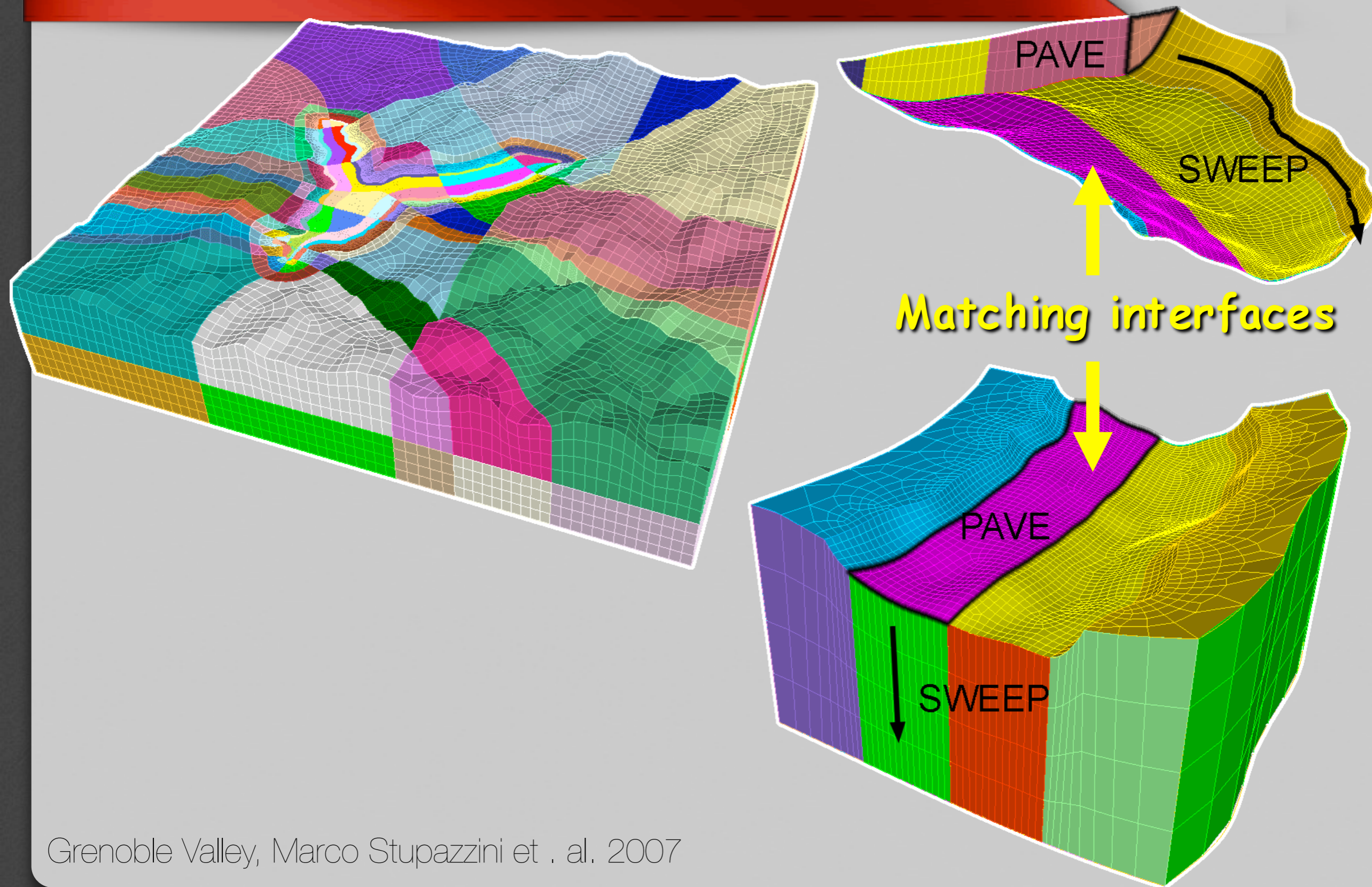


MESHING STRATEGIES

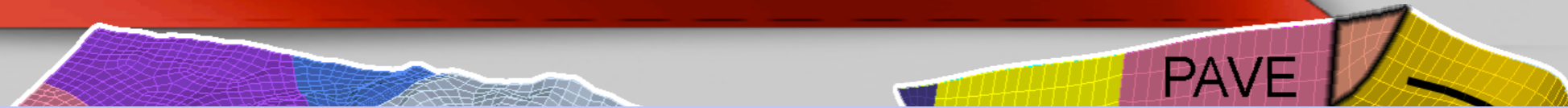
- a) brutal (by hand in cubit)
- b) GEOcubit (scripting)
- c) "Not-honoring"



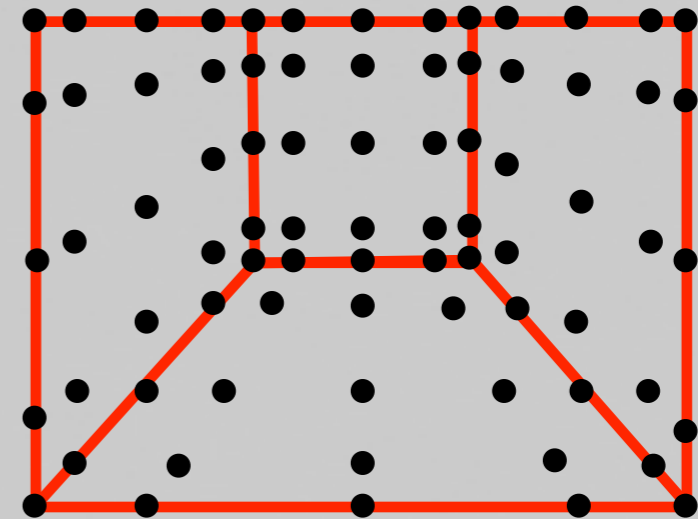
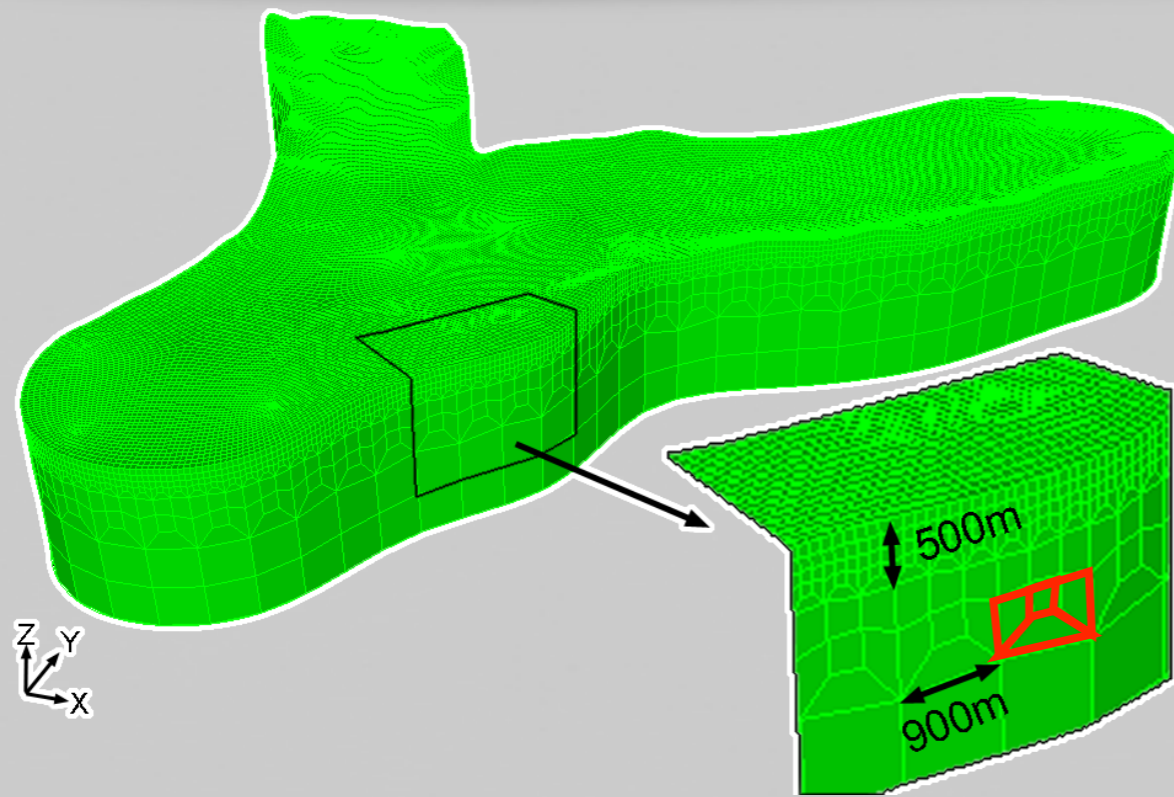
MESHING STRATEGIES (a)



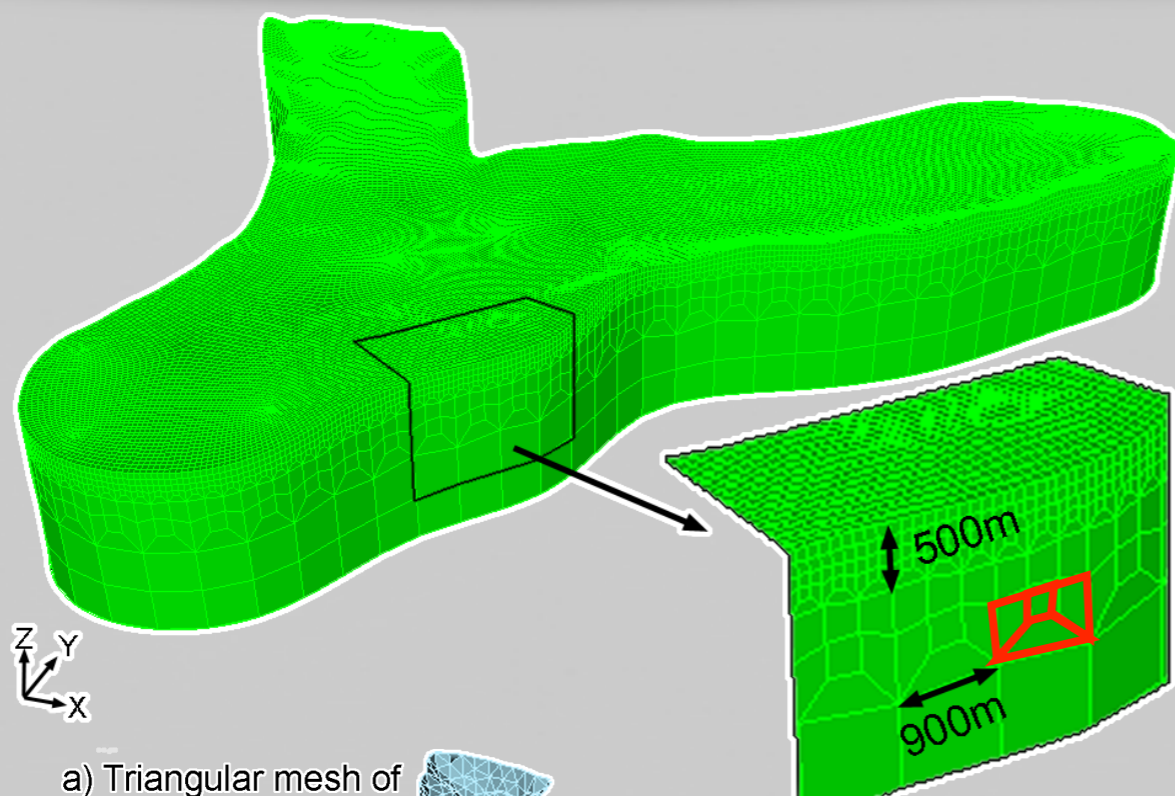
MESHING STRATEGIES (a)



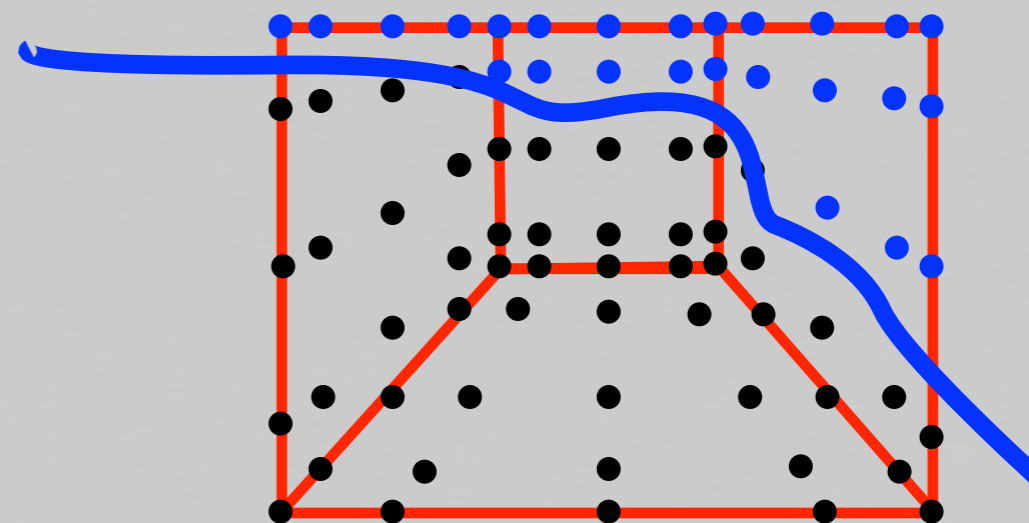
MESHING STRATEGIES (c)



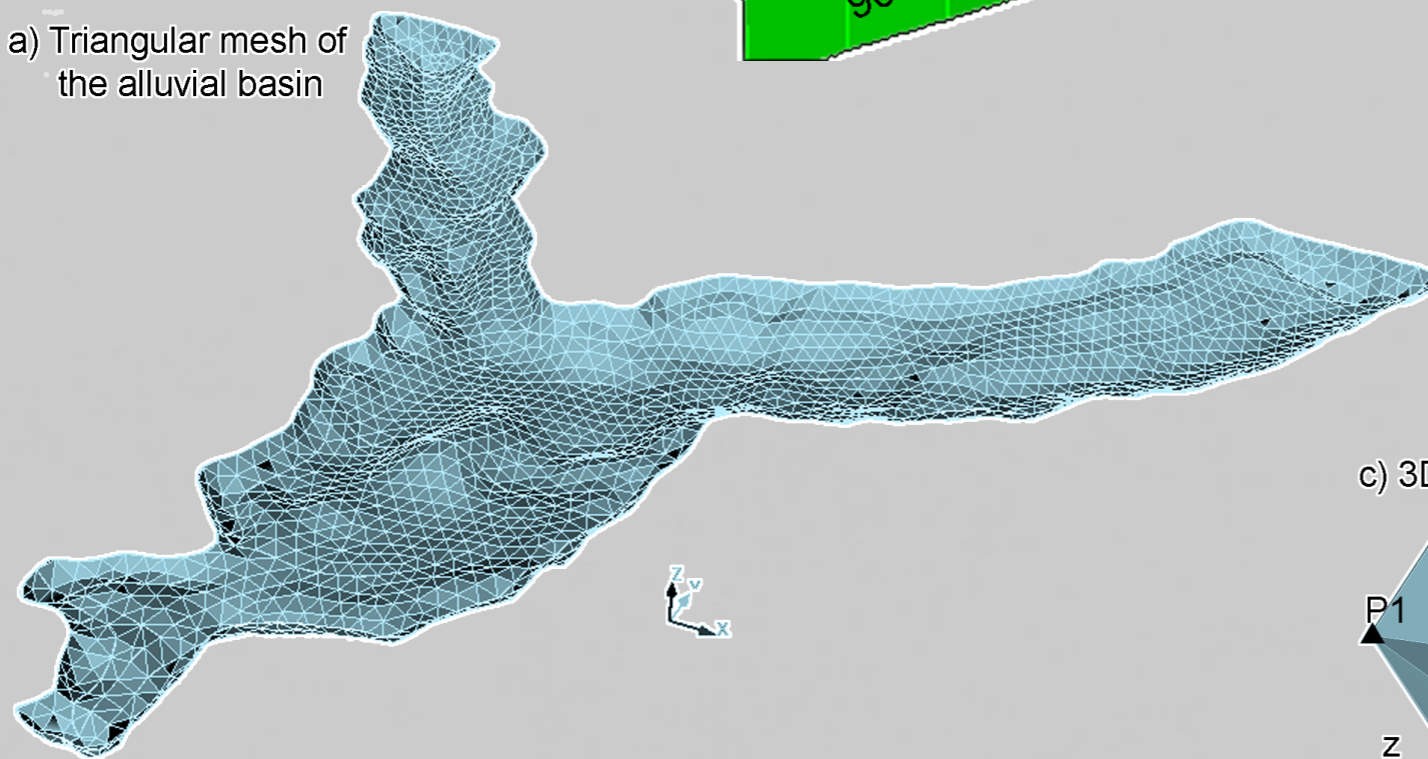
MESHING STRATEGIES (c)



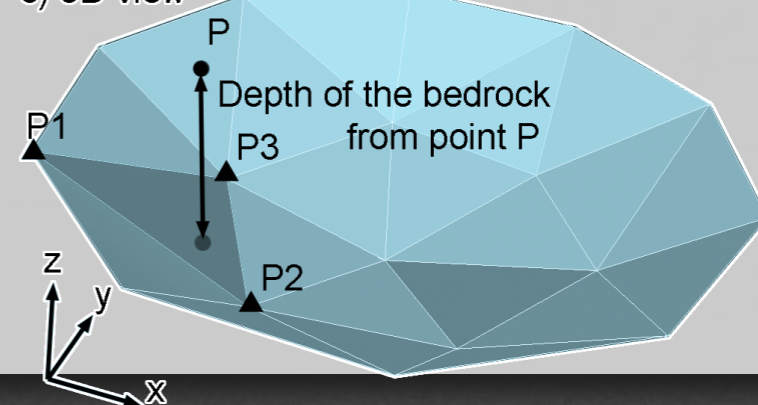
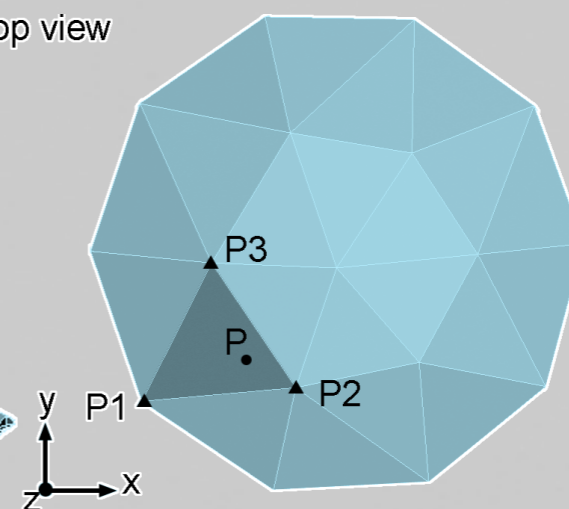
a) Triangular mesh of the alluvial basin



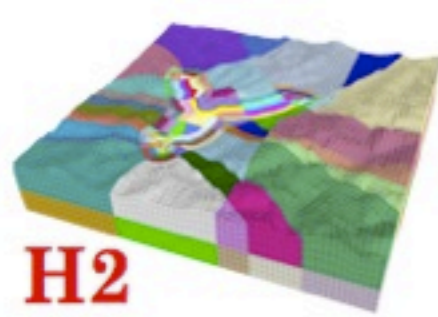
b) Top view



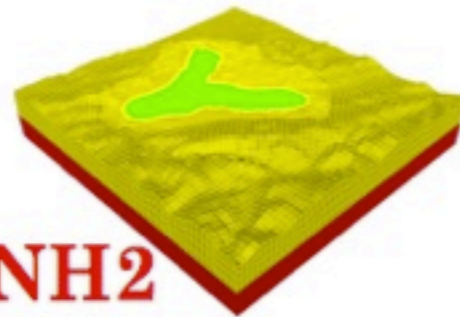
c) 3D view



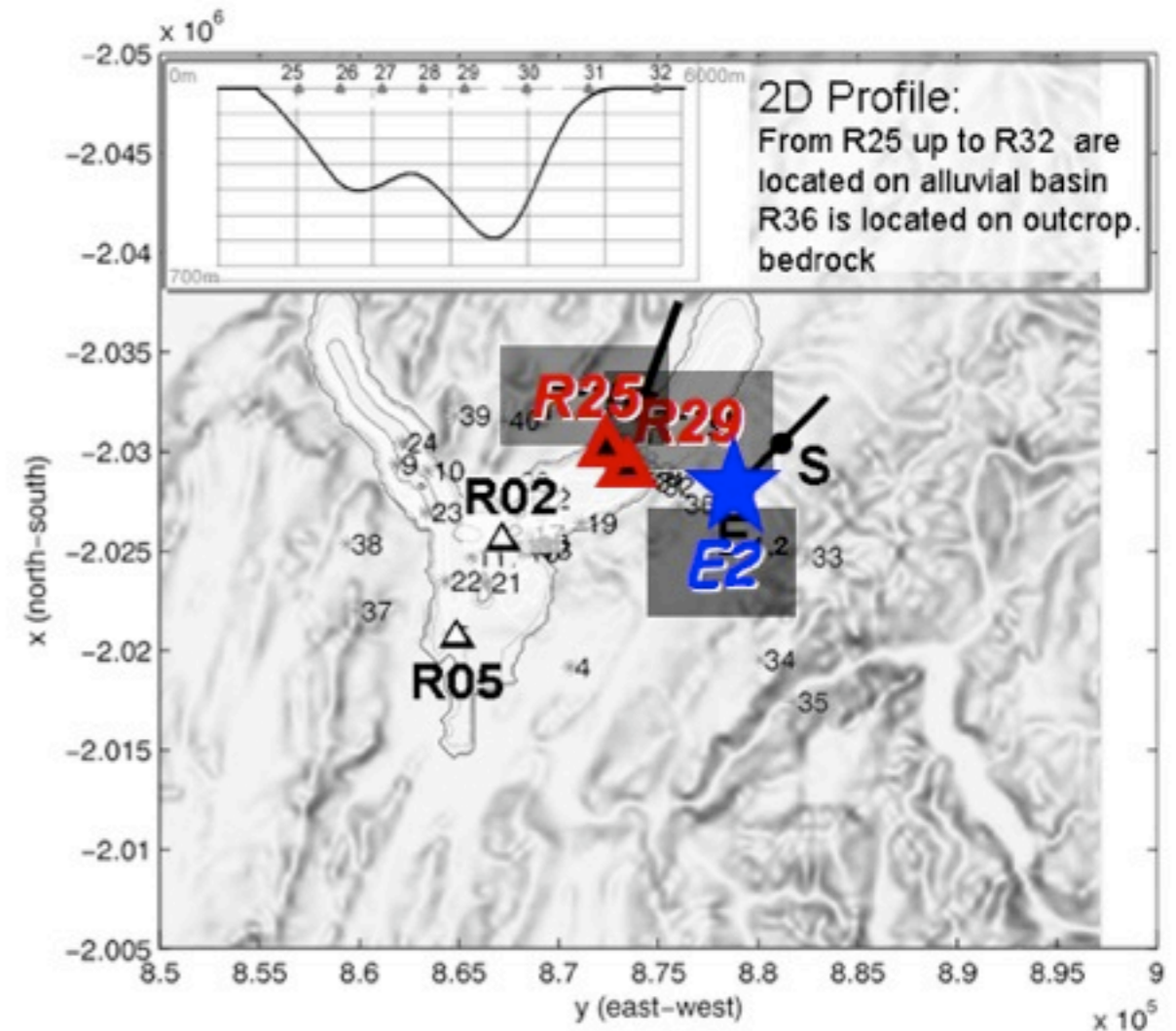
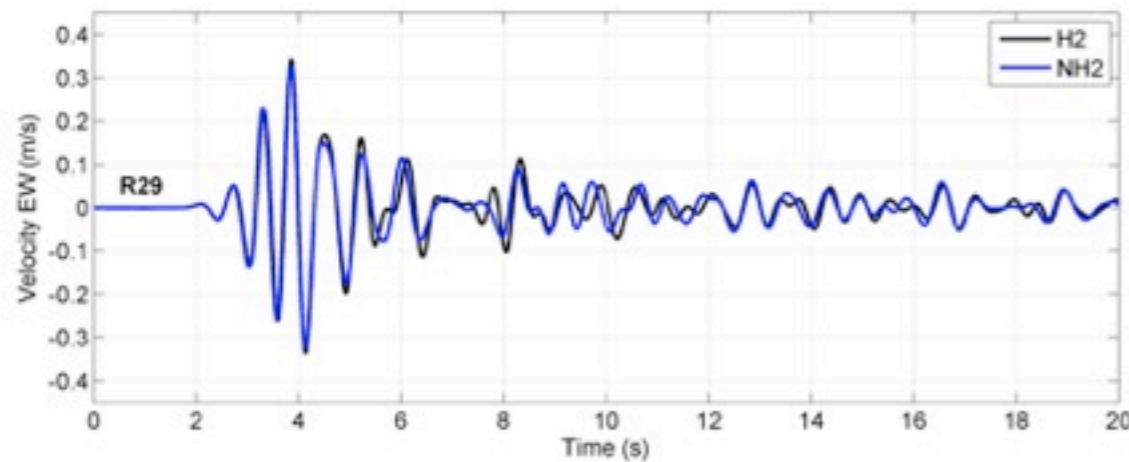
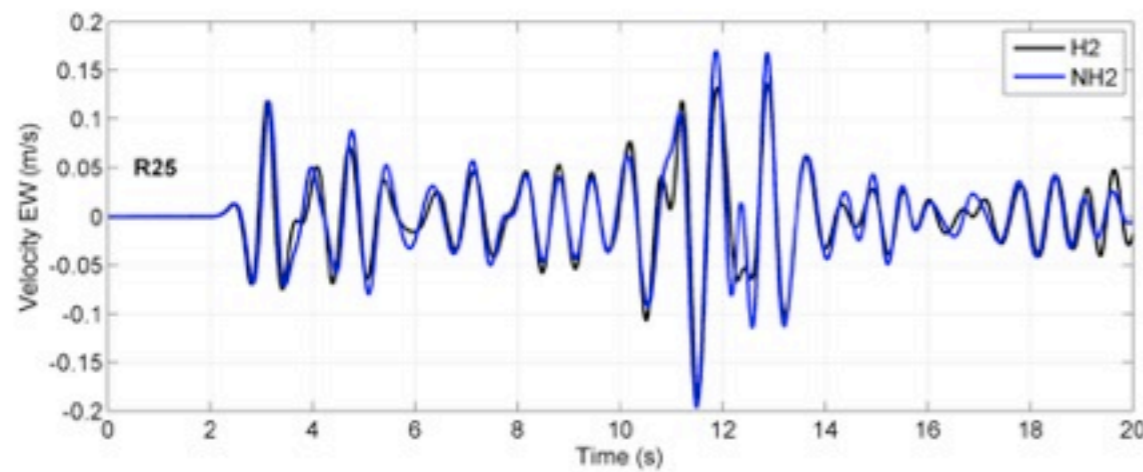
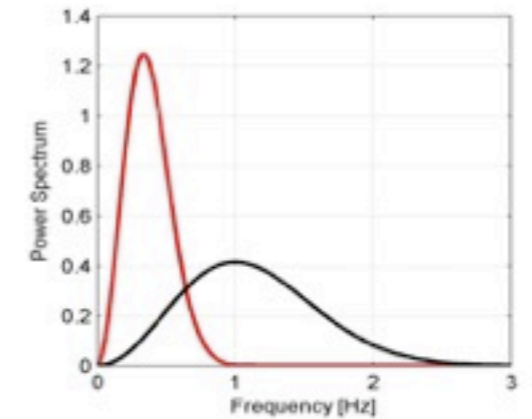
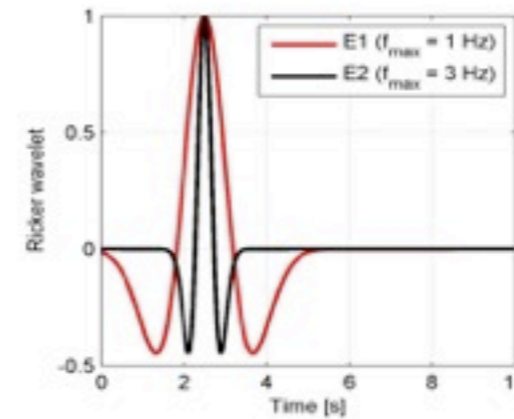
MESHING STRATEGIES (c)



H2

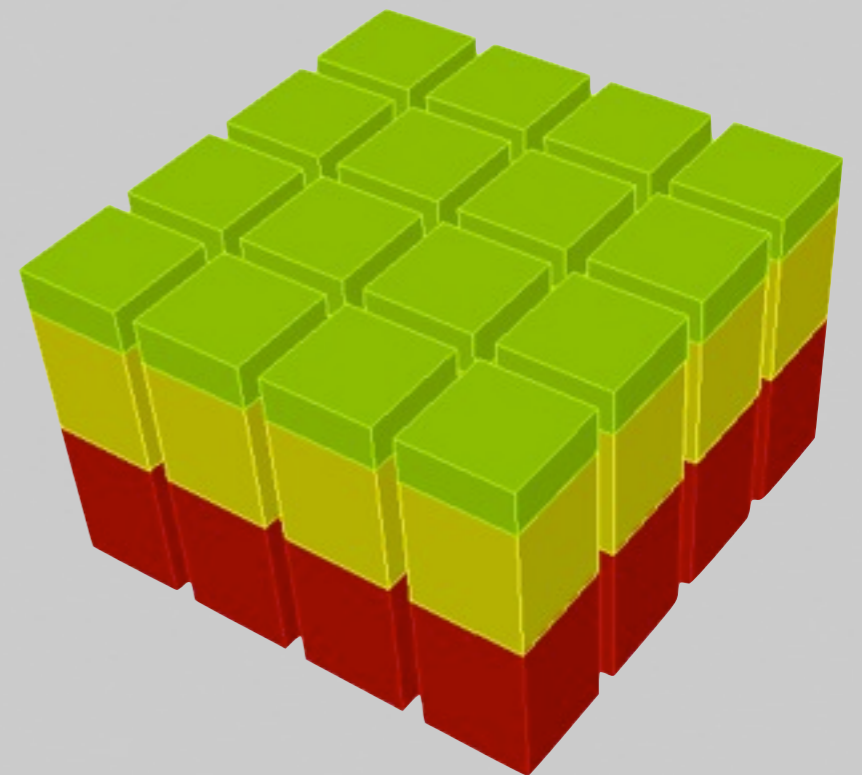
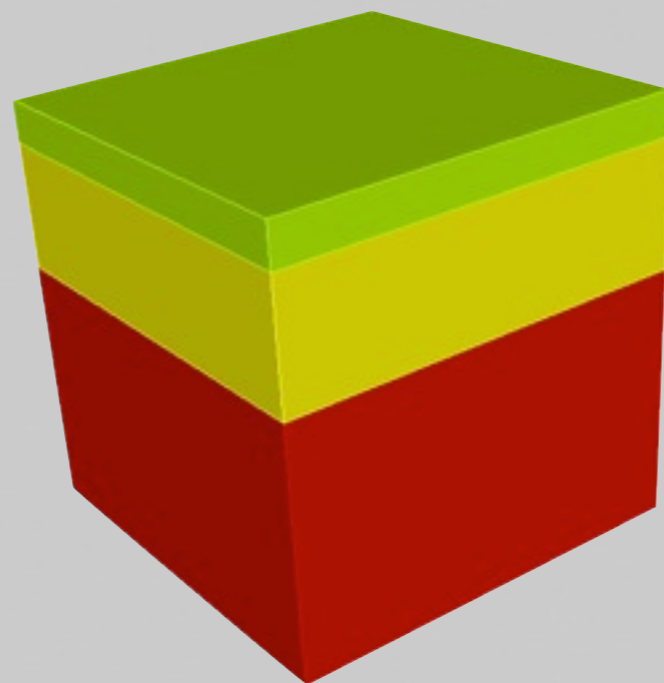
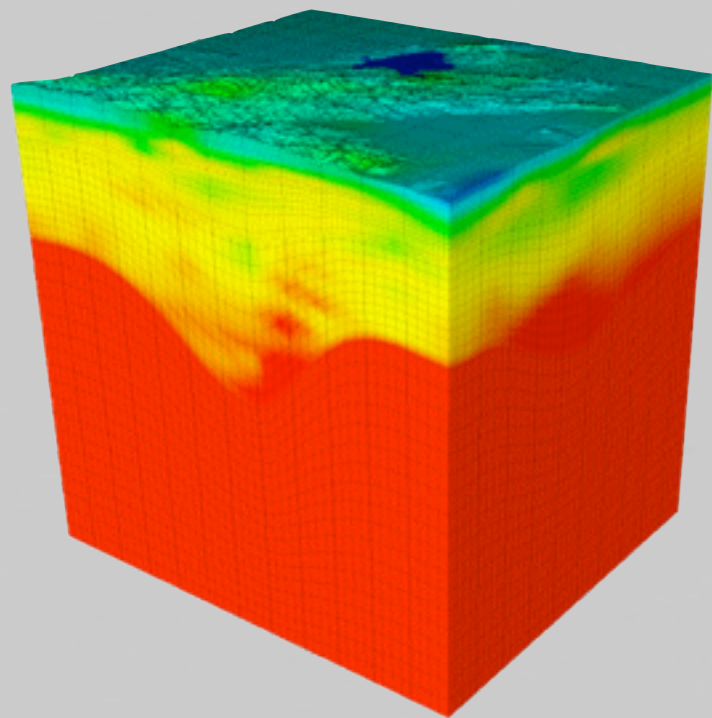


NH2



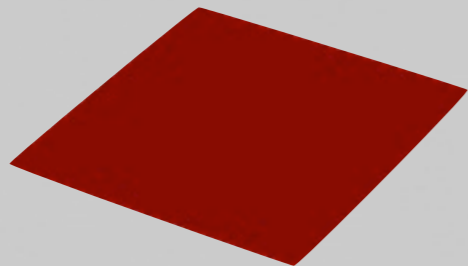
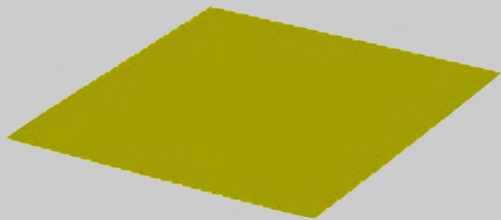
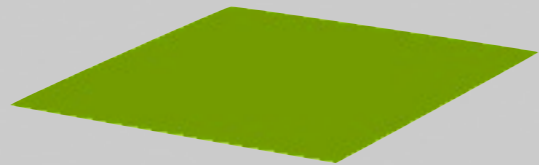
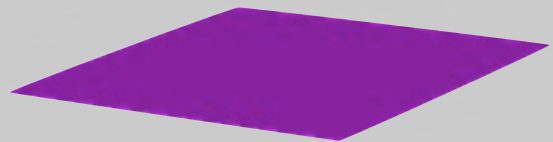
MESHING STRATEGIES (c)

goal: meshing automatically some reference geological cases



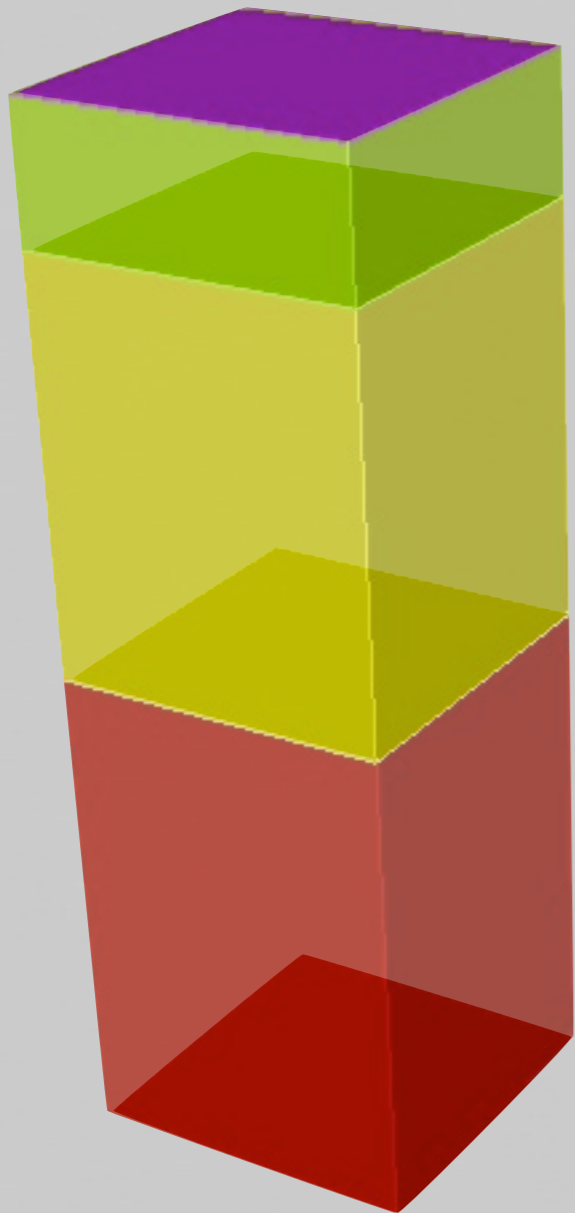
MESHING STRATEGIES (c)

goal: meshing automatically some reference geological cases



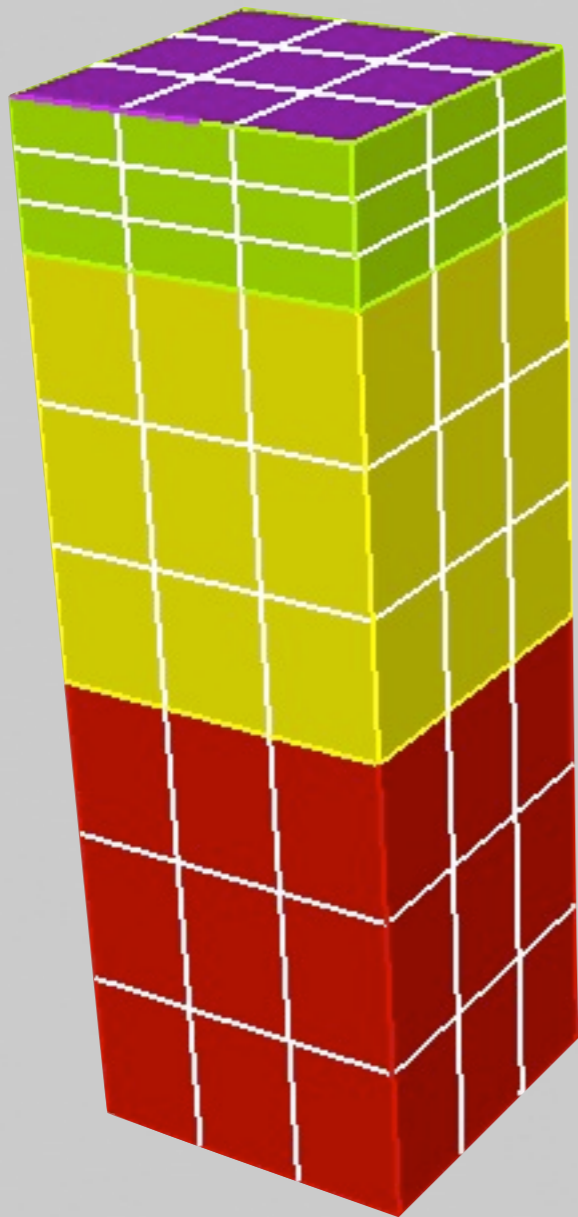
MESHING STRATEGIES (c)

goal: meshing automatically some reference geological cases



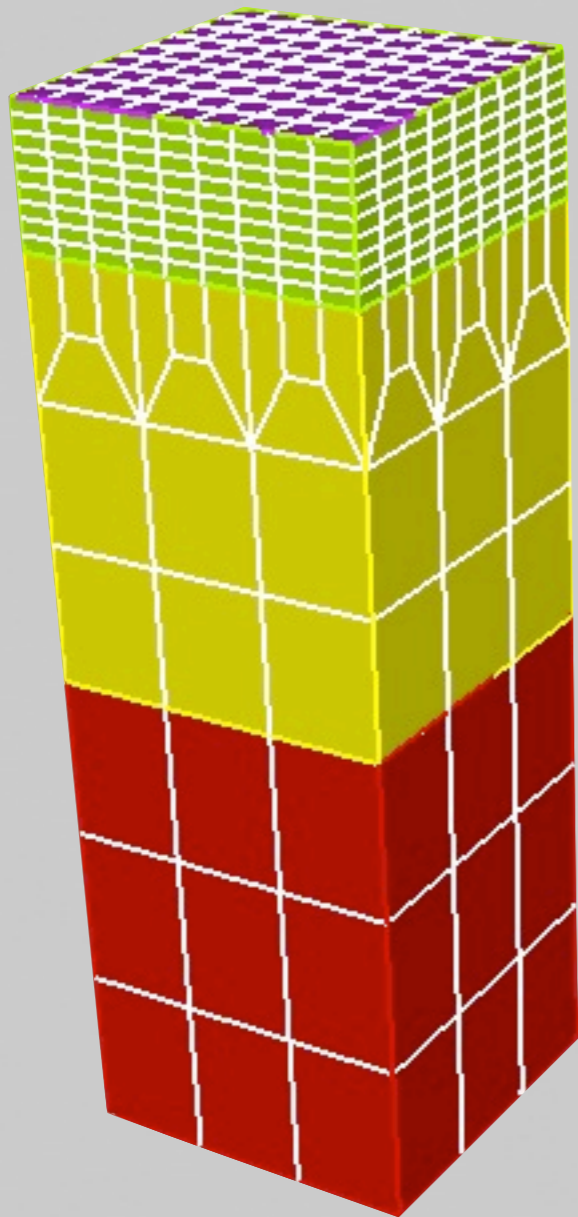
MESHING STRATEGIES (c)

goal: meshing automatically some reference geological cases



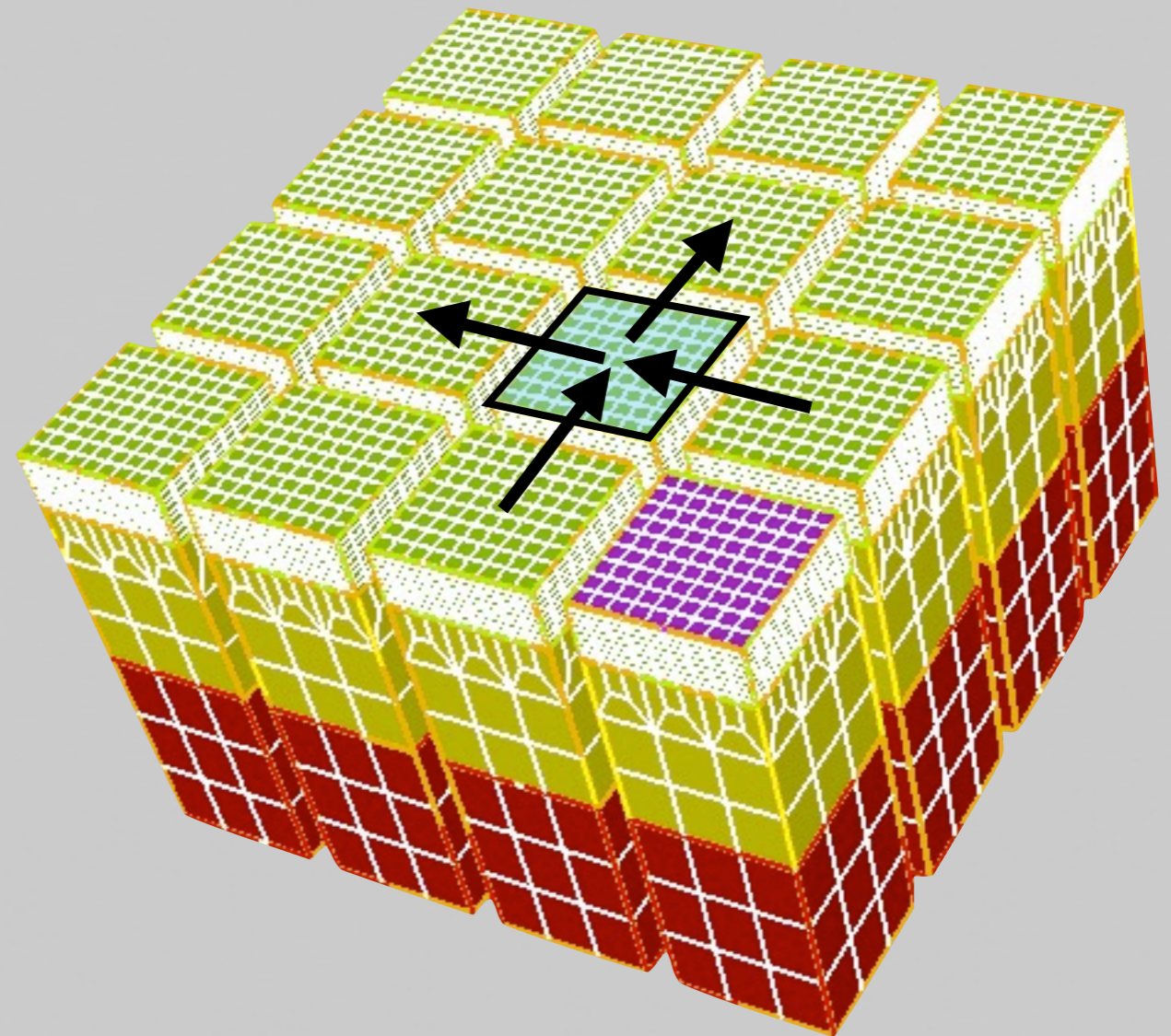
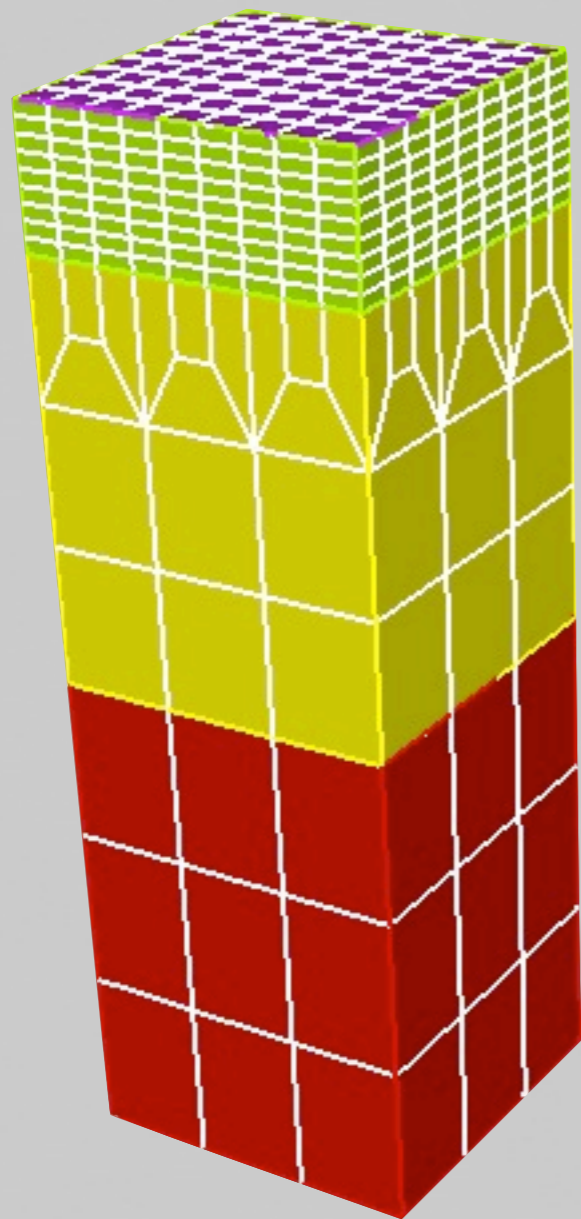
MESHING STRATEGIES (c)

goal: meshing automatically some reference geological cases



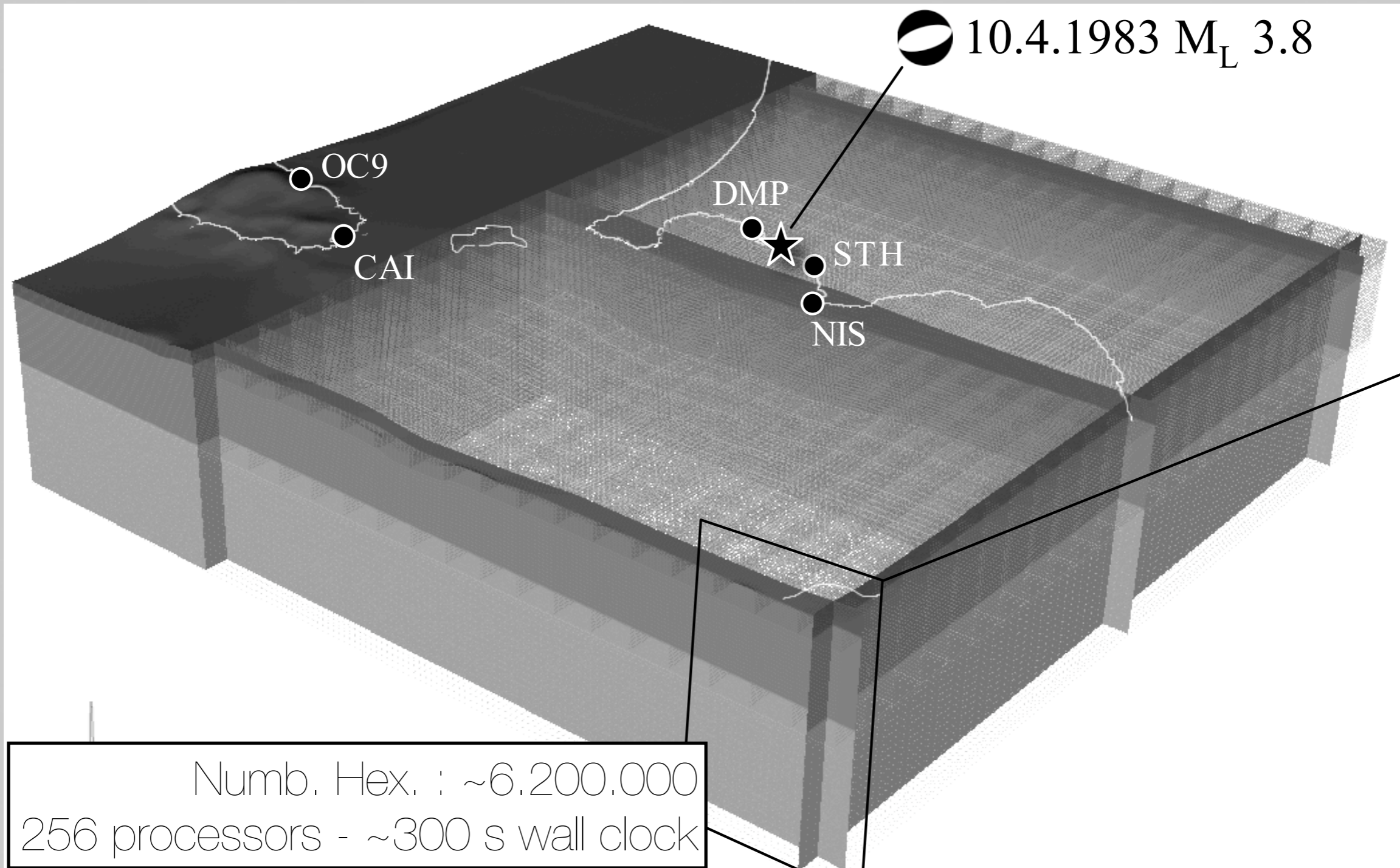
MESHING STRATEGIES (c)

goal: meshing automatically some reference geological cases



MESHING STRATEGIES (c)

goal: meshing automatically some reference geological cases



MESHING STRATEGIES (c)

goal: meshing automatically some reference geological cases

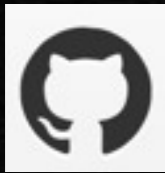
- Semi-automatic (user defines interfaces, tomography, topography, T_0 , Δh)
- Parallel (faster both for the creation of the NURBS geometry and for the mesh - huge mesh and volume)
- "cake-layered" volume (main discontinuities honored + tomography)
- Each chunk has the same number of elements

GEOCUBIT



stable

<http://www.geodynamics.org/wsvn/cig/seismo/3D/GEOCUBIT>



developer*

<https://github.com/casarotti/GEOCUBIT--experimental>

mesh: layered geological volume (parallel)

mesh: automatic assign of the boundary condition

mesh: export in SPECFEM3D_cartesian format

environment: python script, cubit GUI, interative, cluster queue

mesh: spherical layered geological volume*

mesh: vertical "sandwich" layered geological volume*

mesh: hex27*

mesh: cpml*

GEOCUBIT - simplify

```
[cubit.options]
cubit_info=off
echo_info=off
working_dir=mesh_california/
output_dir=mesh_california/output
```

```
[simulation.cpu_parameters]
number_processor_xi      =15
number_processor_eta    =15
#
```

```
[geometry.volumes]
volume_type      = layercake_volume_ascii_regulargrid_regularmap
latitude_min     = 131000
latitude_max     = 738000
longitude_min    = 3480000
longitude_max    = 4058000
nx              = 6071
ny              = 5781
unit            = utm
```

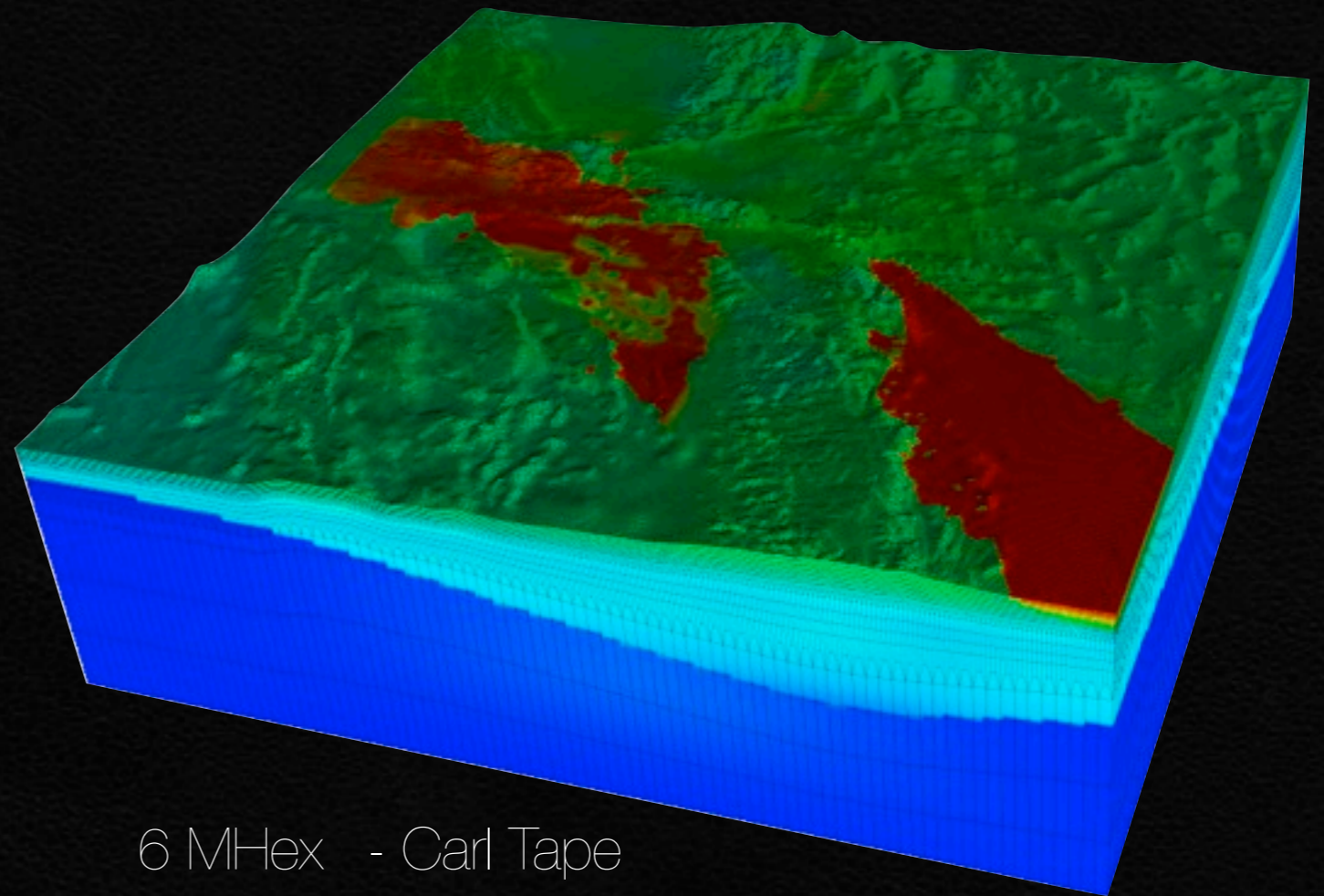
```
[geometry.volumes.layercake]
nz = 3
bottomflat = True
depth_bottom = -60000
filename =moho_6071_5781surf.xyz,topo_6071_5781surf.xyz,
geometry_format=ascii
```

```
[meshing]
map_meshing_type=regularmap
iv_interval=3,4
size=7500
or_mesh_scheme=map
ntripl=2
smoothing=False
coarsening_top_layer=False
refinement_depth=2,2
```

```
GEOCUBIT.py --build_volume --mesh --cfg=examples/scal.cfg
```

```
GEOCUBIT.py --collect --meshfiles=mesh_vol_0.cub --export2SPECFEM3D
```

```
GEOCUBIT.py --collect --meshfiles=mesh_vol_0.cub --cpml --cpml_size=7000 --export2SPECFEM3D
```

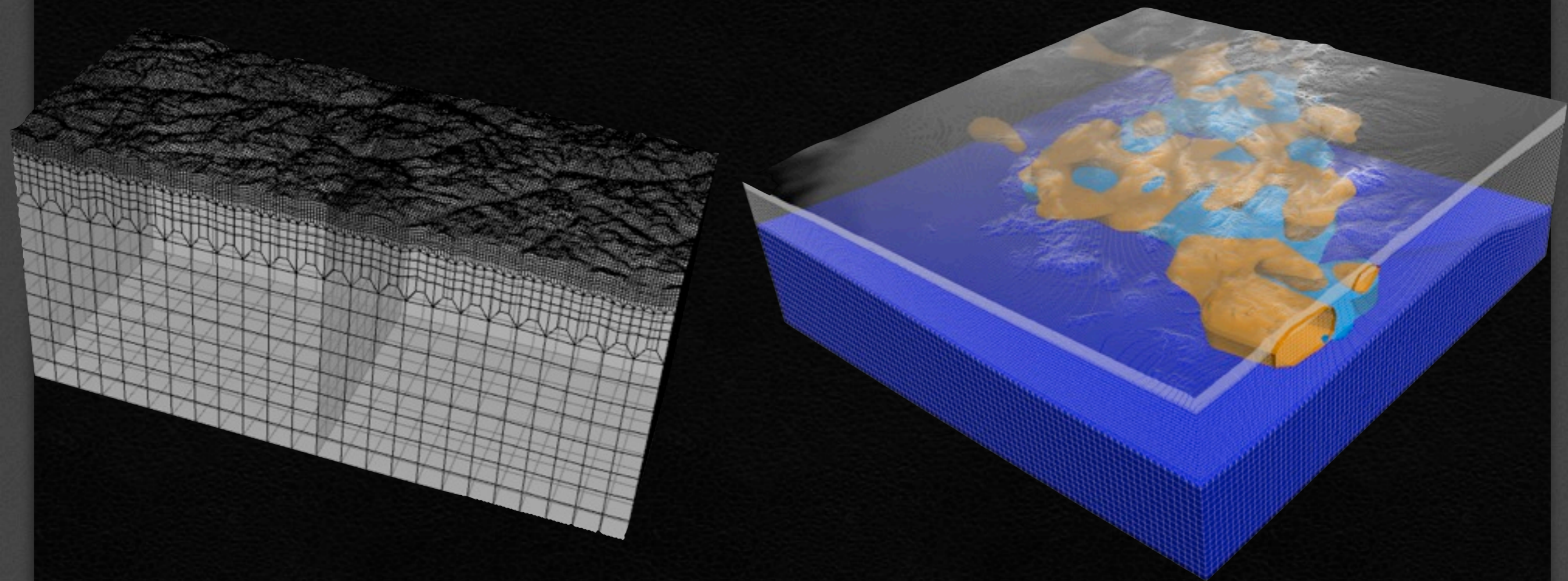


6 MHex - Carl Tape

GEOCUBIT - scripting

Italy divided in 256 meshed block

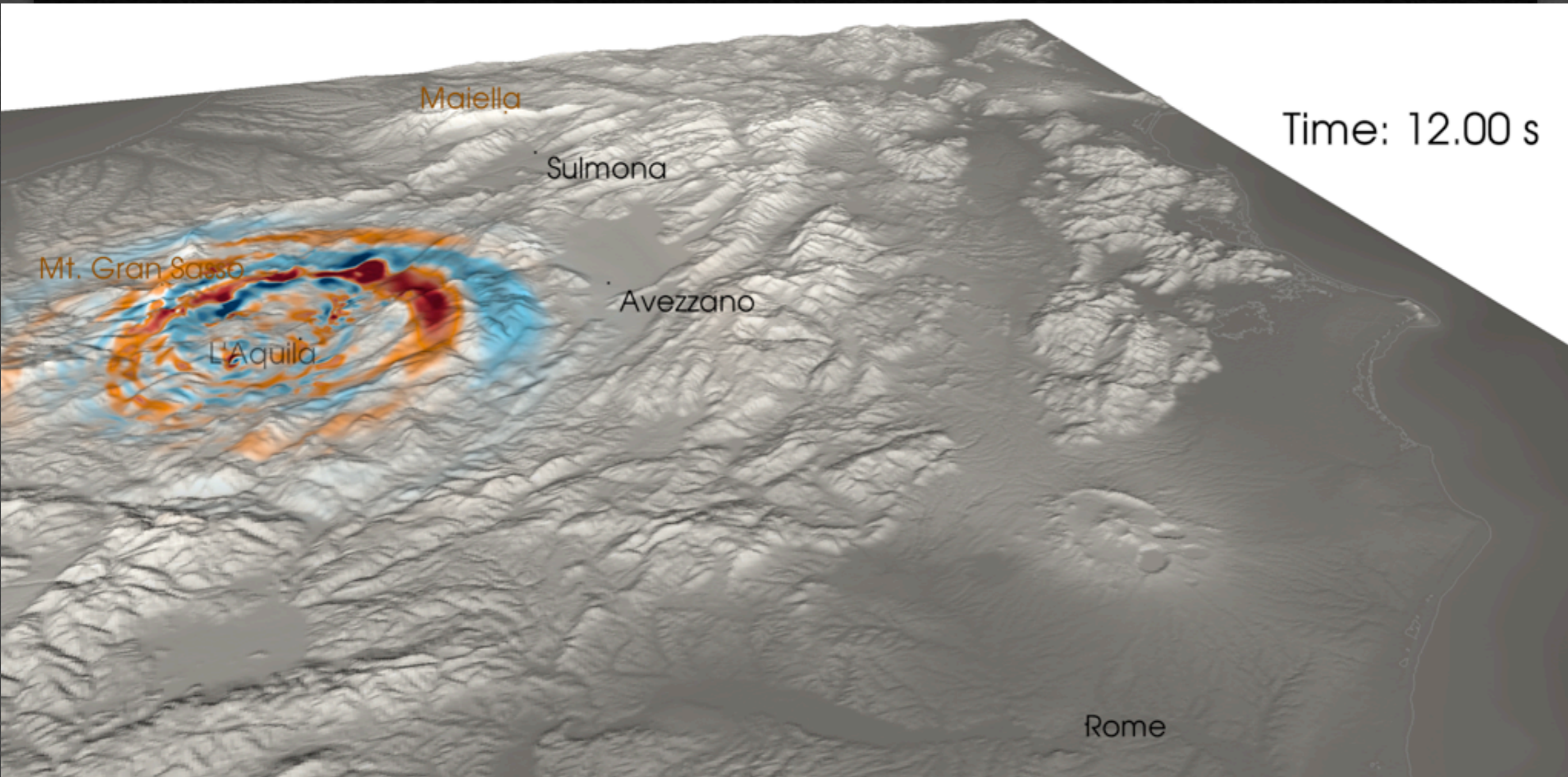
For each $M > 5$ some blocks are selected and stitched



GEOCUBIT - scripting

Italy divided in 256 meshed block

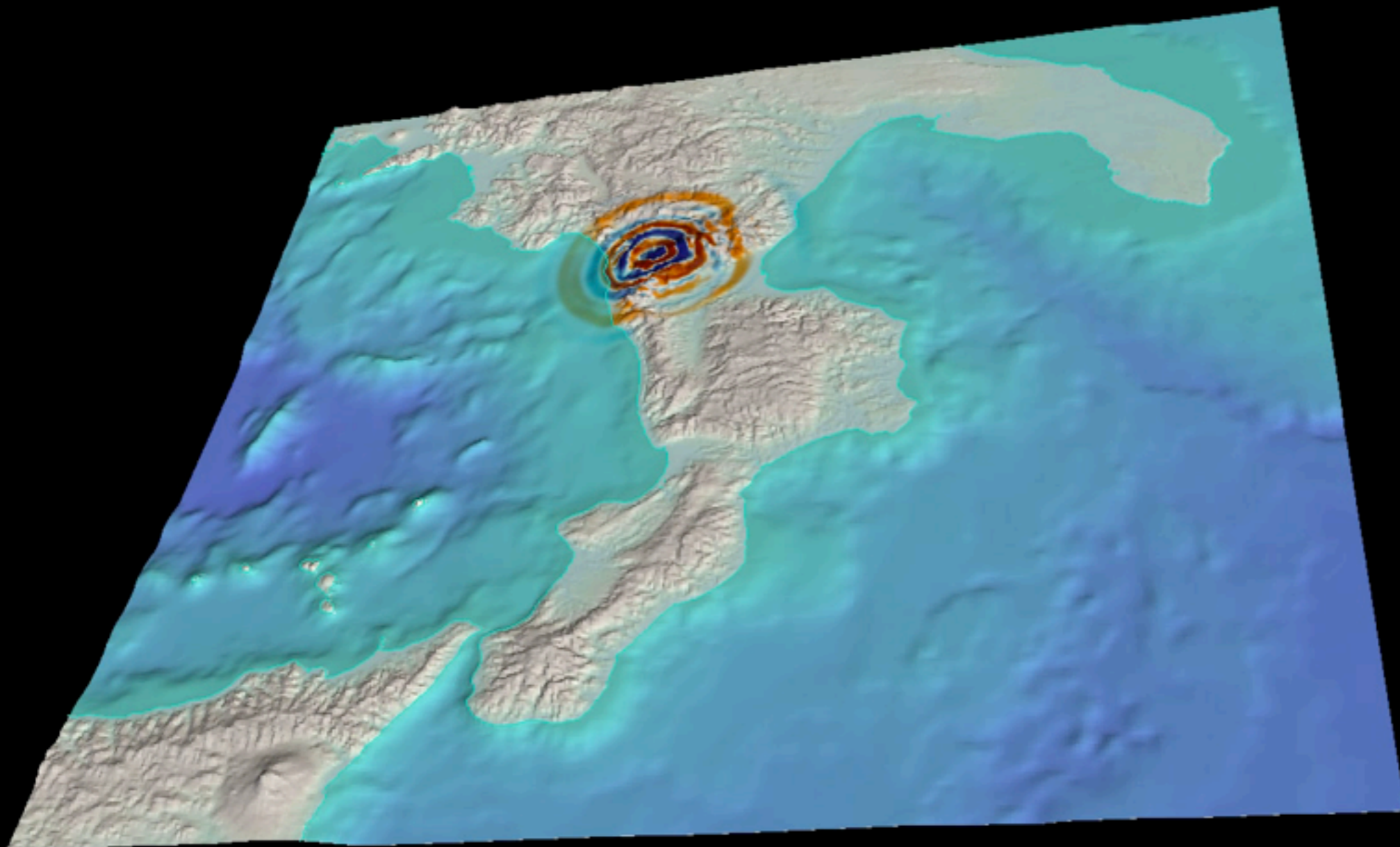
For each $M > 5$ some blocks are selected and stitched



GEOCUBIT - scripting

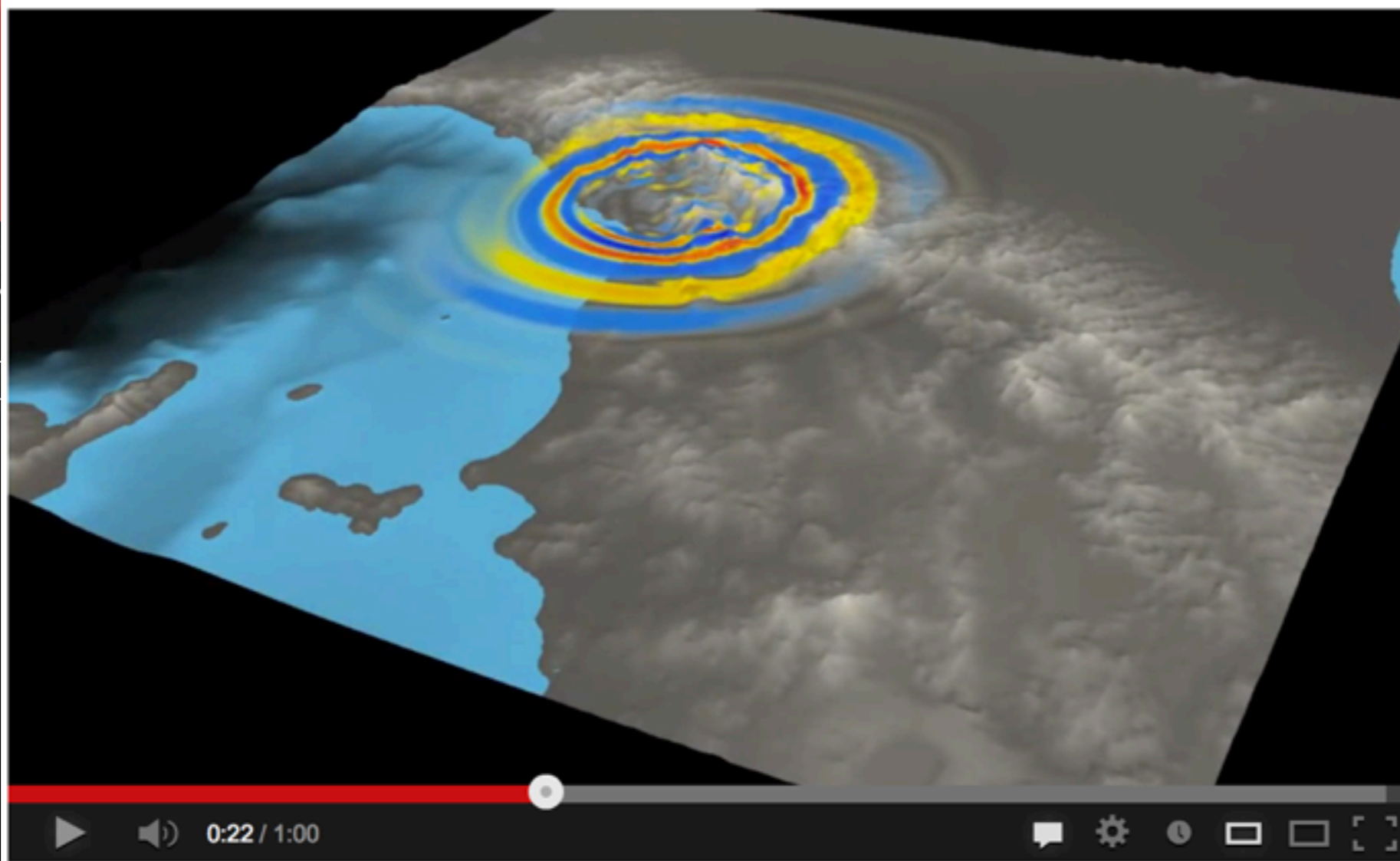
Italy divided in 256 meshed block

For each $M > 5$ some blocks are selected and stitched



Italy div
For each

ned



21.Giugno.2013 Animazione terremoto MI 5.2 nella Lunigiana



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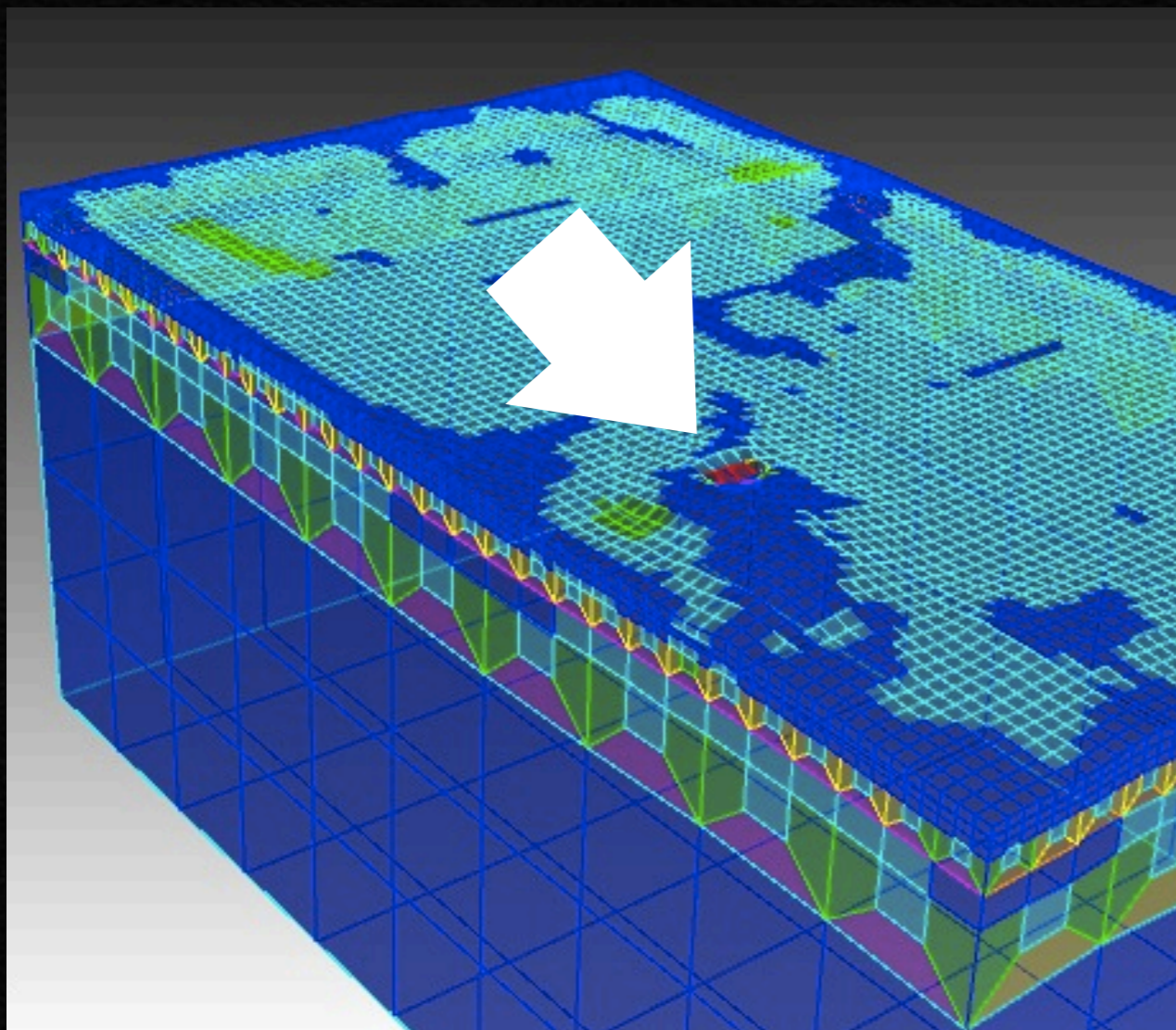
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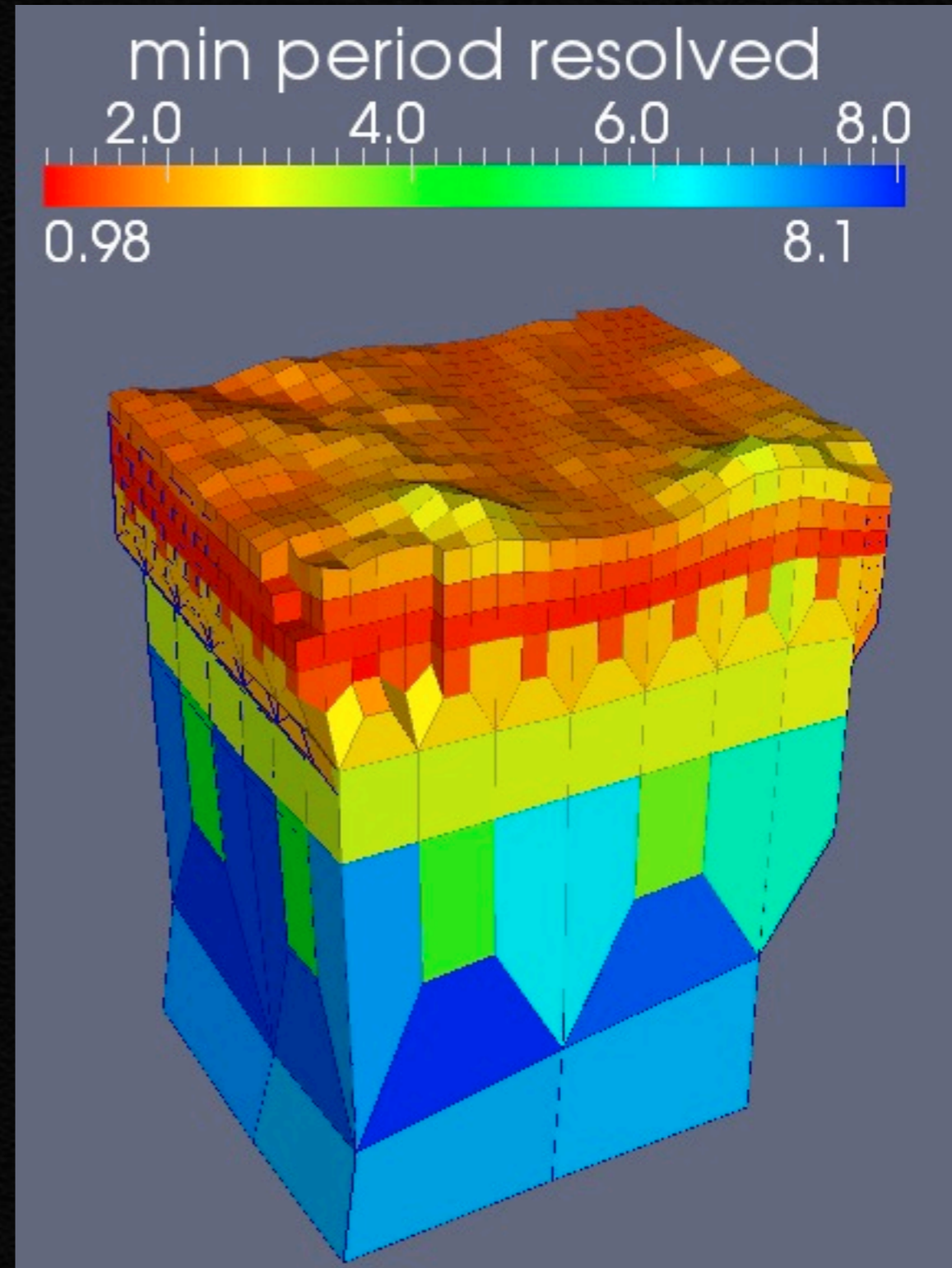
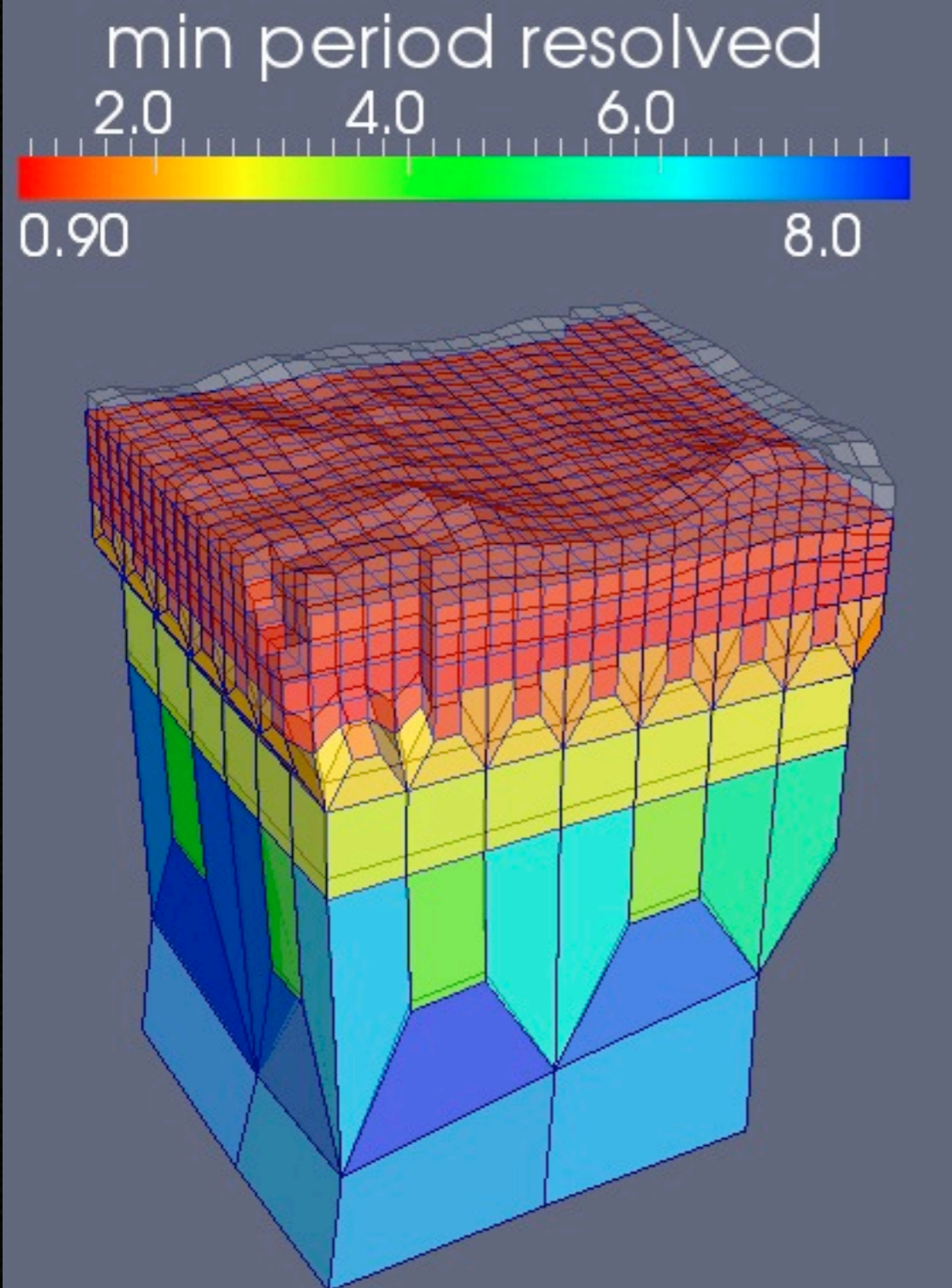
Published on Jun 21, 2013

SHAKEmovie: Animazione della propagazione sulla superficie terrestre delle onde sismiche generate dal terremoto di MI 5.2 delle ore 12.33 del 21 giugno 2013 in Lunigiana.

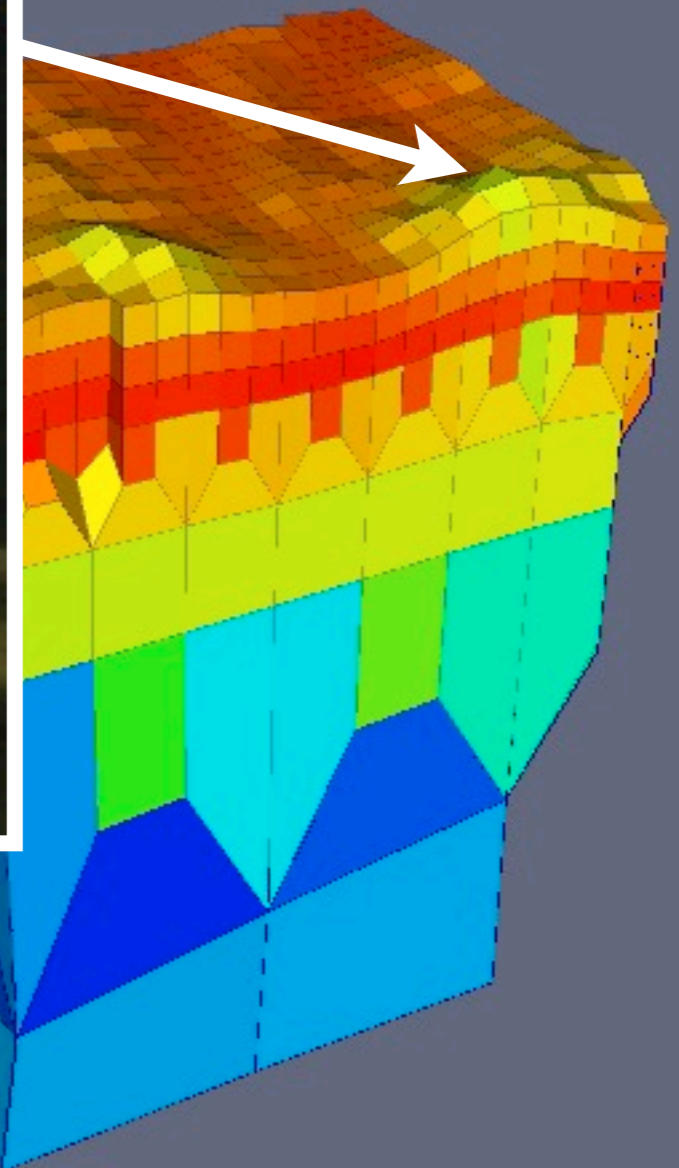
meshing - control Δt (S. California)



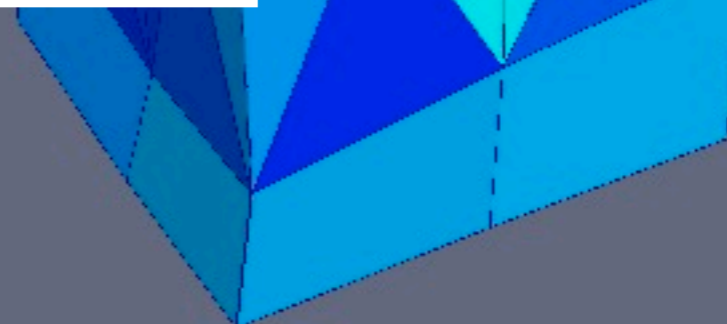
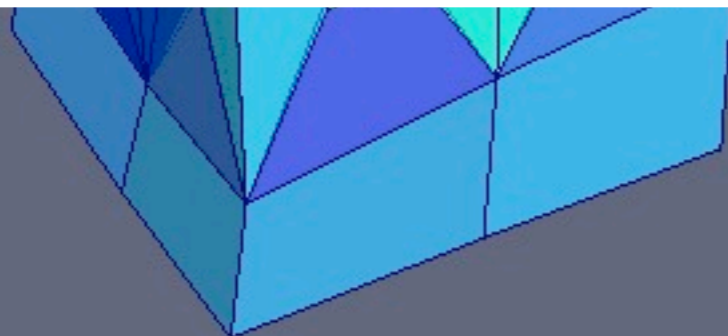
meshing - control resolution (Alaska)



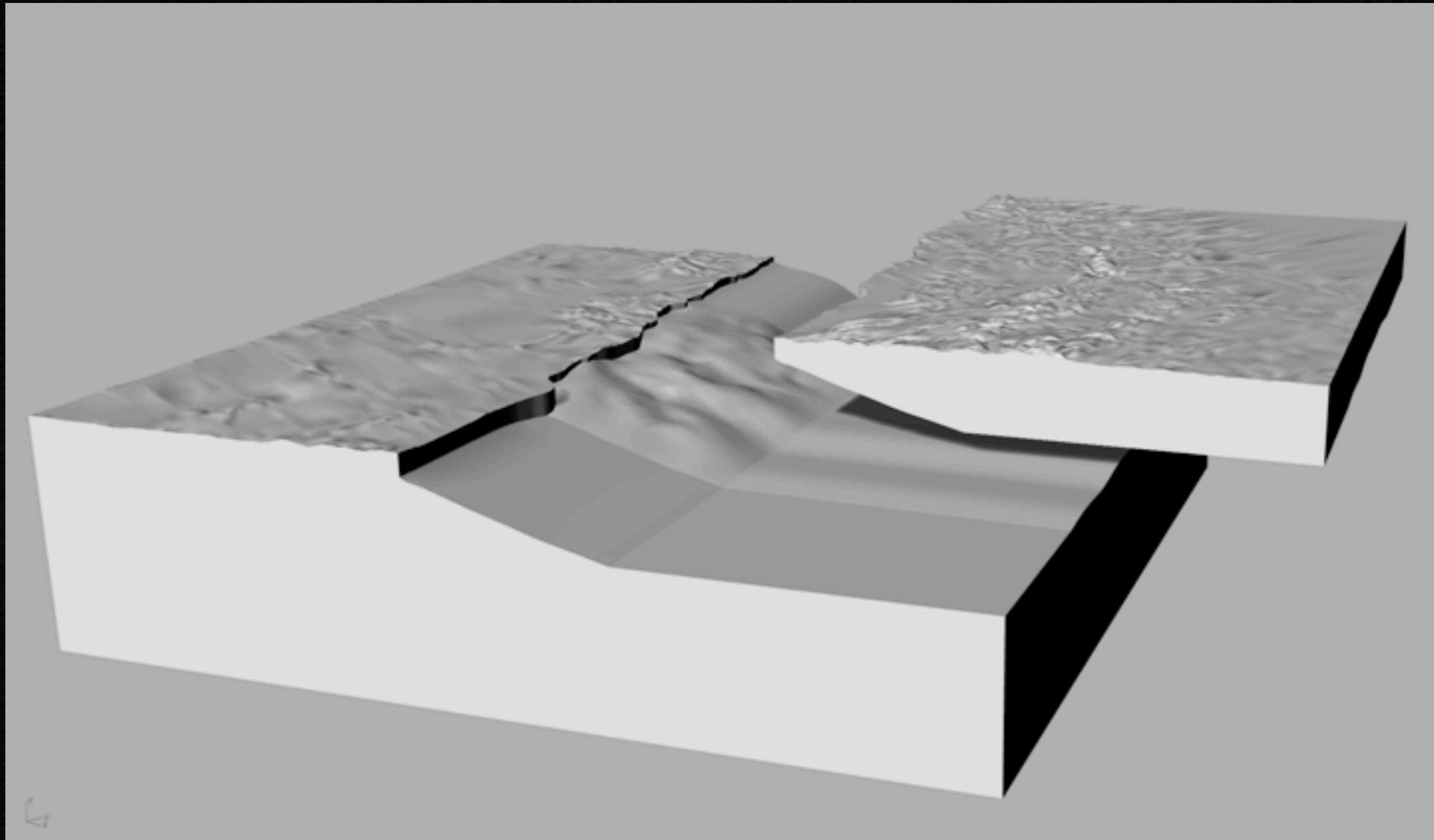
meshing - control resolution (Alaska)



0.9

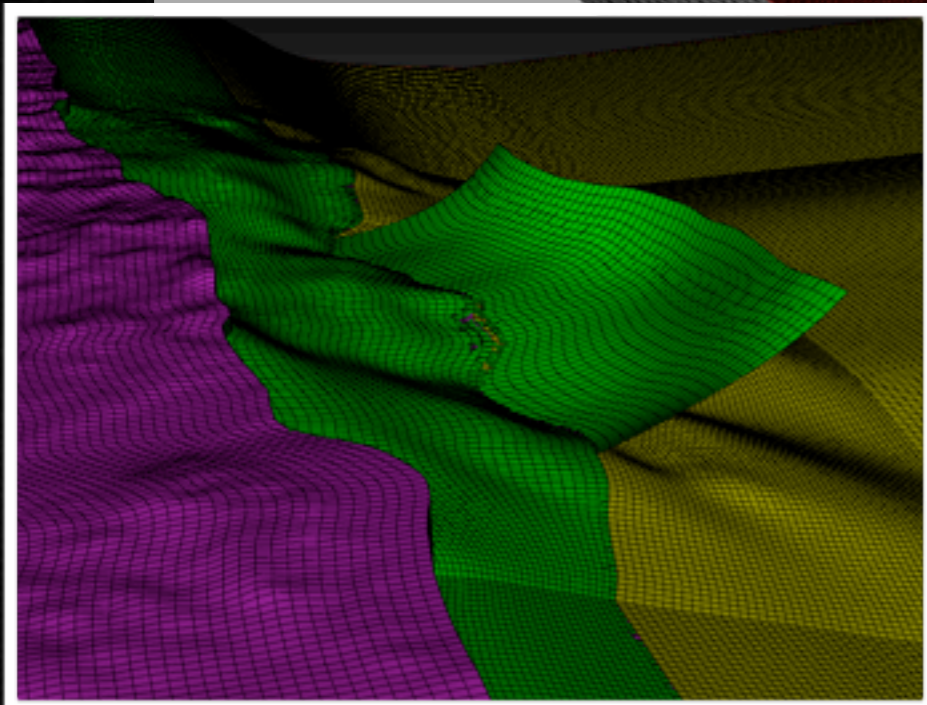
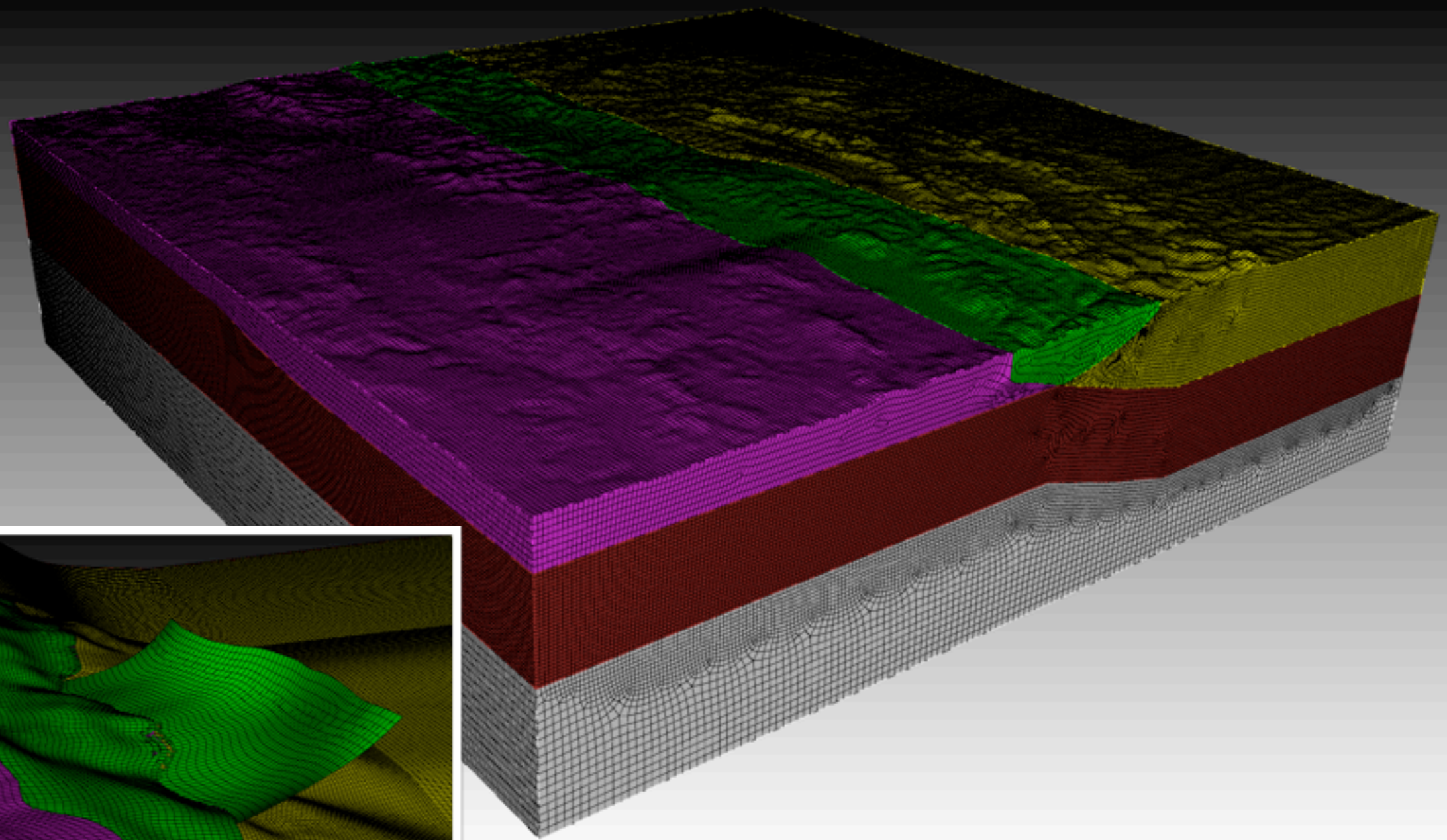


working in progress - low angles (ATF)



Geometry from Rhinoceros
(Luigi Vadacca)

working in progress - low angles (ATF)



Geometry from Rhinoceros
(Luigi Vadacca)

THANKS

TUTORIAL: 16.7.2013 - 20:30

Trelis (trial version) <http://goo.gl/RC7oP>

