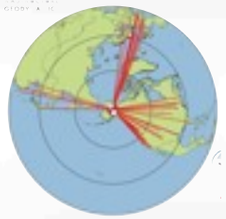
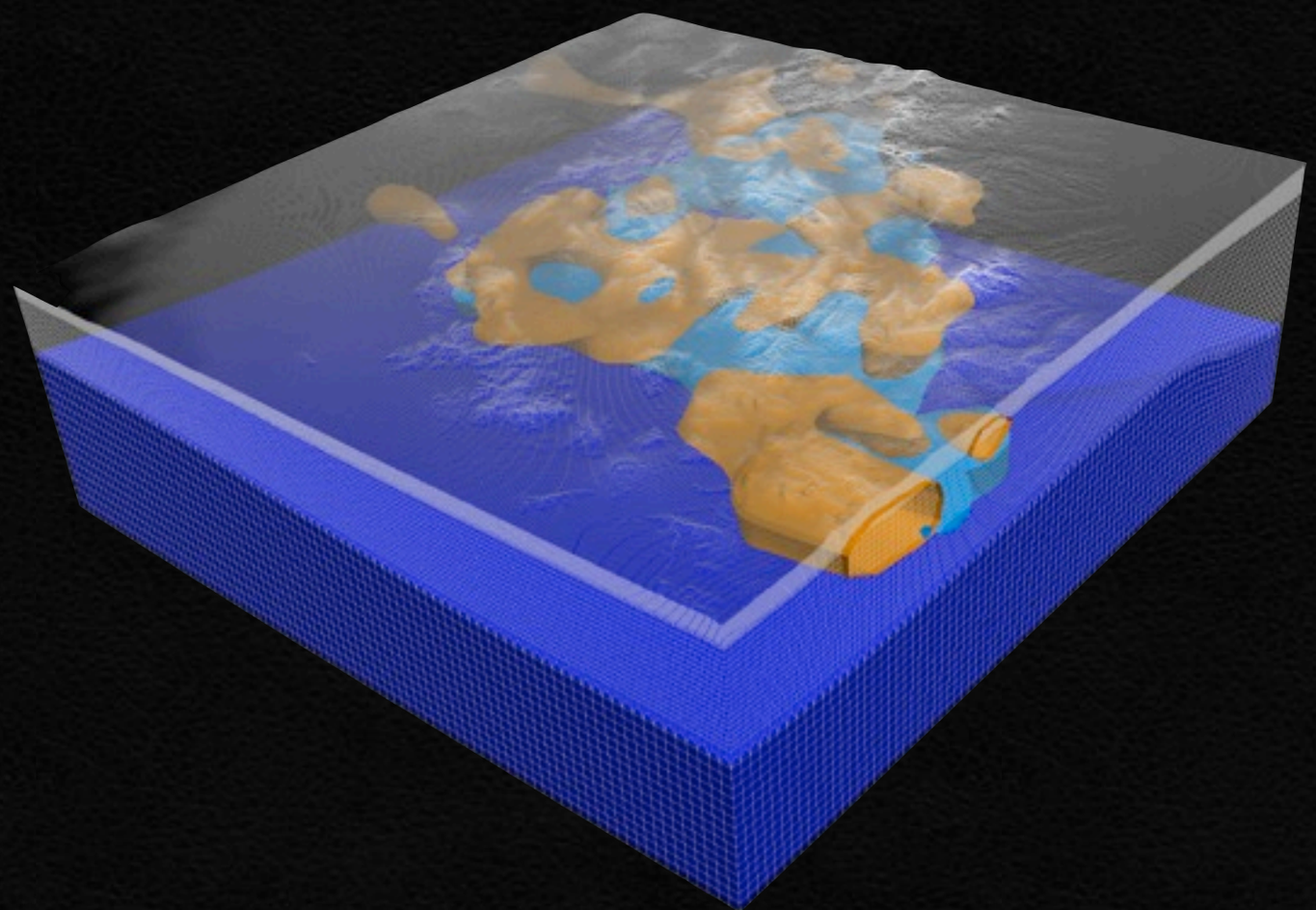


15.7.2013
CIG-QUEST-IRIS
workshop

Seismic Imaging
of structure
and source

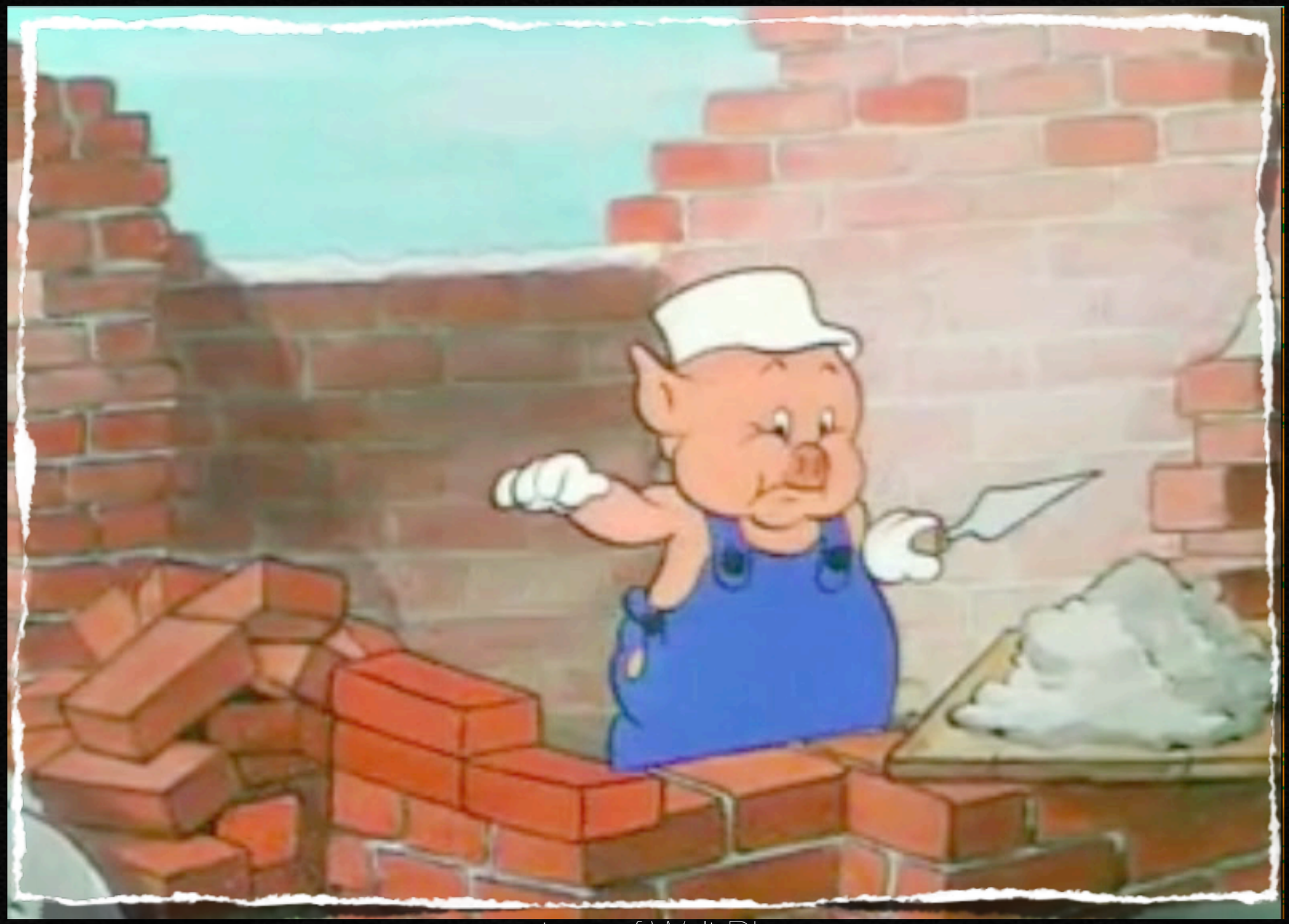
Univ. of Alaska
Fairbanks



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 proprieties 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 ACC ds

Suitable for imple tures

Mechanical prop lement

Low Number of

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

HEX

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

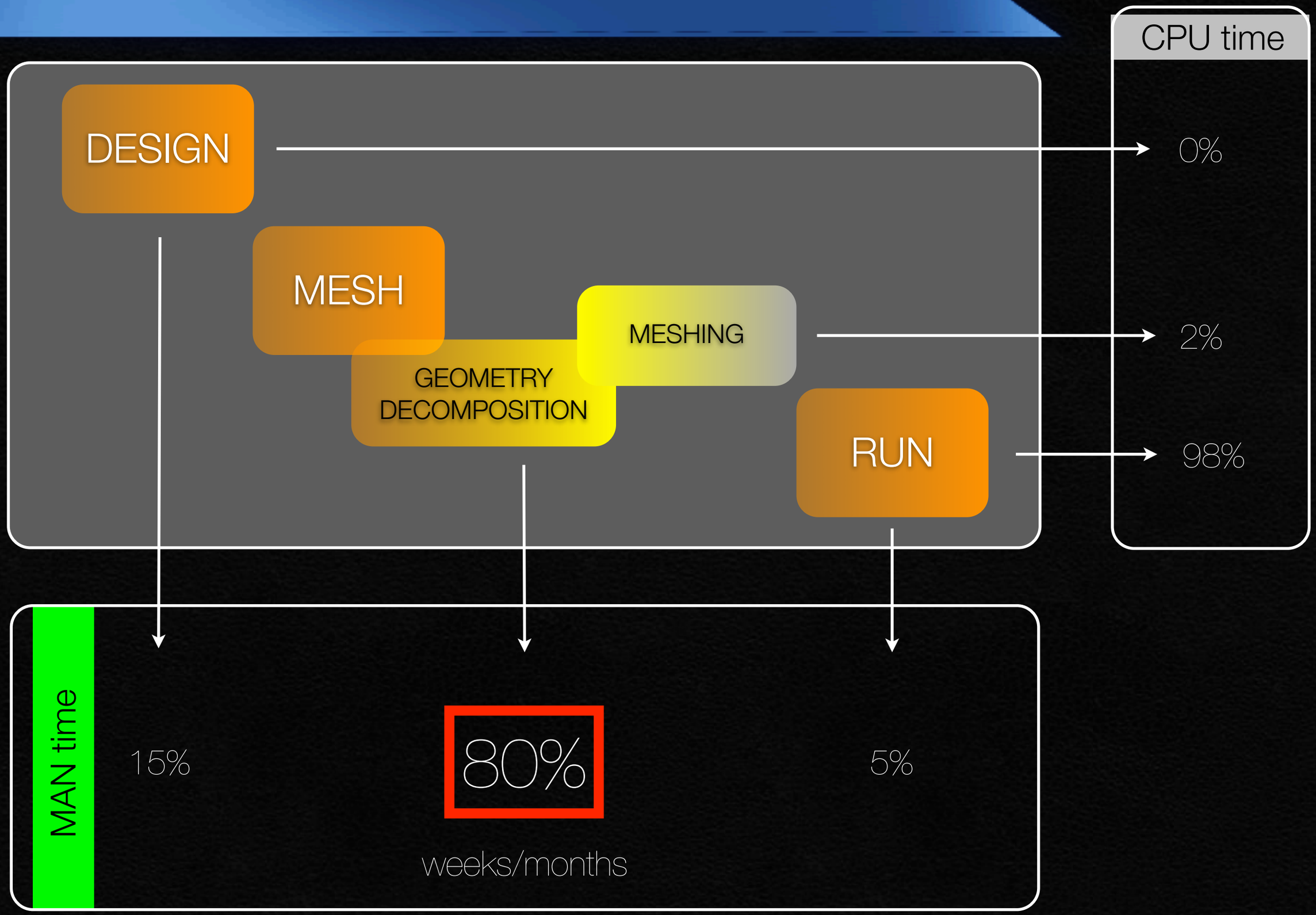
UNSTRUCTURED - ANISOTROPIC - CONFORMAL

(honoring the geology) (usually the dimension of the elements increase with depth)

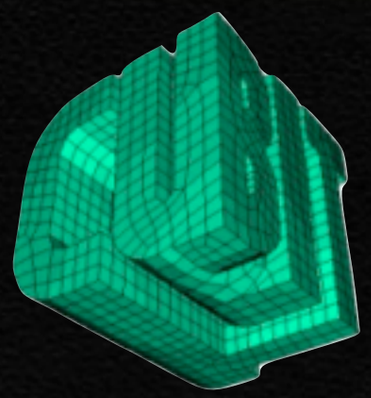
MESH: parallelism

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

MESH: no automatic solution



MESHER: CUBIT



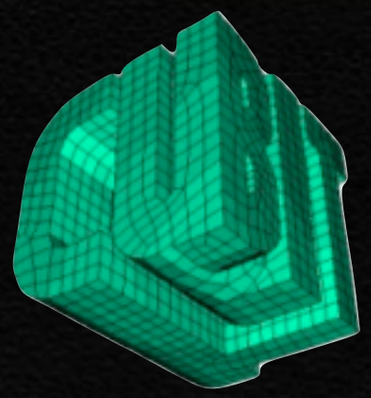
The CUBIT Geometry and Mesh Generation Toolkit

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



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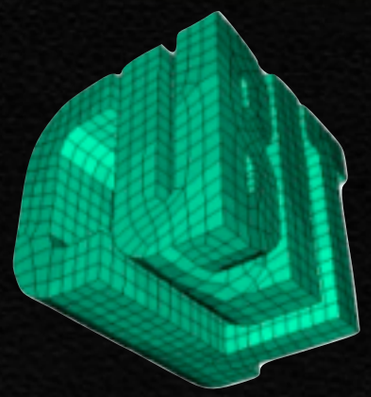
MESHER: CUBIT



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:

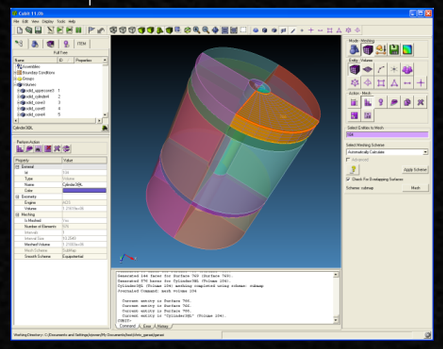
- Geometry preparation
- Automatic meshing algorithms
- Quality analysis
- Hexahedra/Tetrahedra

MESHER: CUBIT

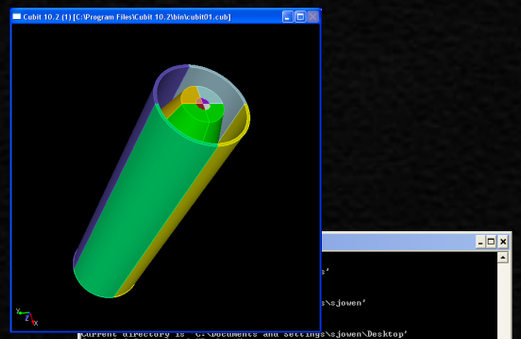
CAD

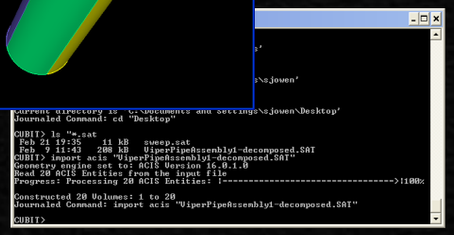
ACIS (CUBIT, Autocad)
STEP
IGES (Rhinoceros)
Facets (GOCAD)
STL
ExodusII

Graphical Interface



Command line



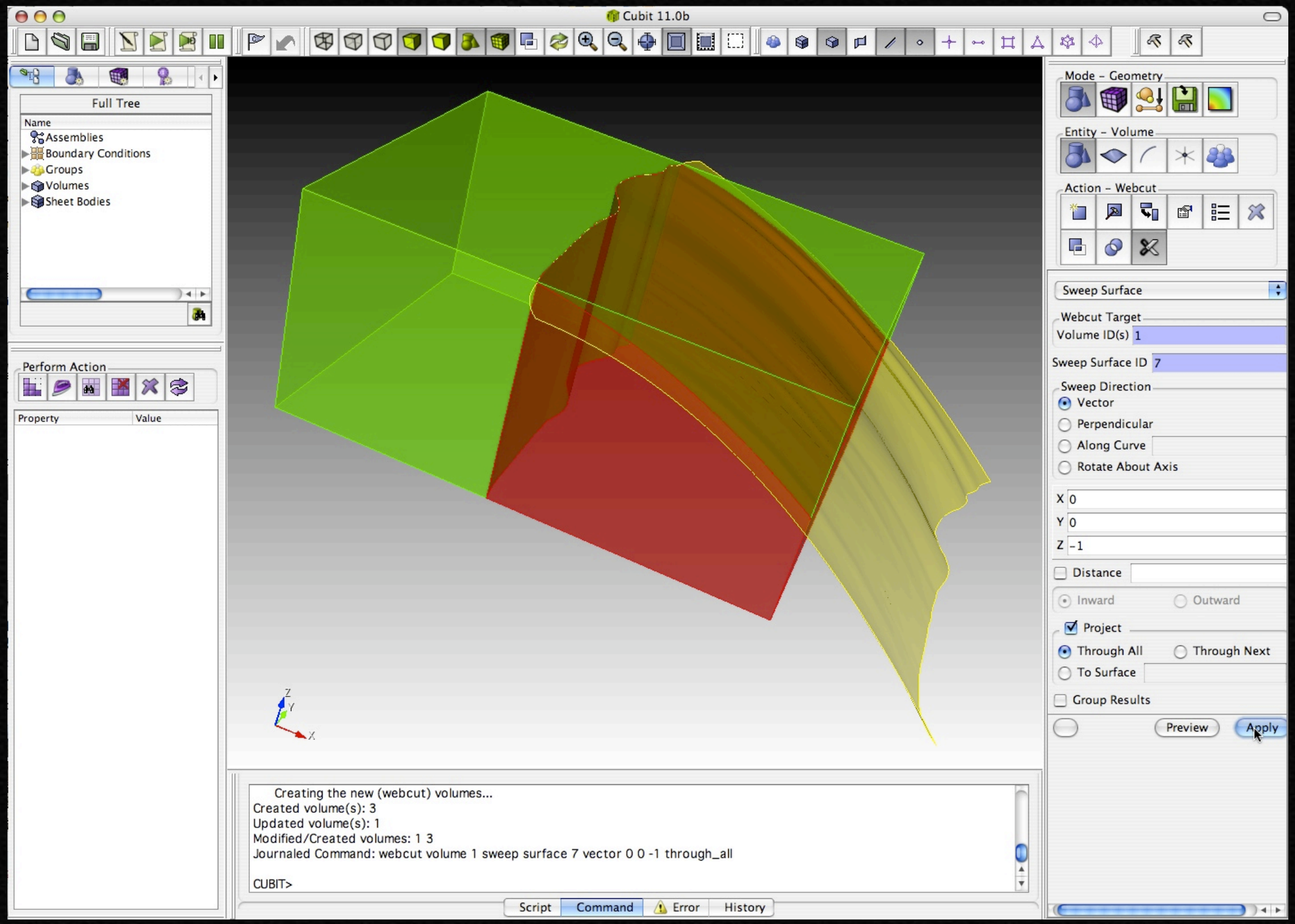


Python API

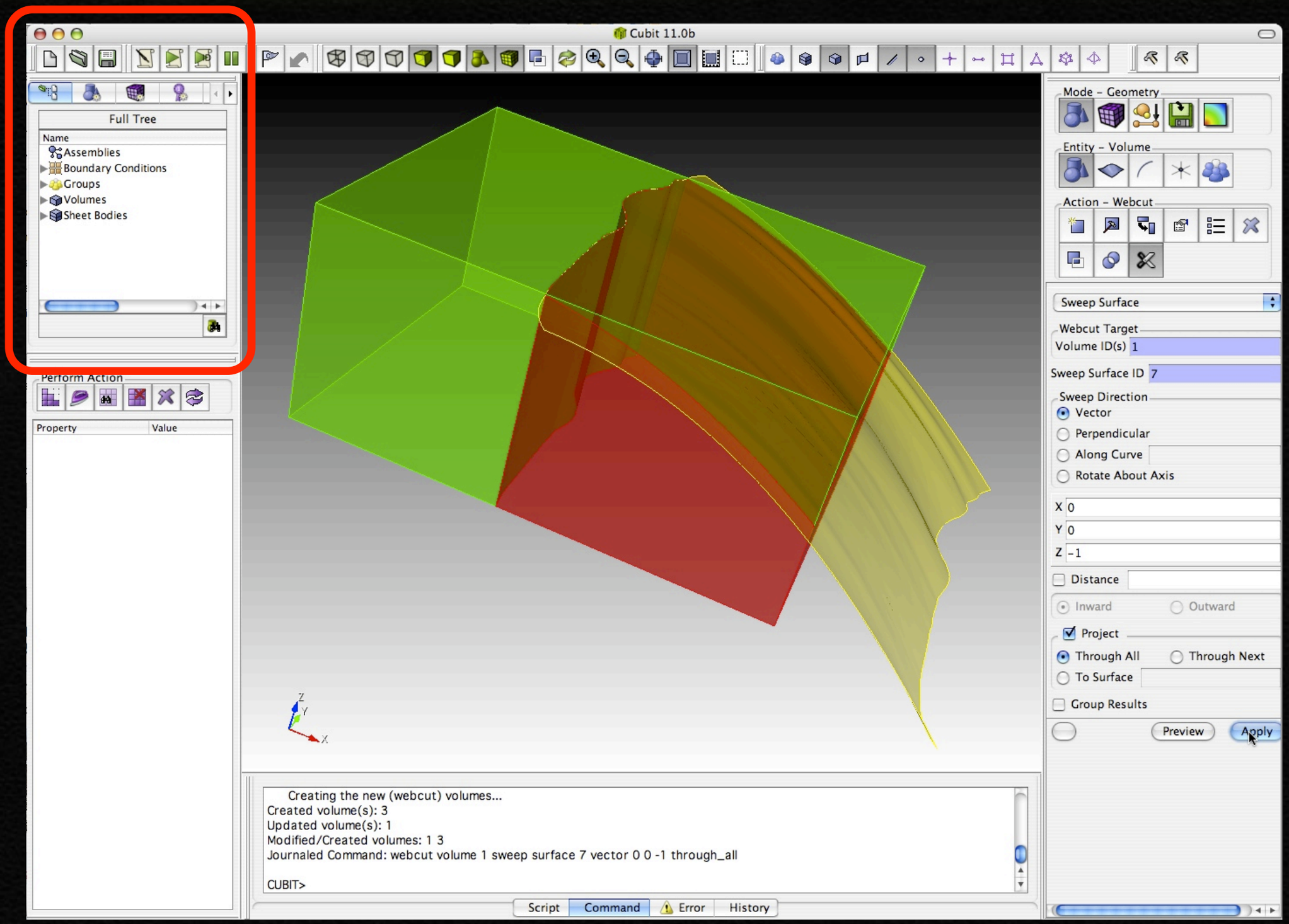
MESH

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

MESHER: CUBIT



MESHER: CUBIT



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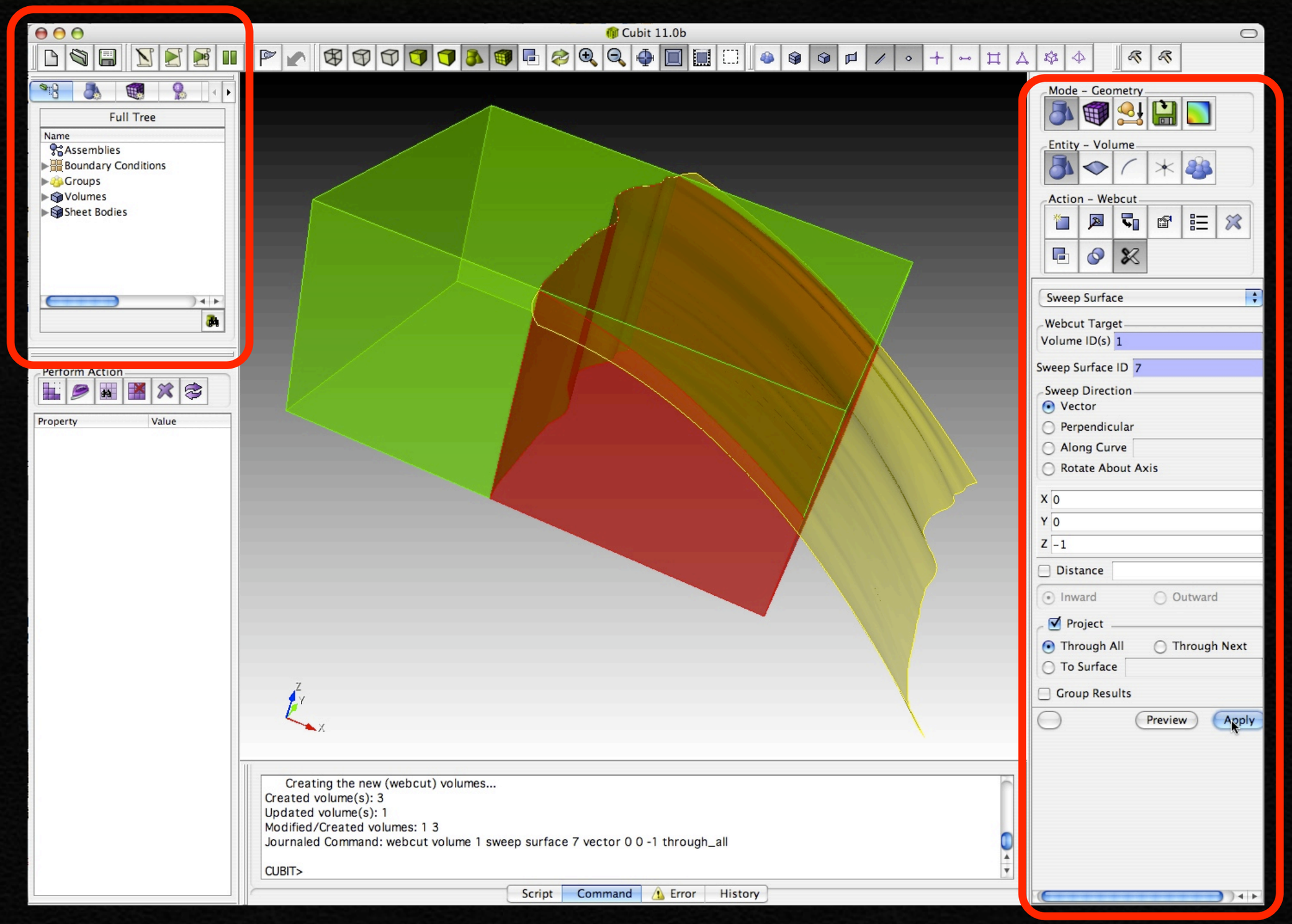
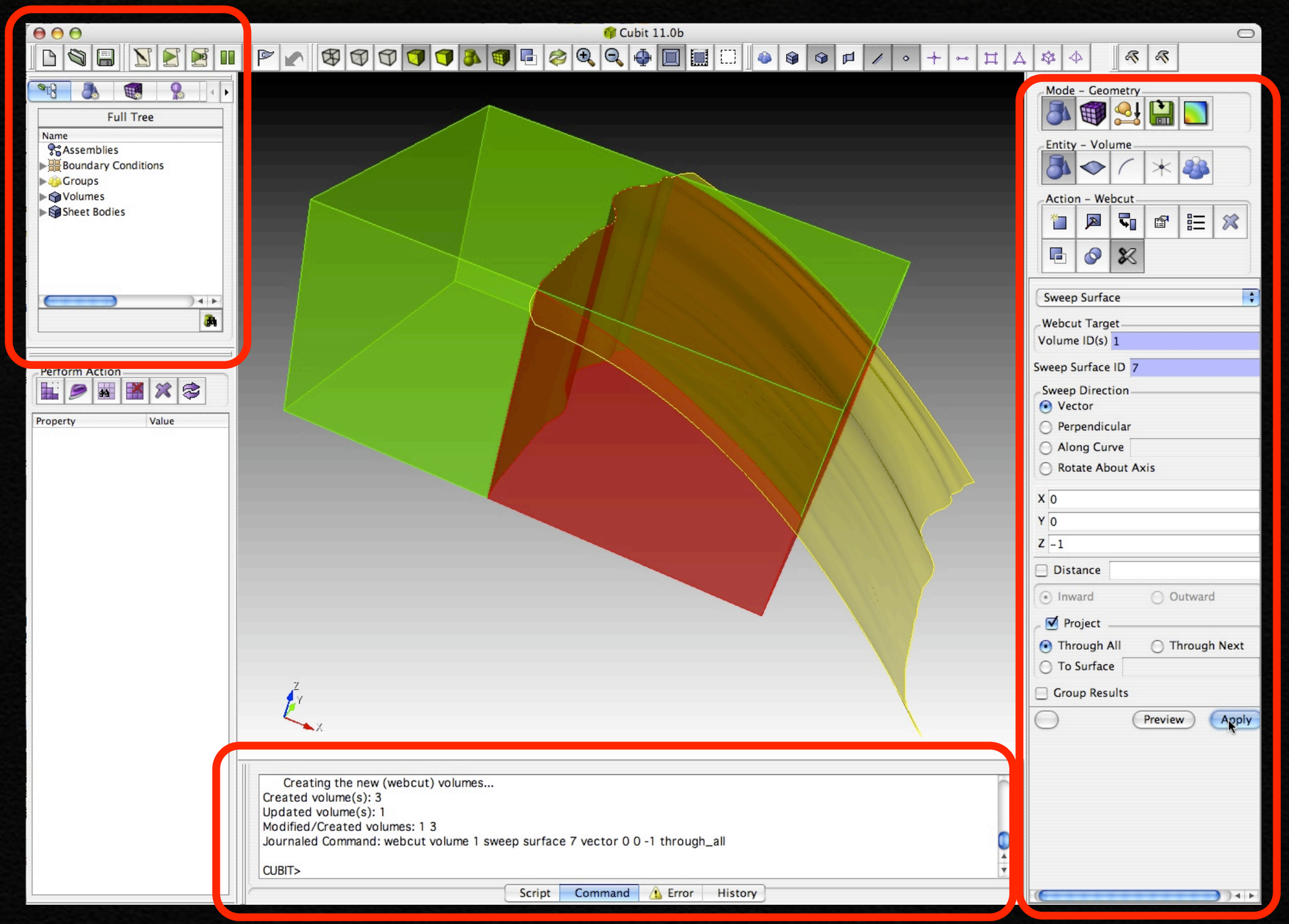
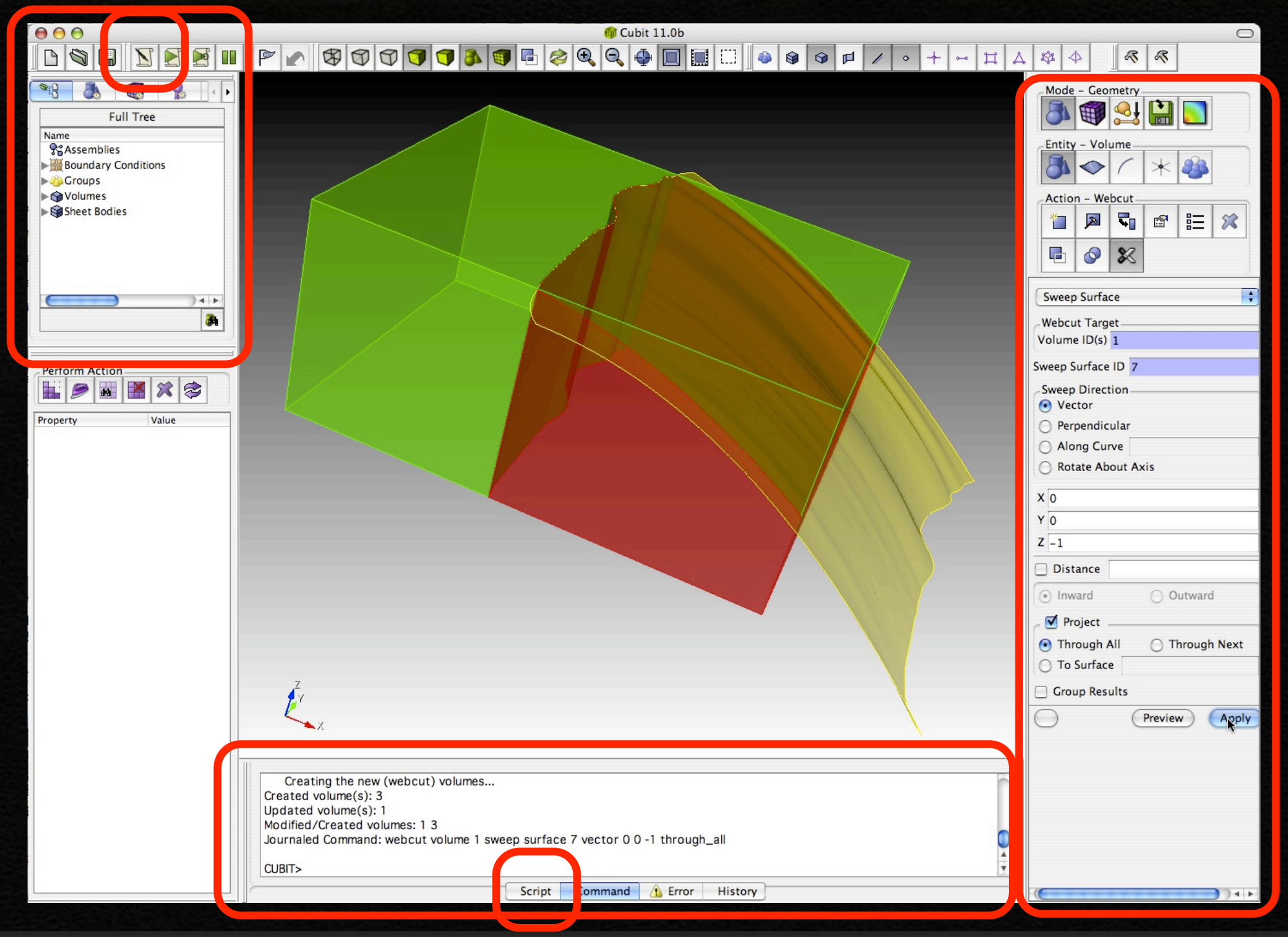


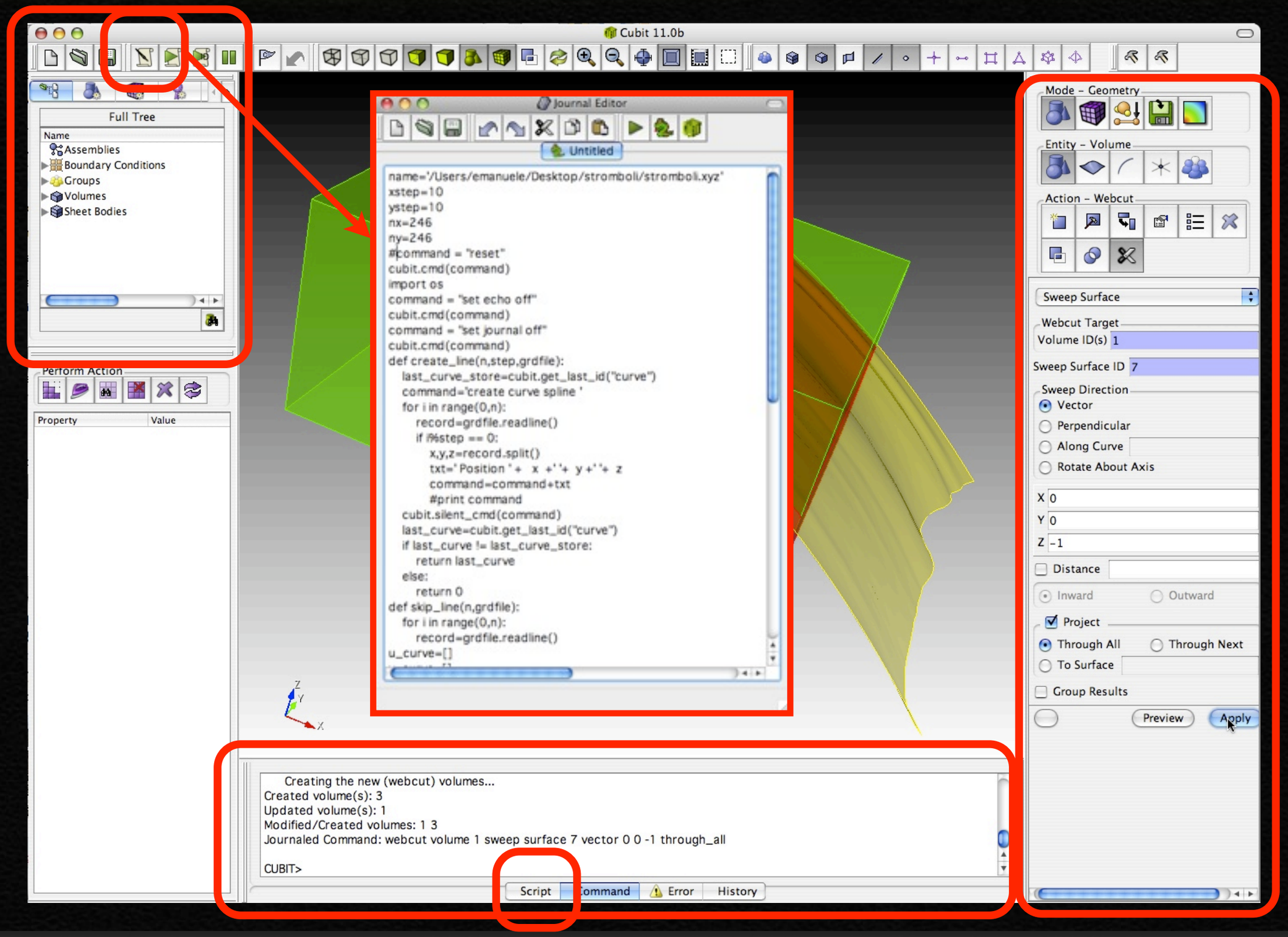
MESHER: CUBIT



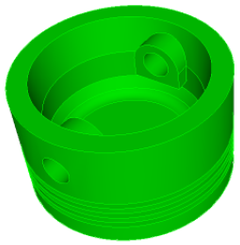
MESHER: CUBIT



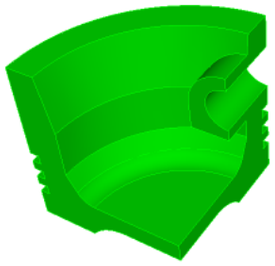
MESHER: CUBIT



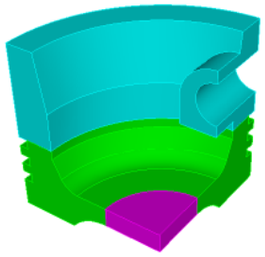
THE MESHING PROCESS



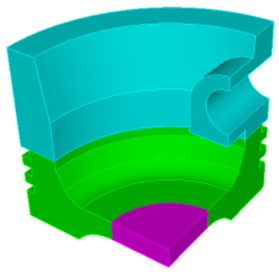
1 **Import Solid Model**



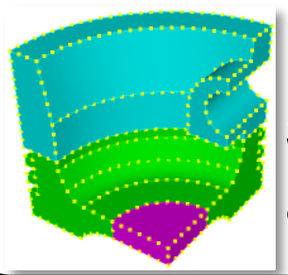
2 **Simplify Geometry**



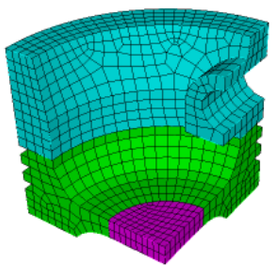
3 **Decompose Geometry**



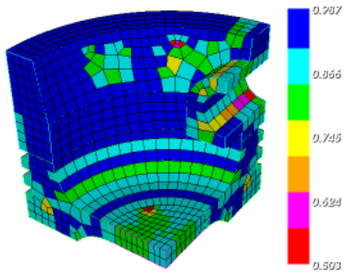
4 **Imprint & Merge**



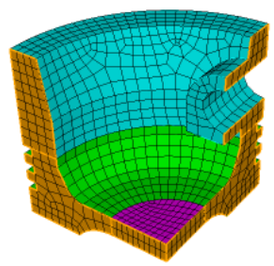
5 **Set Schemes & Intervals**



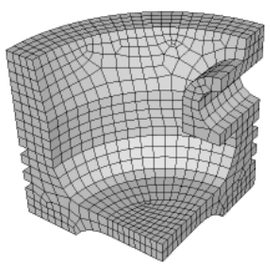
6 **Mesh**



7 **Check Quality**

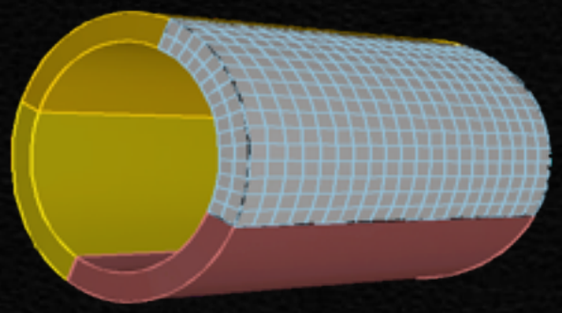


8 **Apply B.C.s**

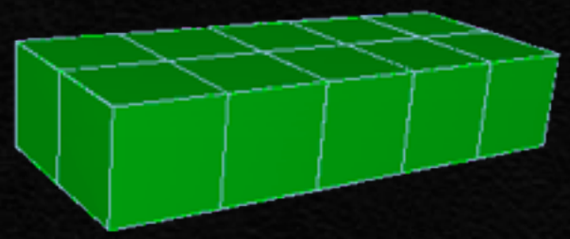


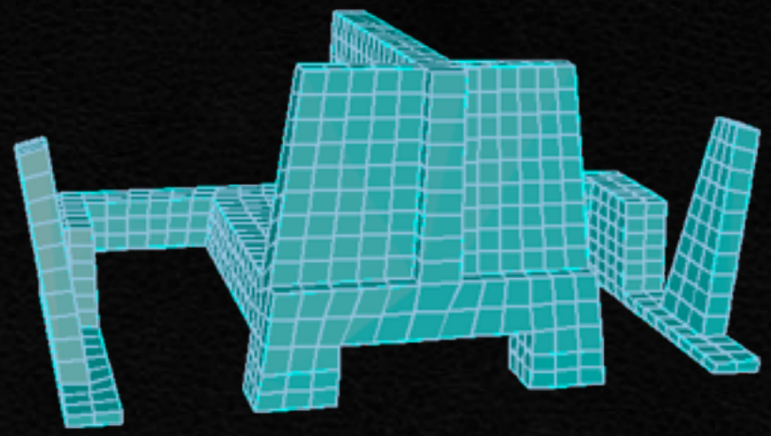
9 **Export Mesh**

THE MESHING PROCESS

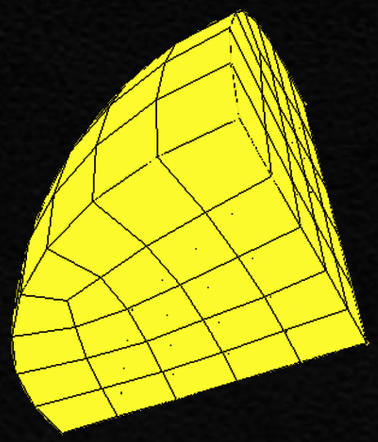


Map

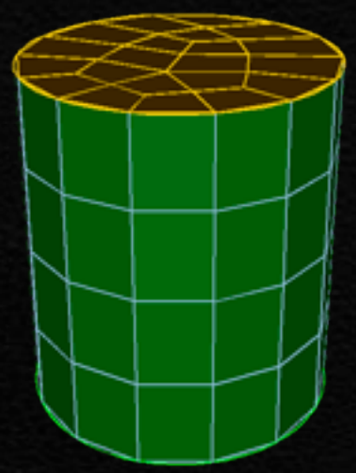


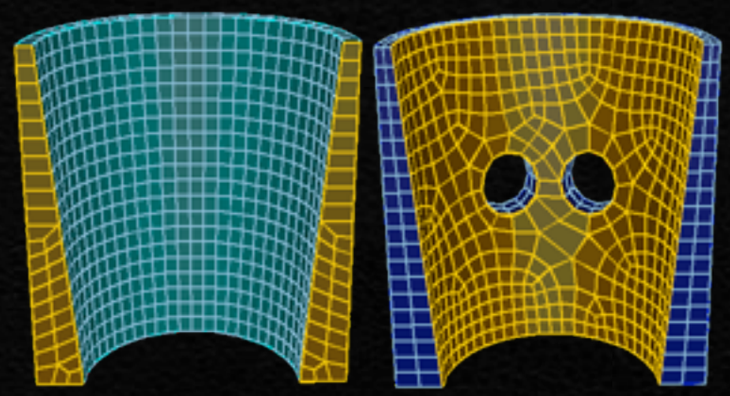


Sub-map

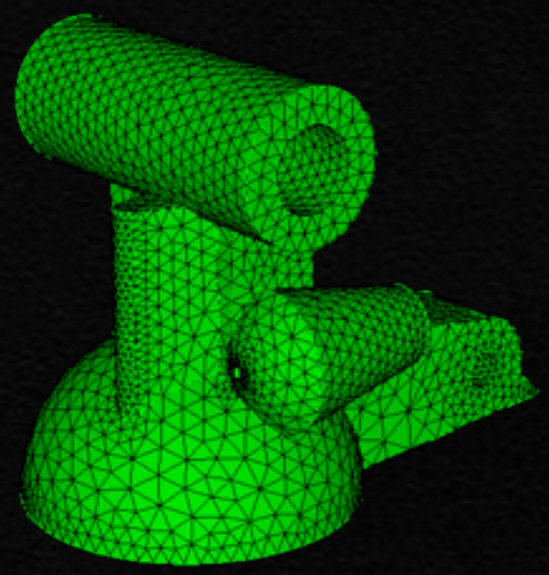


Triprimitive

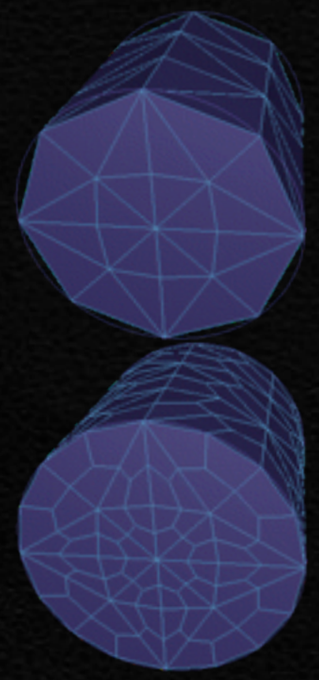




Sweep

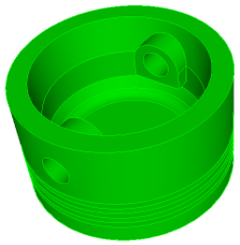


Tetmesh

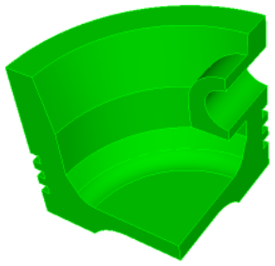


THEX

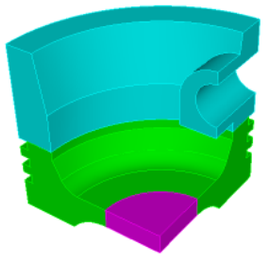
THE MESHING PROCESS



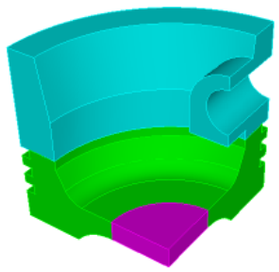
1 **Import Solid Model**



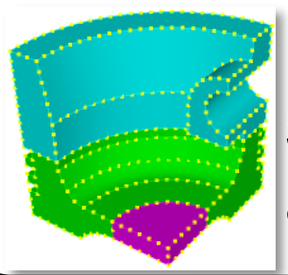
2 **Simplify Geometry**



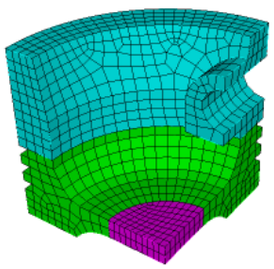
3 **Decompose Geometry**



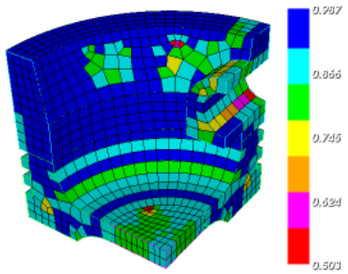
4 **Imprint & Merge**



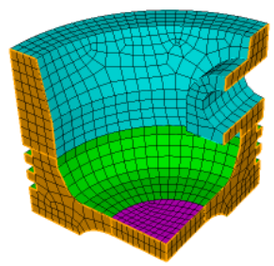
5 **Set Schemes & Intervals**



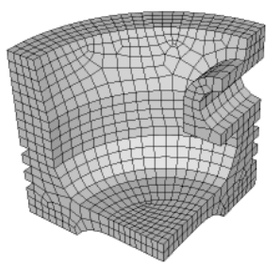
6 **Mesh**



7 **Check Quality**



8 **Apply B.C.s**



9 **Export Mesh**

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 availabl (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

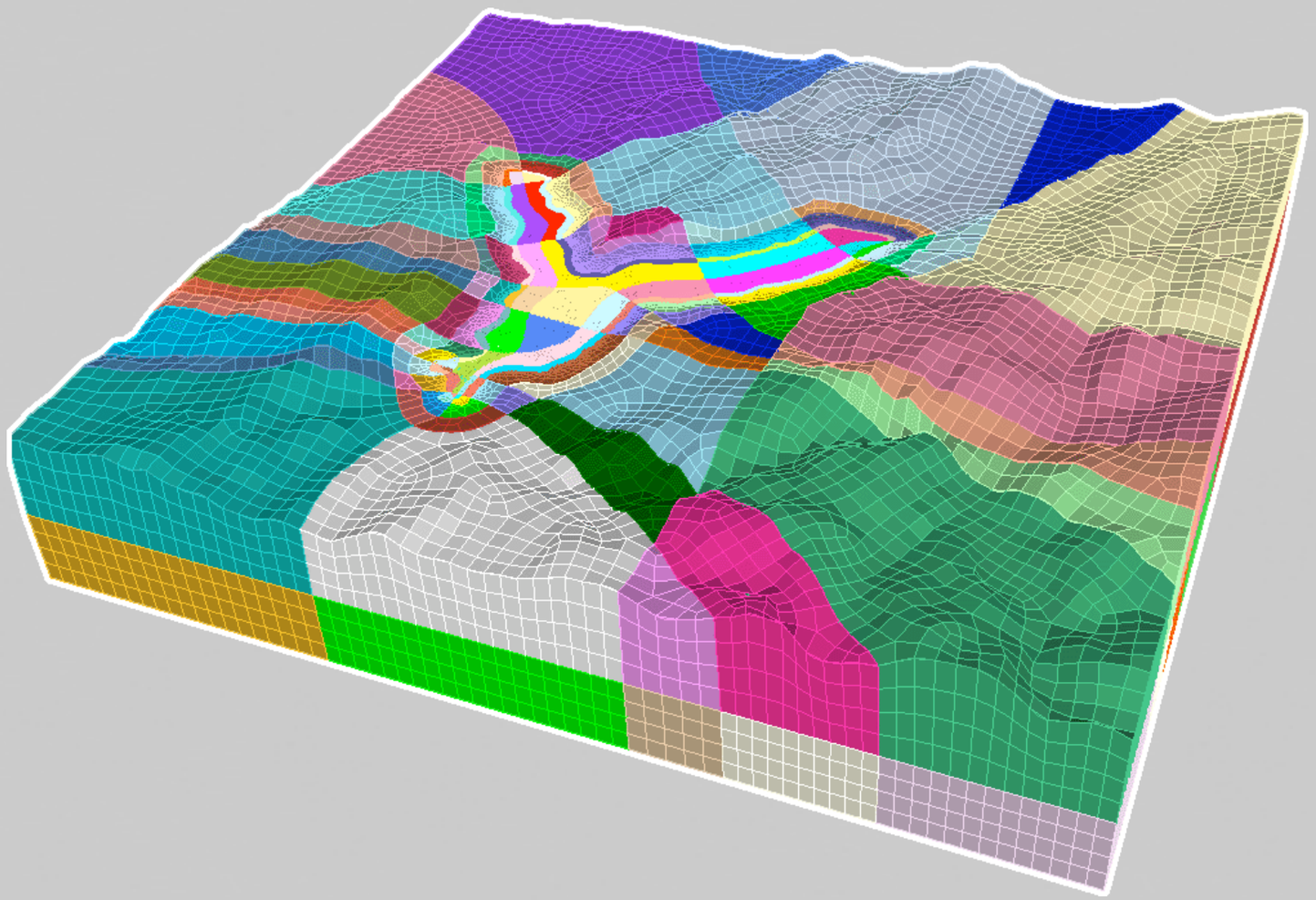
I - Construction of the geometry

II - Meshing the geometry

III - Boundary condition + Export the mesh

MESHING STRATEGIES

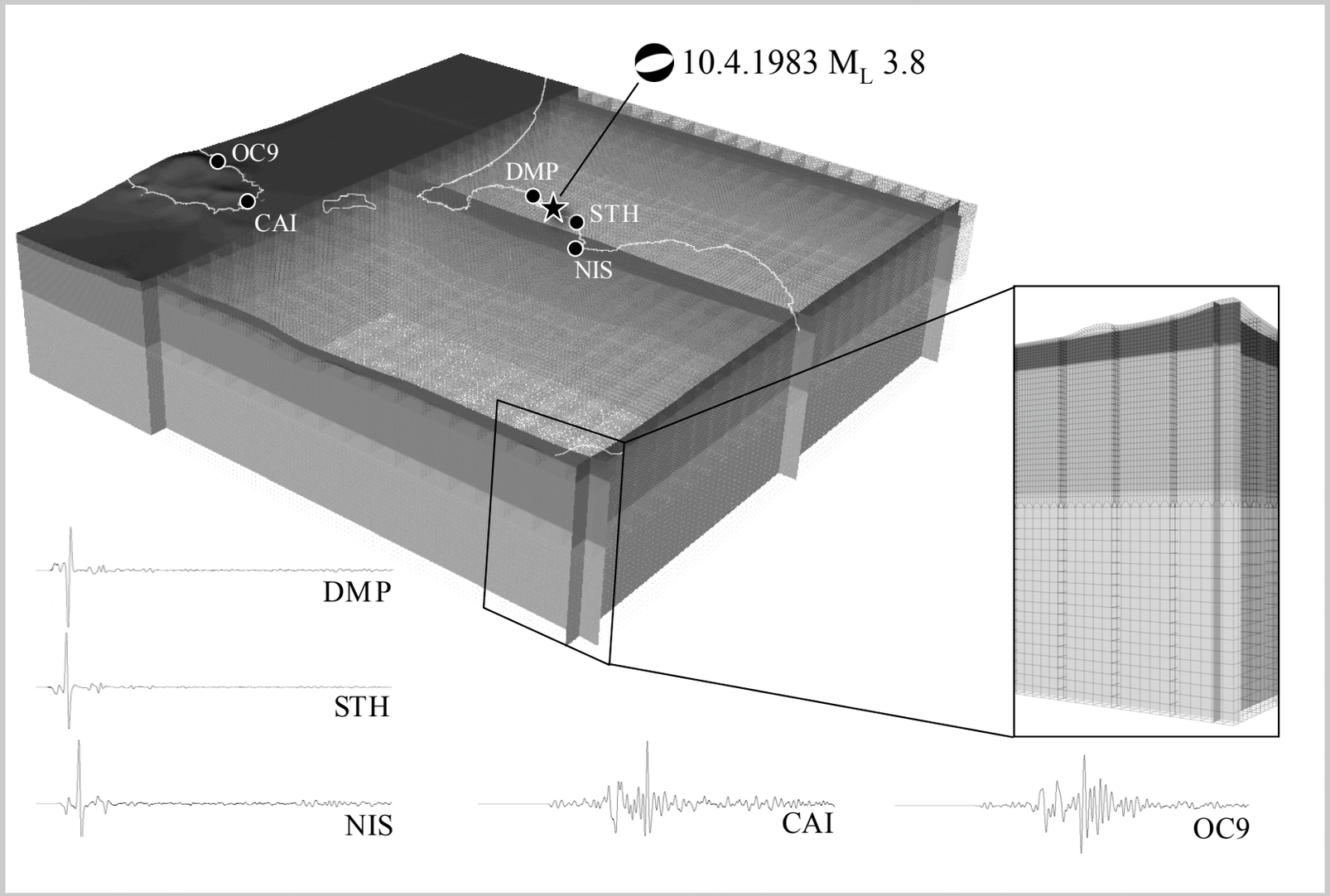
a) brutal (by hand in cubit)



MESHING STRATEGIES

a) brutal (by hand in cubit)

b) GEOcubit (scripting)

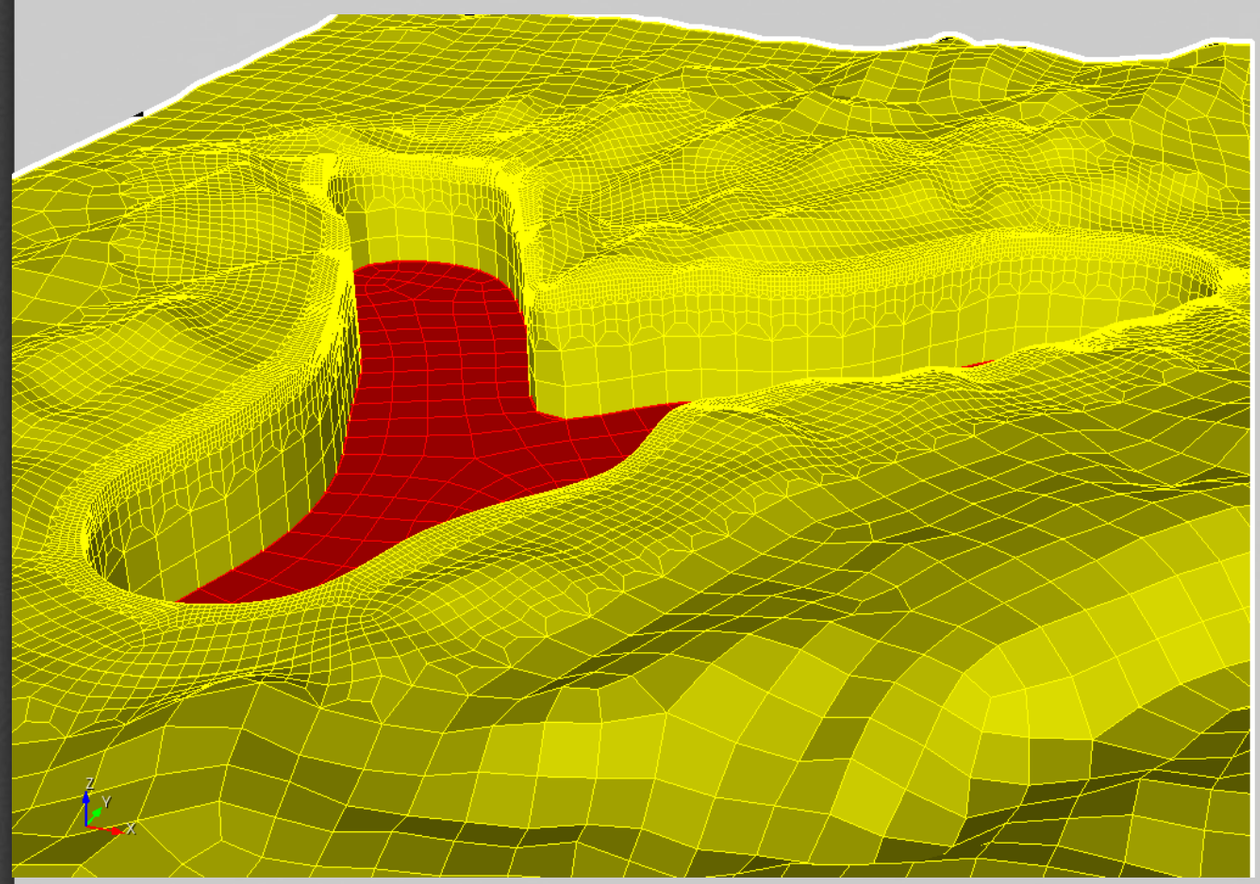


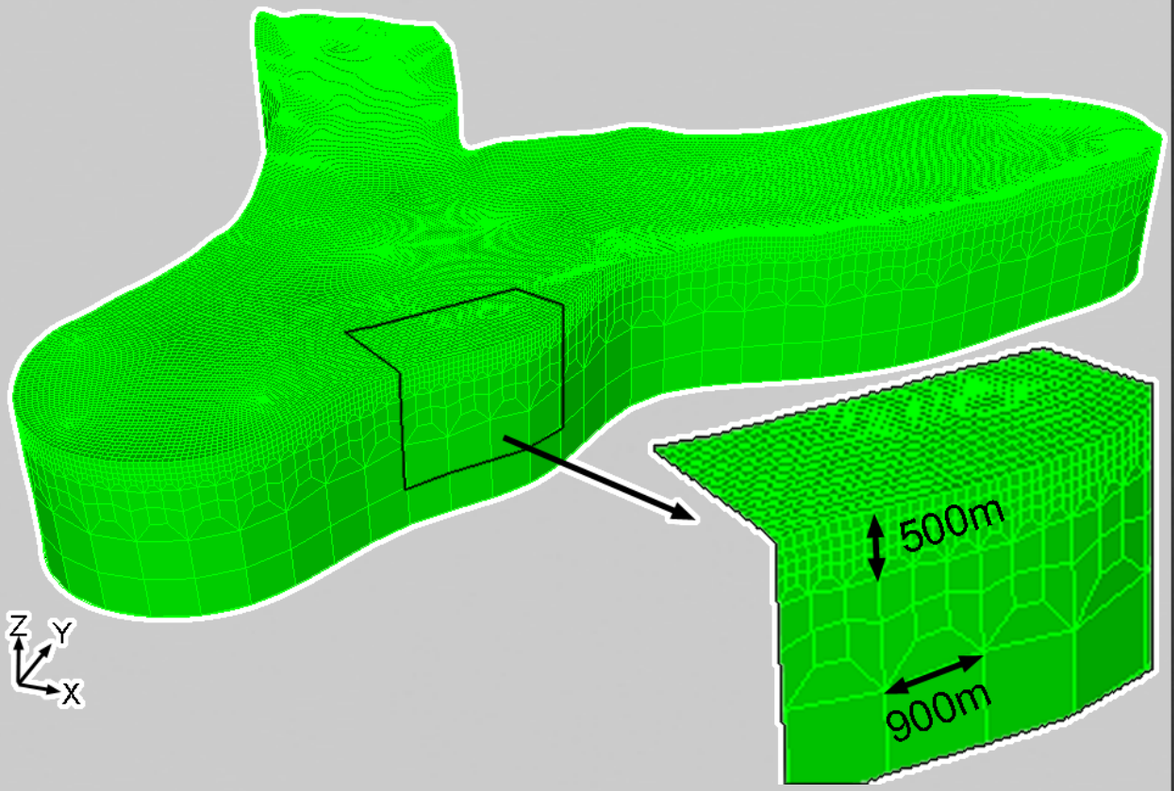
MESHING STRATEGIES

a) brutal (by hand in cubit)

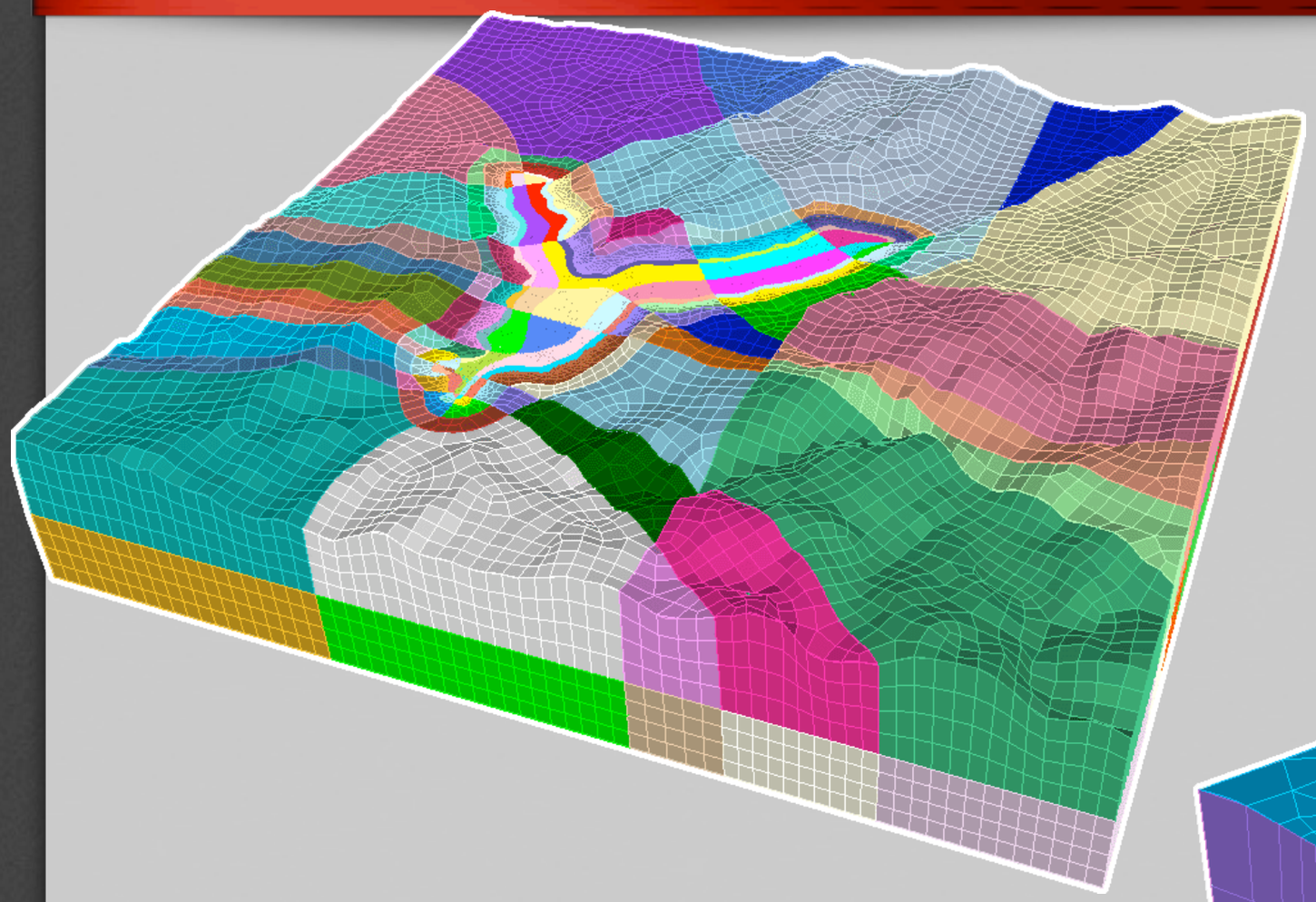
b) GEOcubit (scripting)

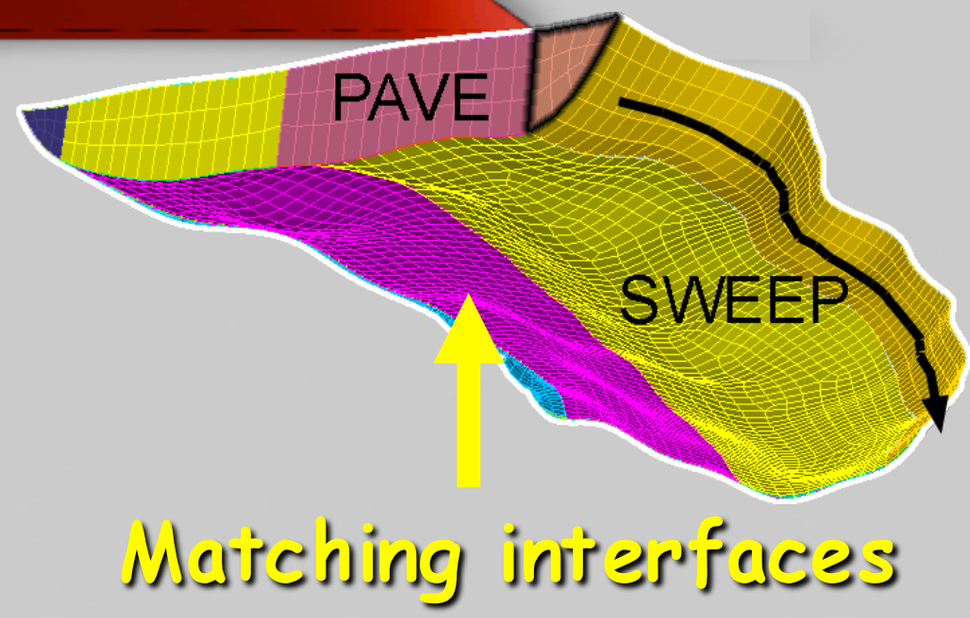
c) "Not-honoring"



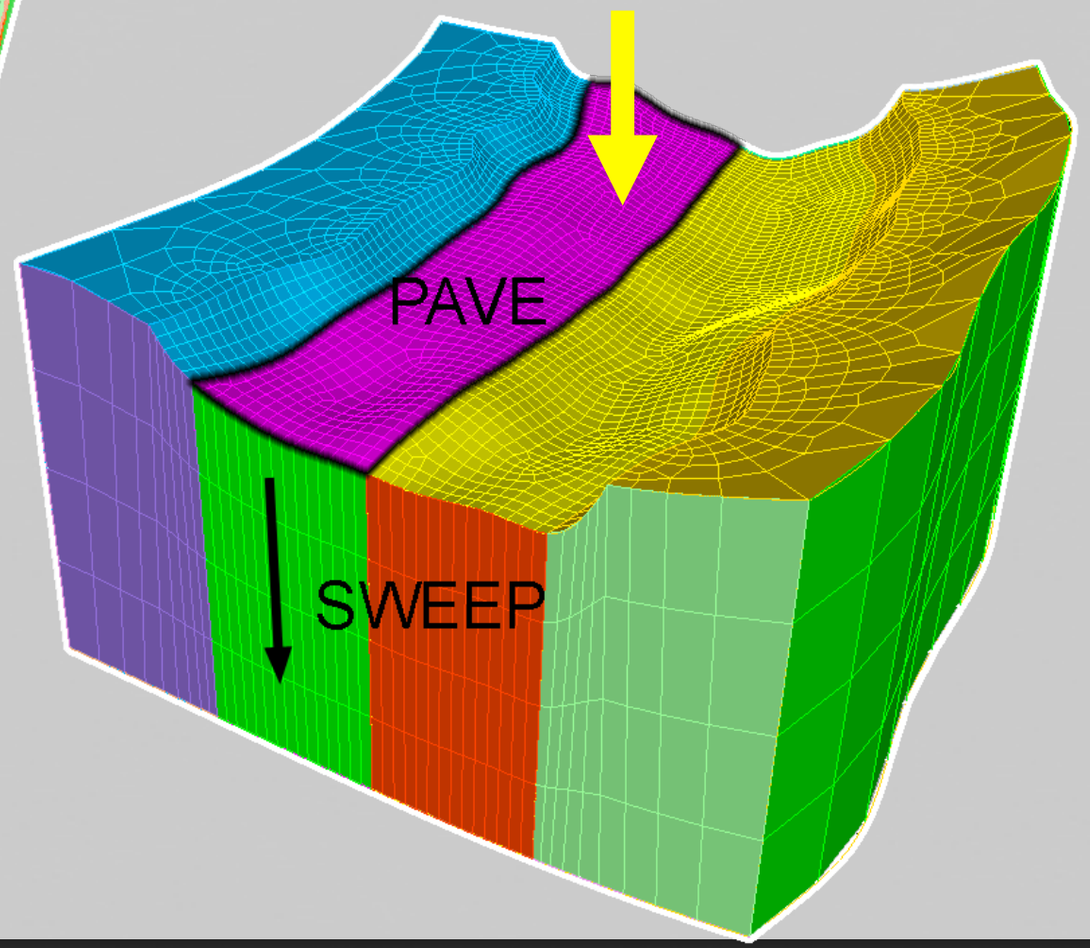


MESHING STRATEGIES (a)





Matching interfaces

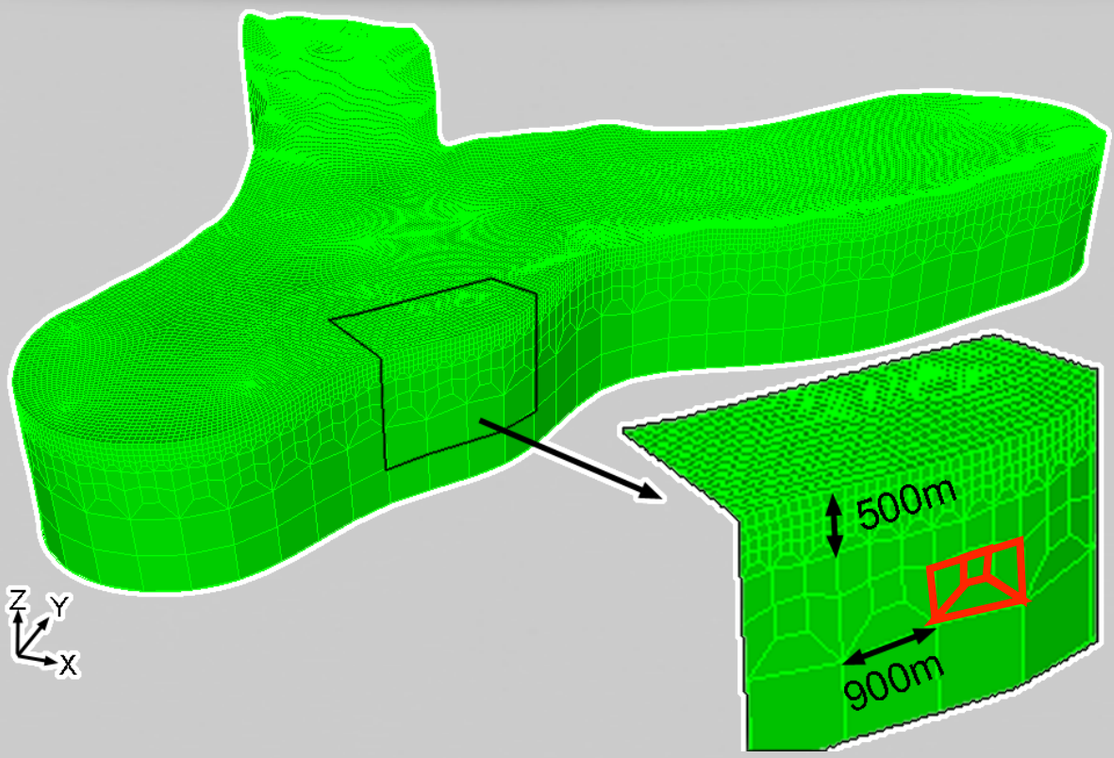


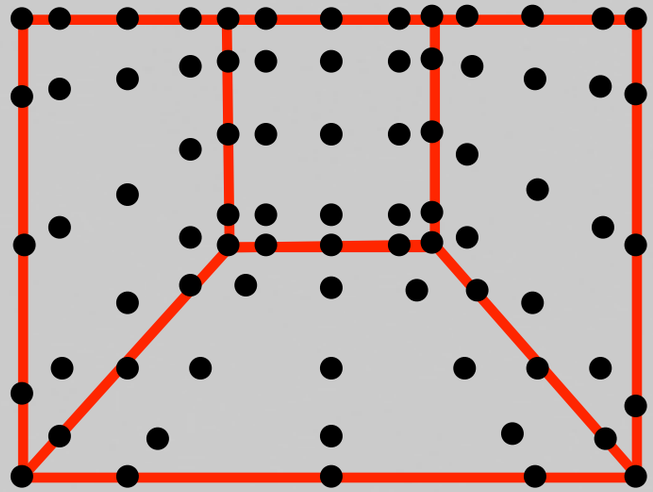
Grenoble Valley, Marco Stupazzini et . al. 2007

MESHING STRATEGIES (a)

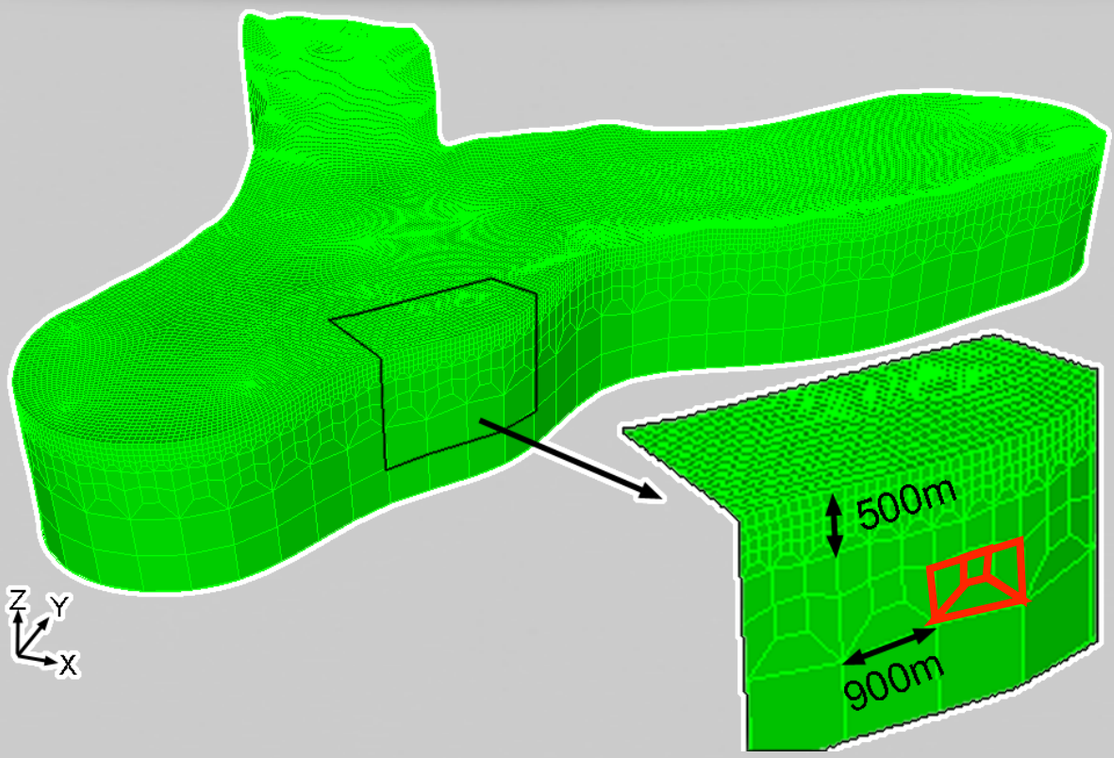
Grenoble Valley, Marco Stupazzini et . al. 2007

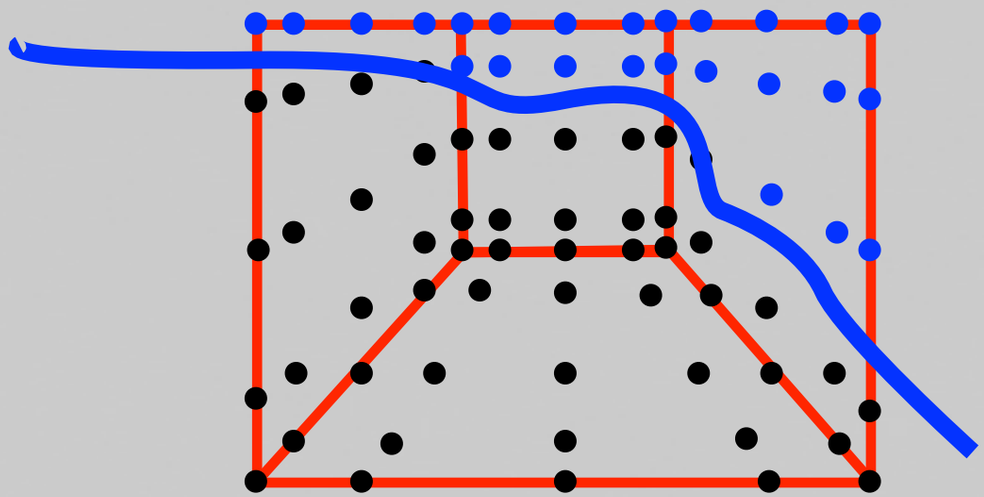
MESHING STRATEGIES (c)



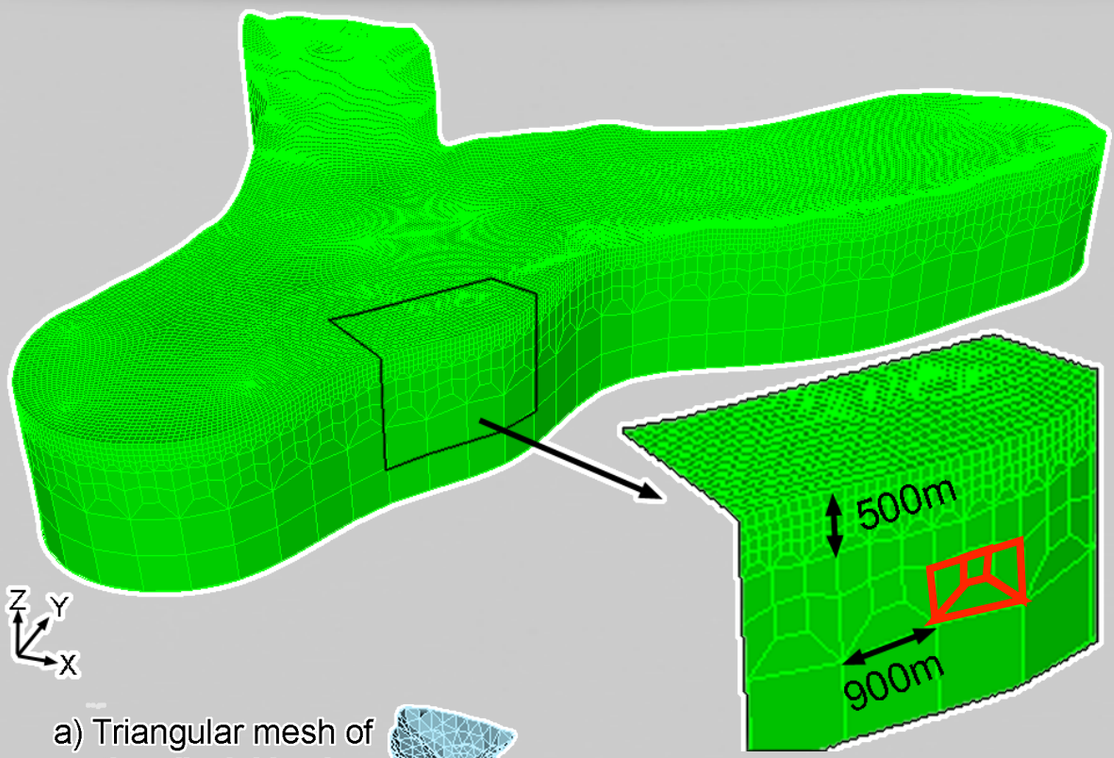


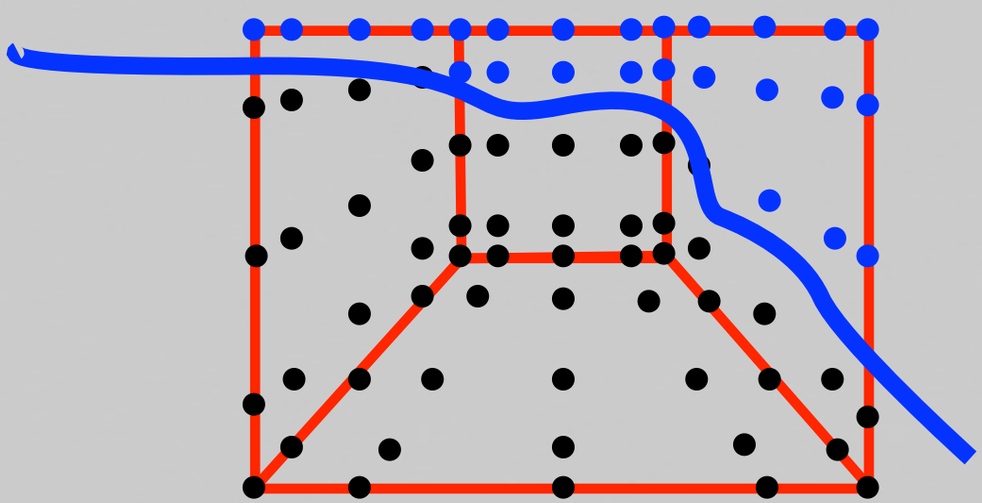
MESHING STRATEGIES (c)



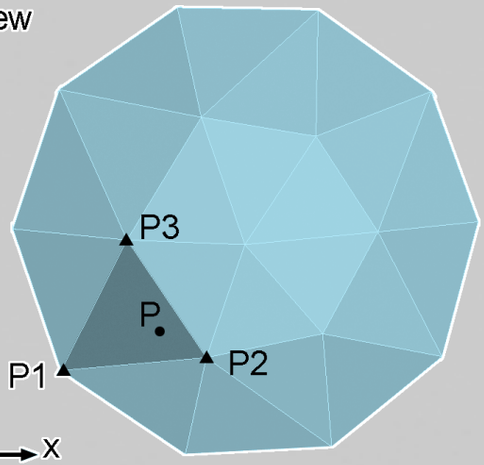


MESHING STRATEGIES (c)

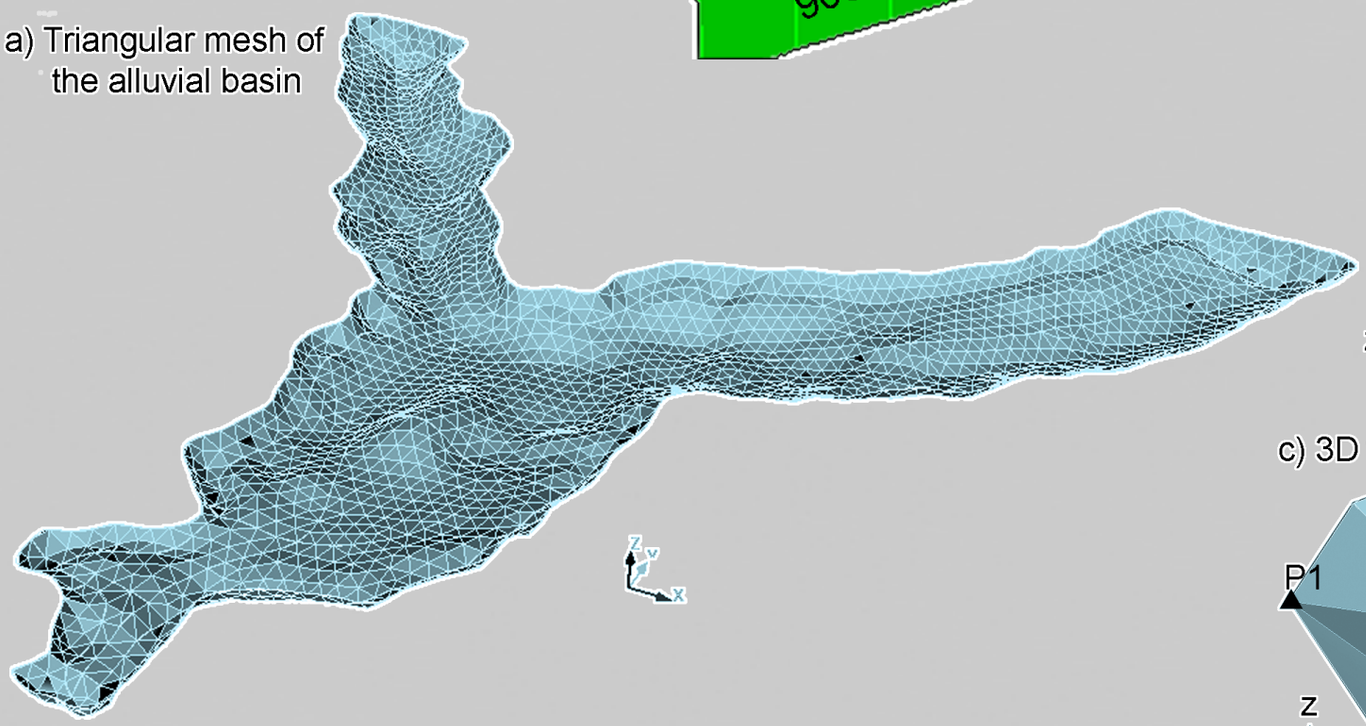




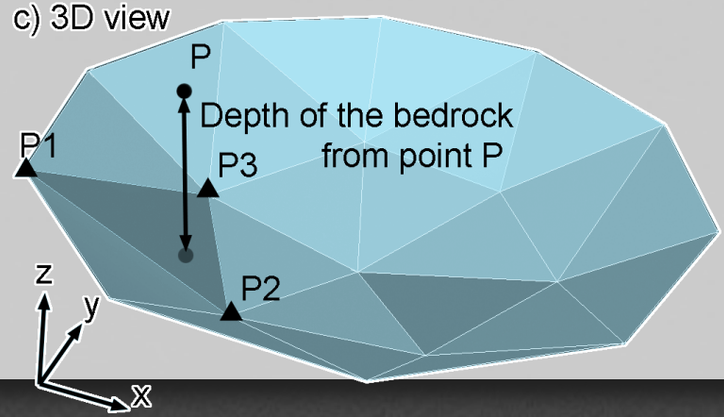
b) Top view



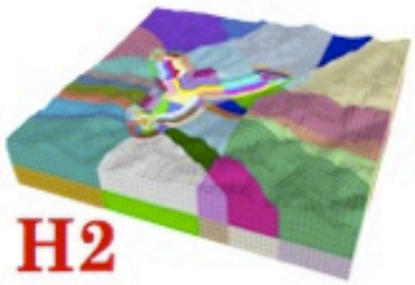
a) Triangular mesh of the alluvial basin

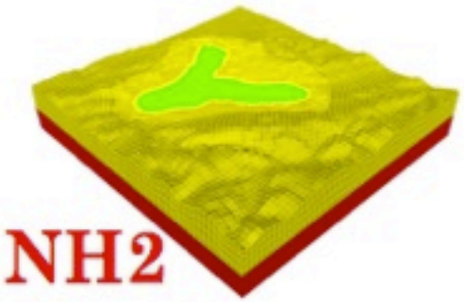


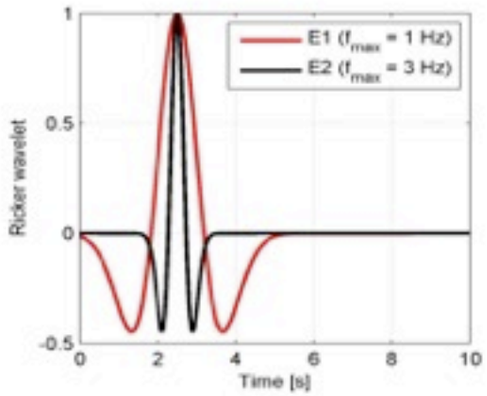
c) 3D view

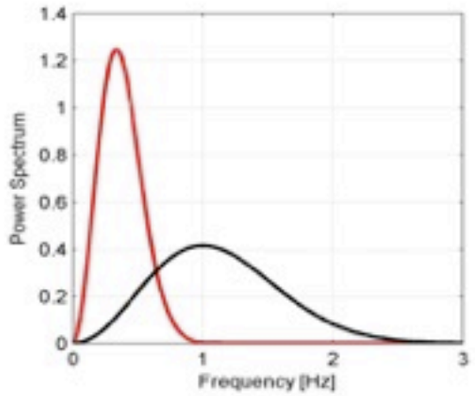


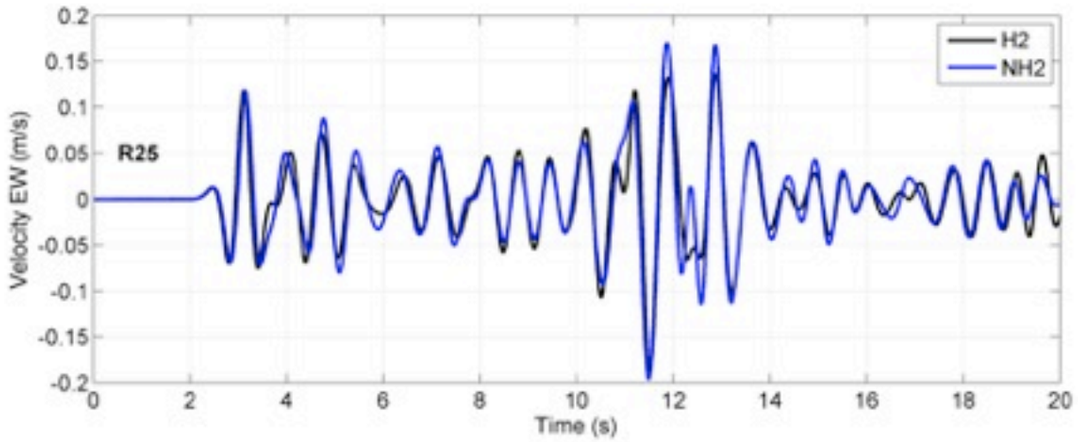
MESHING STRATEGIES (c)

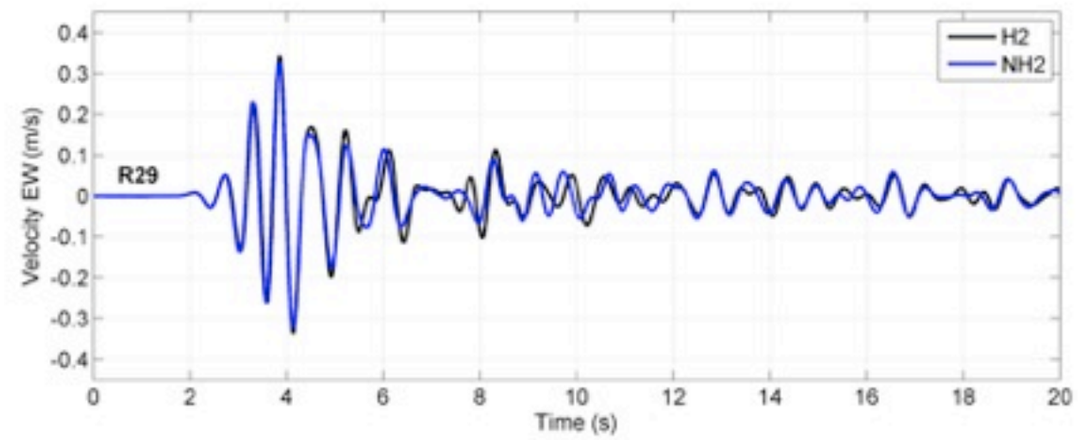


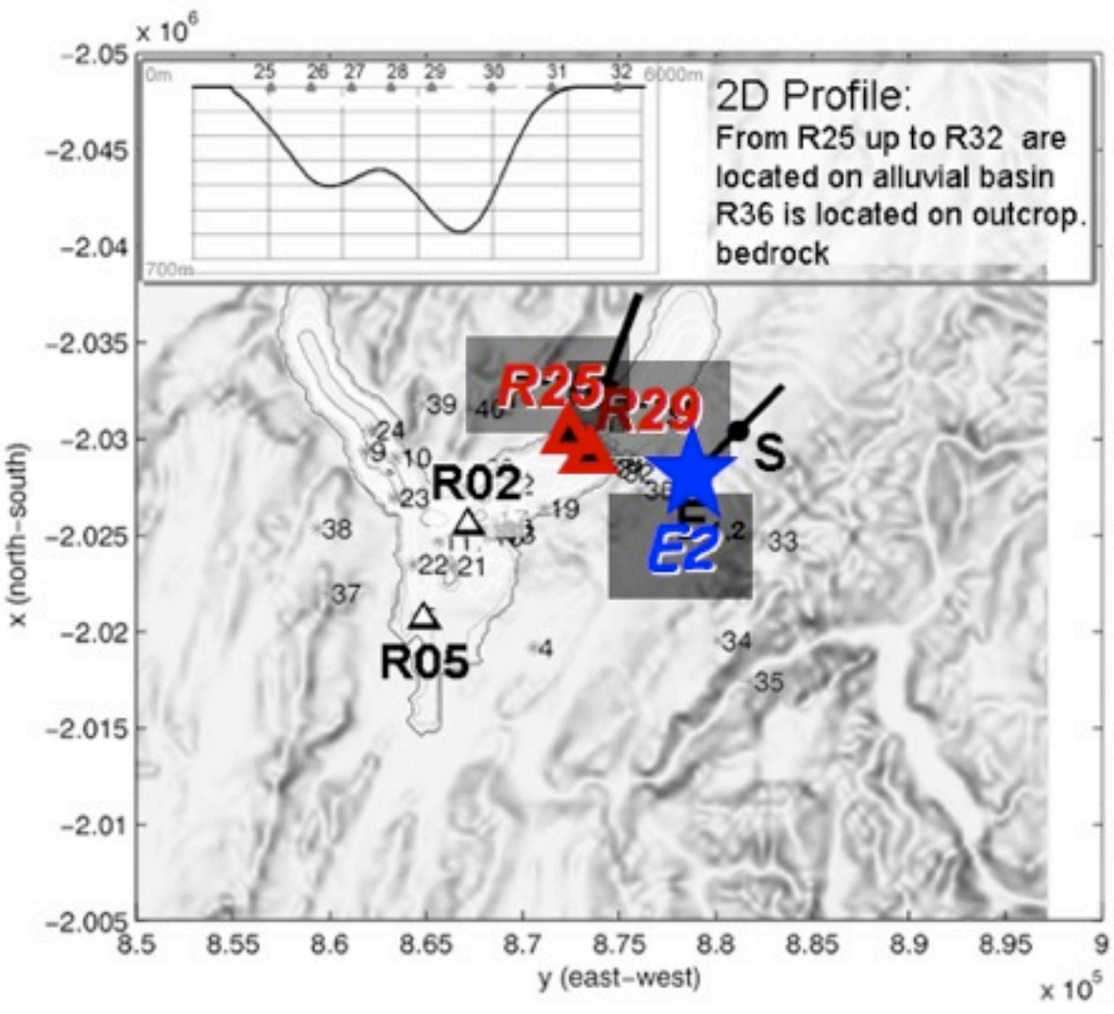






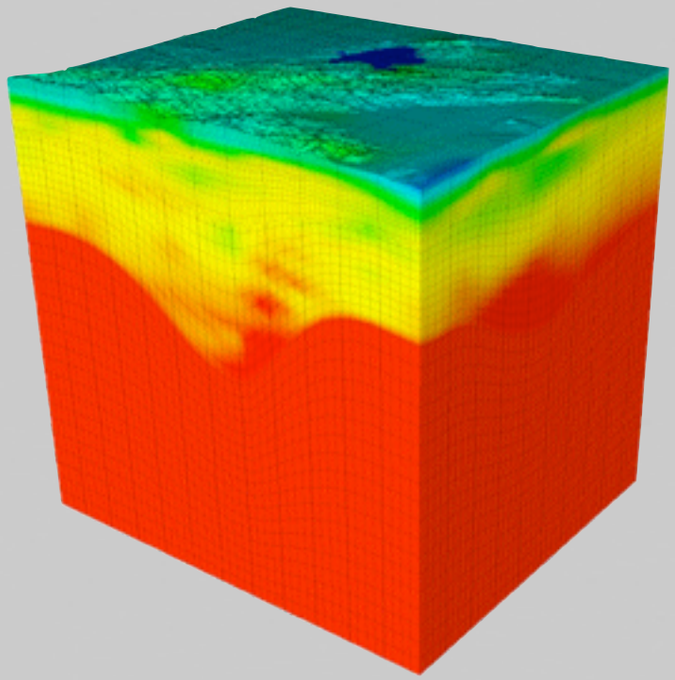


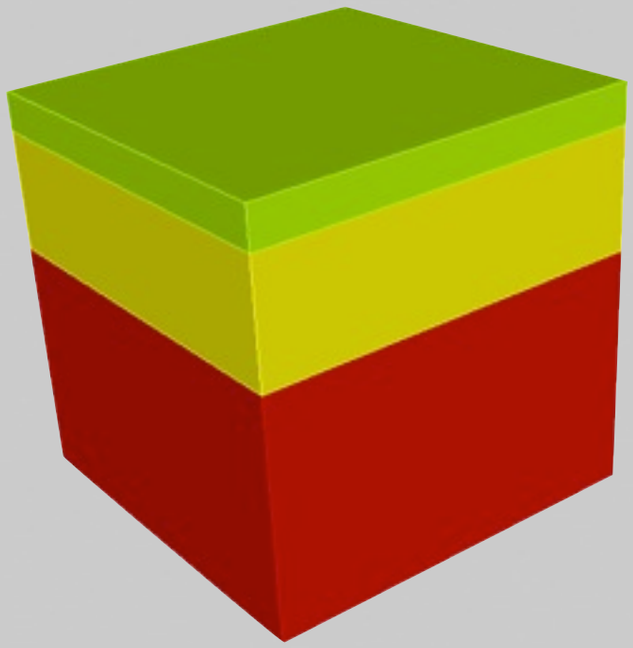


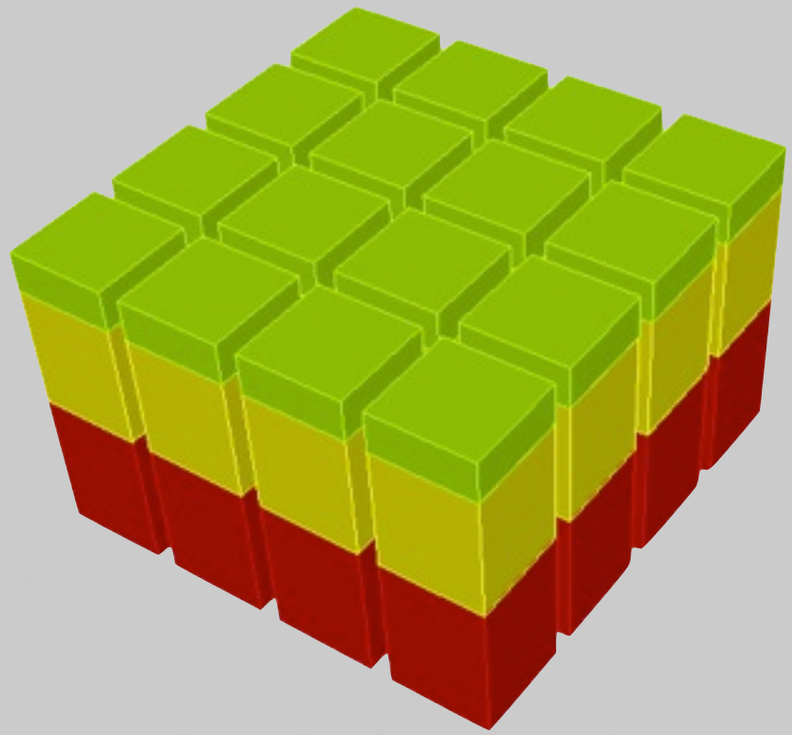


MESHING STRATEGIES (c)

goal: meshing automatically some reference geological cases







MESHING STRATEGIES (c)

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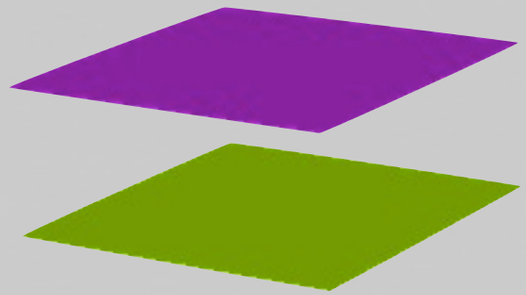
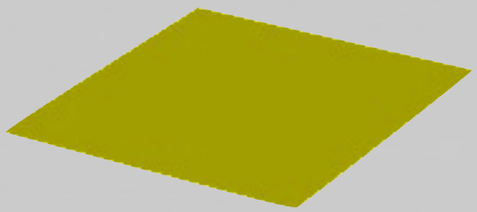
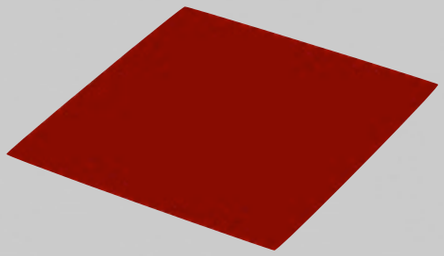
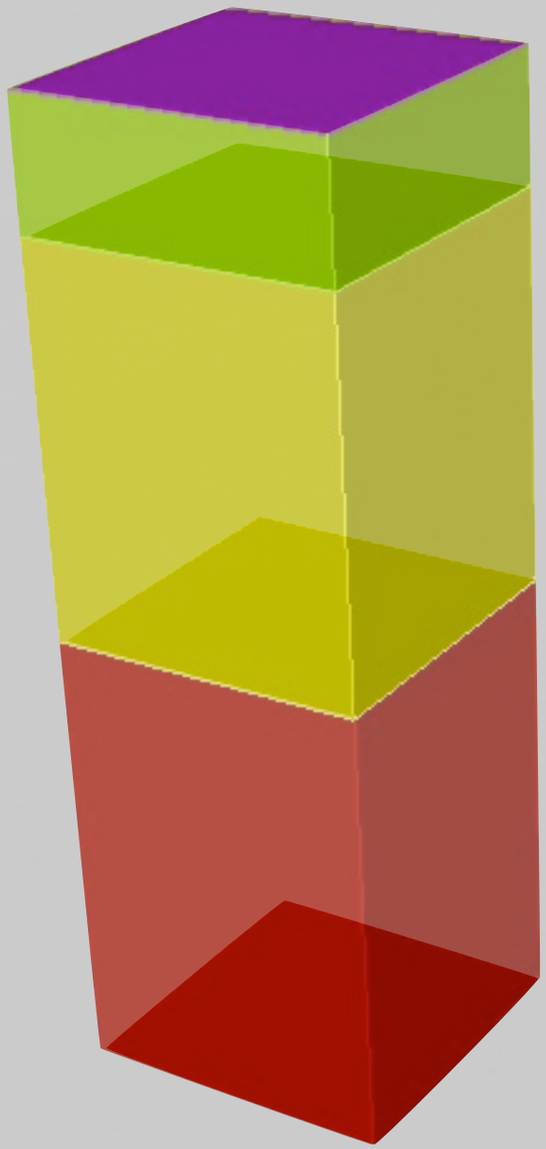






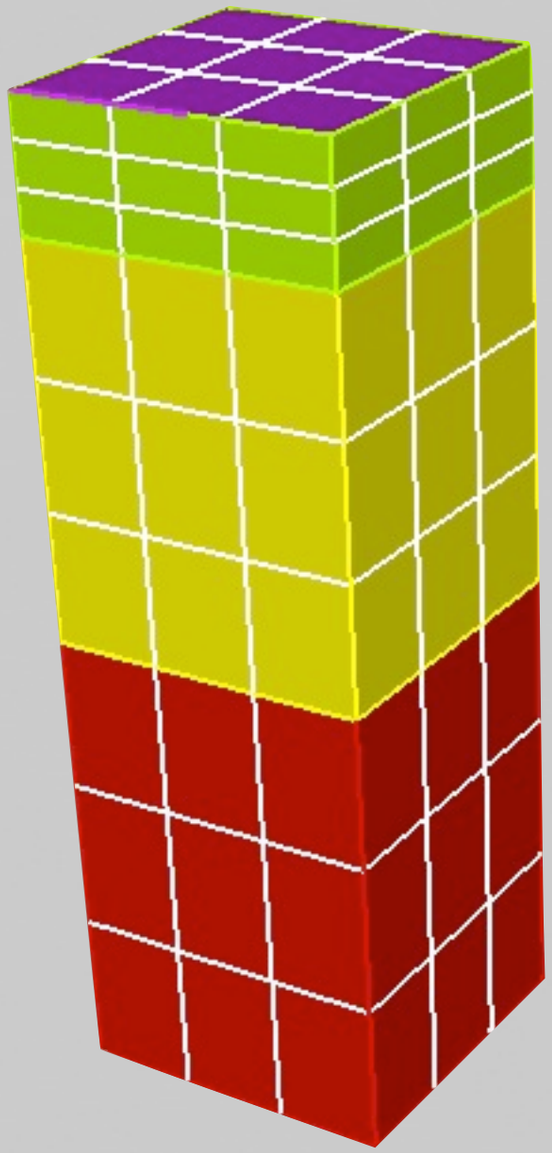
MESHING STRATEGIES (c)

goal: meshing automatically some reference geological cases



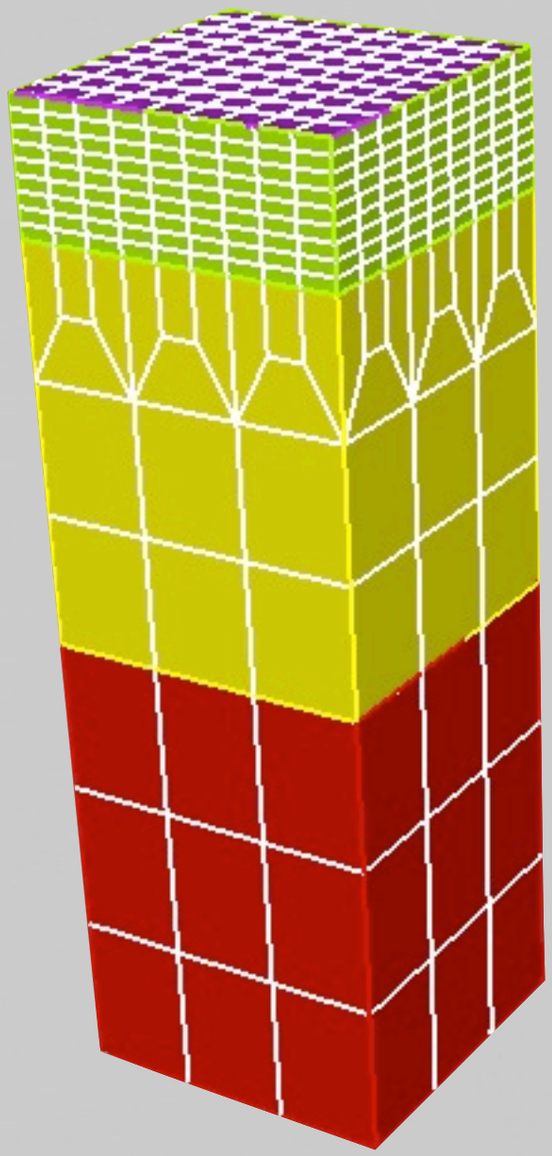
MESHING STRATEGIES (c)

goal: meshing automatically some reference geological cases



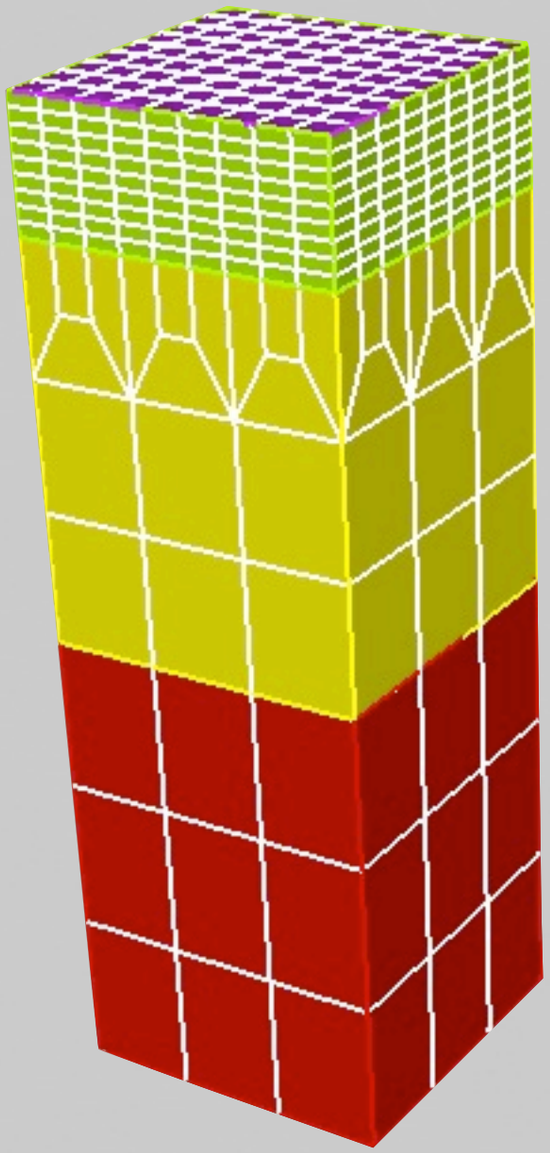
MESHING STRATEGIES (c)

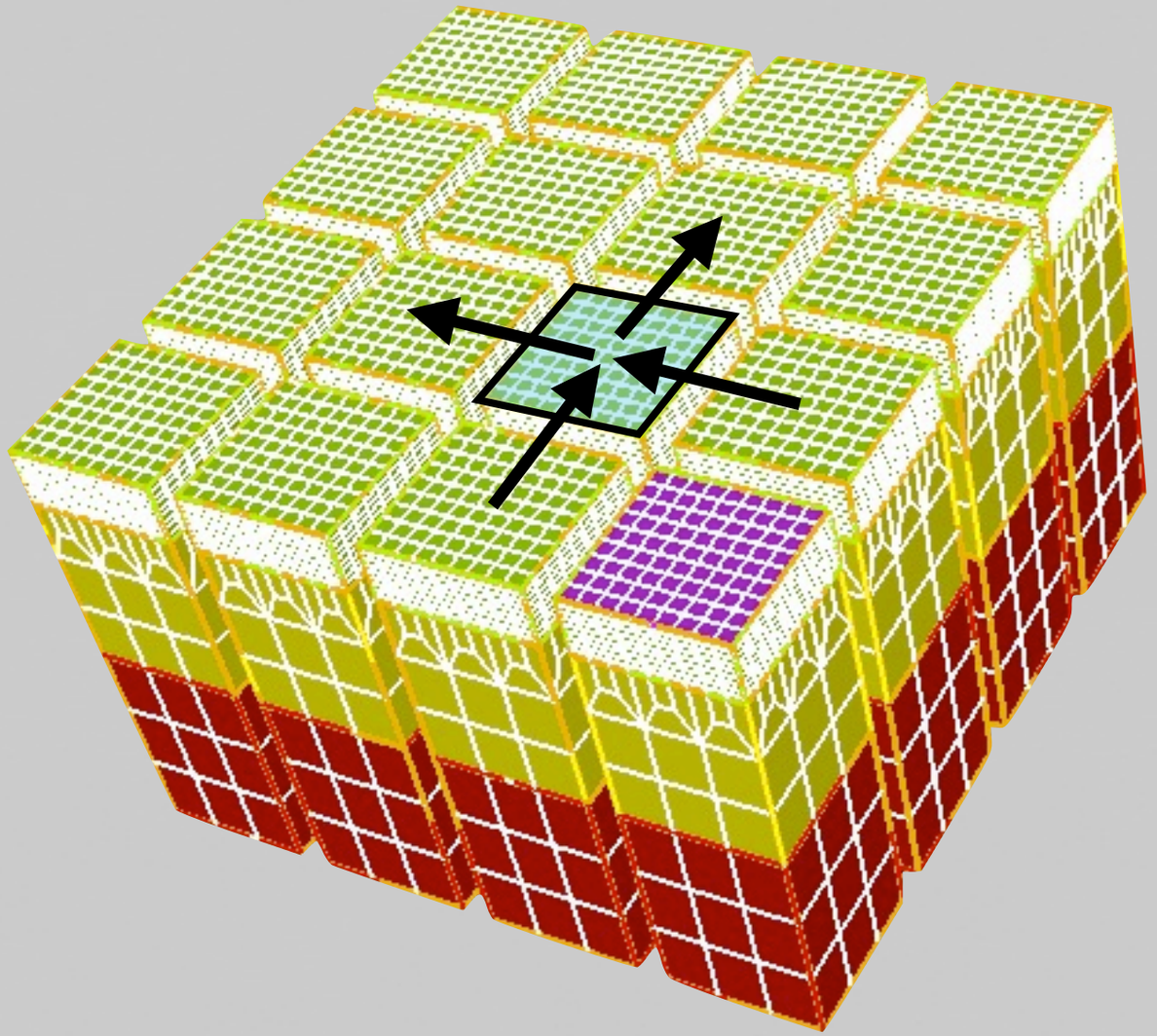
goal: meshing automatically some reference geological cases



MESHING STRATEGIES (c)

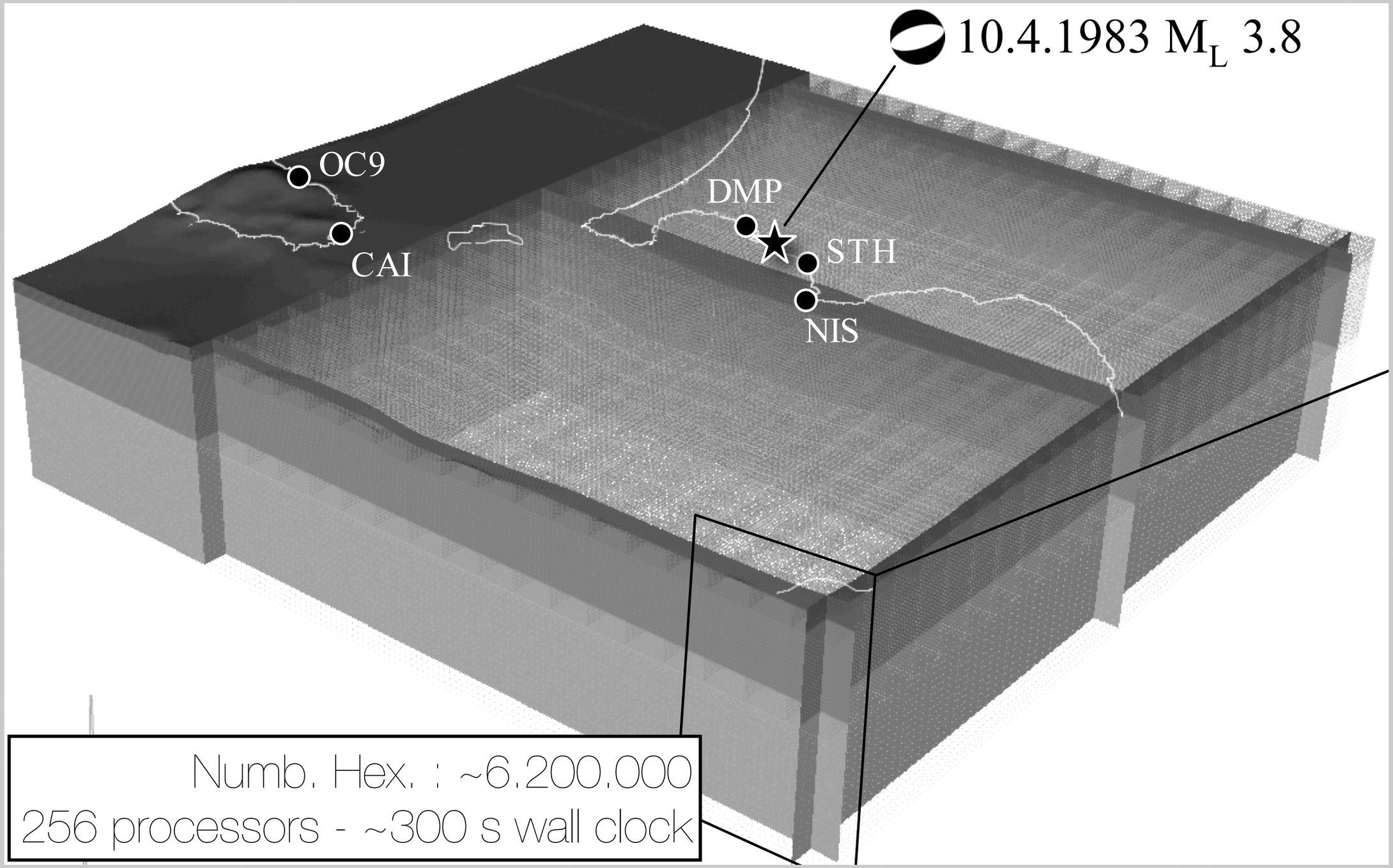
goal: meshing automatically some reference geological cases





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,To, 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*

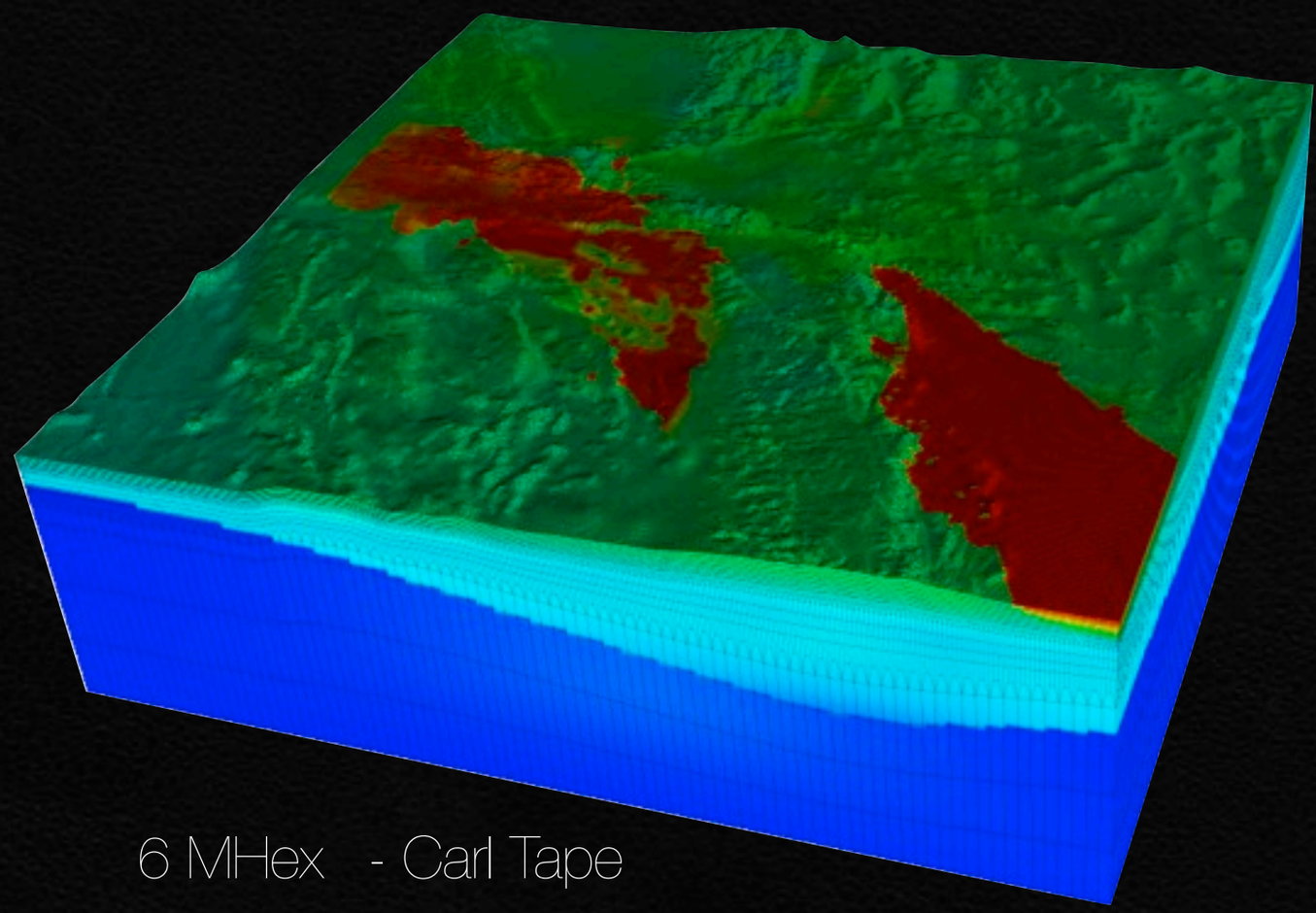
mesh: hex27*

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
```

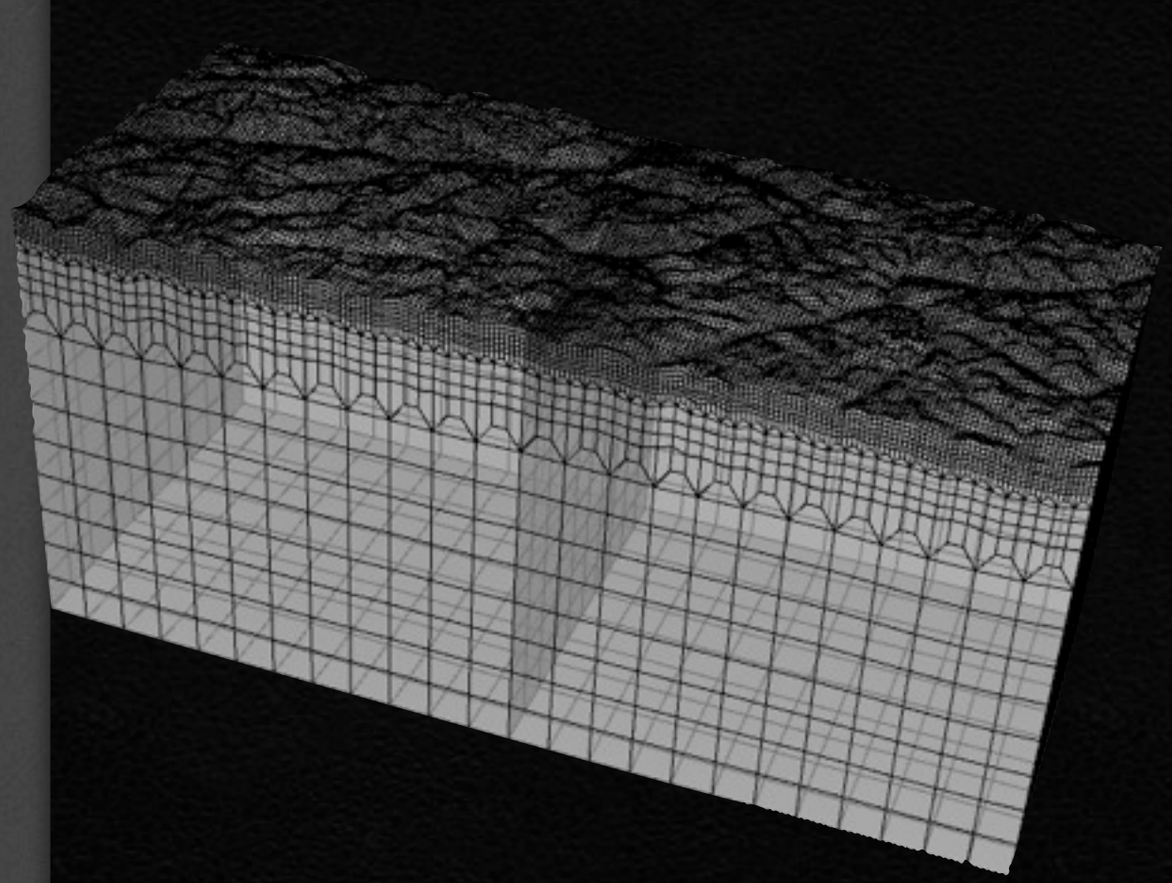
```
GEOCUBIT.py --build_volume --mesh --cfg=examples/scal.cfg

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

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

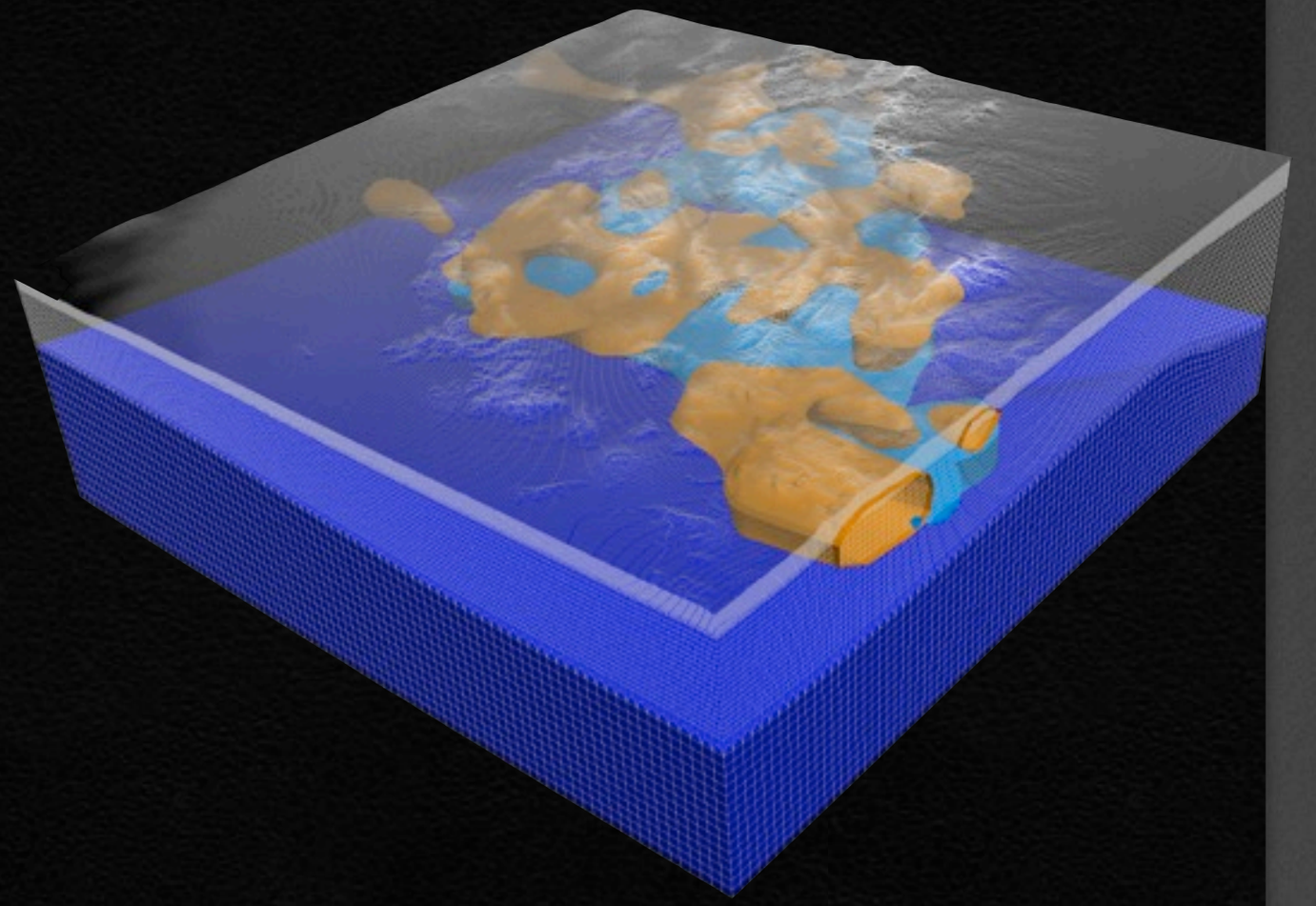


6 MHex - Carl Tape

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
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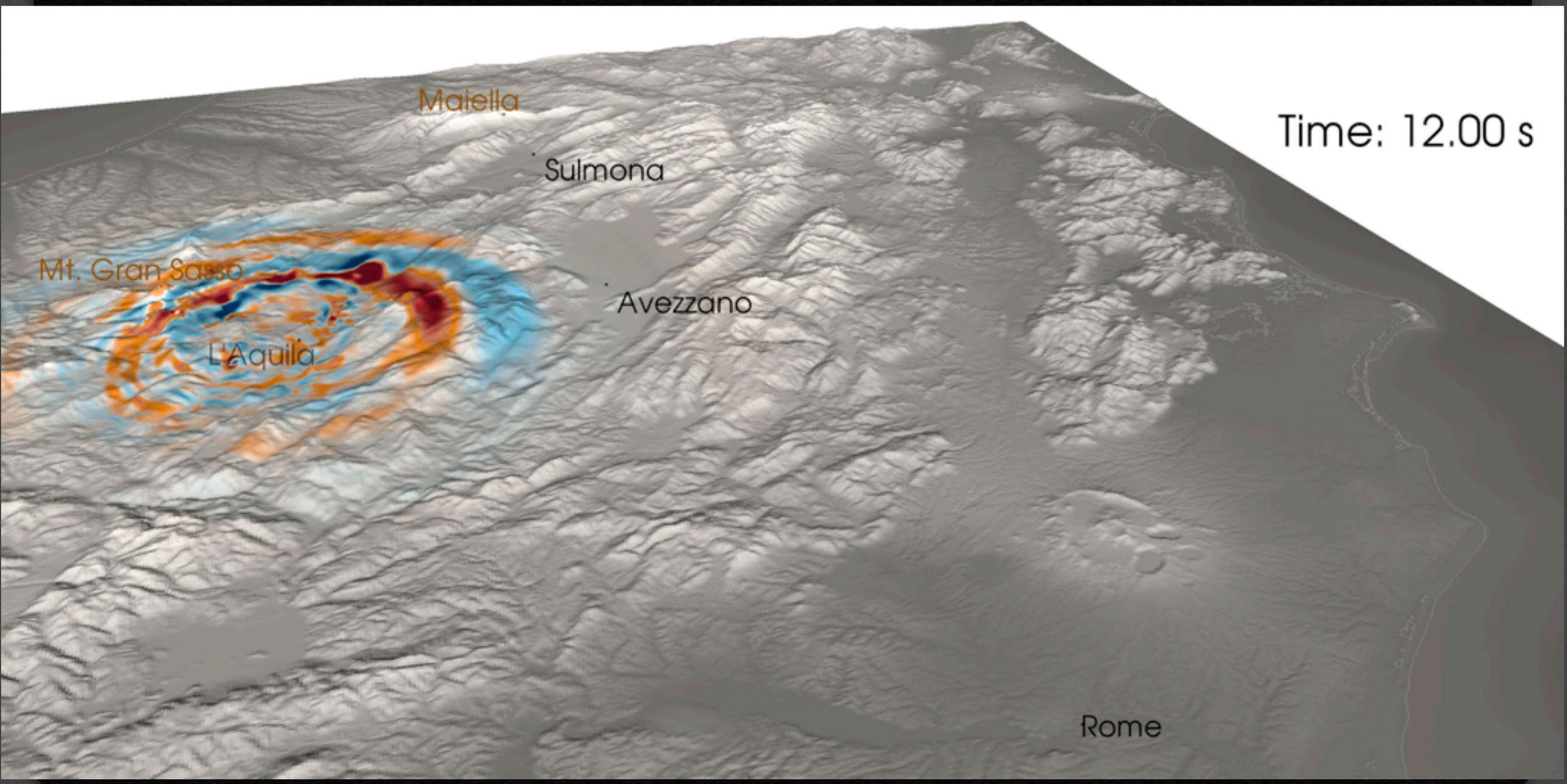

GEOCUBIT - scripting

Italy divided in 256 meshed block
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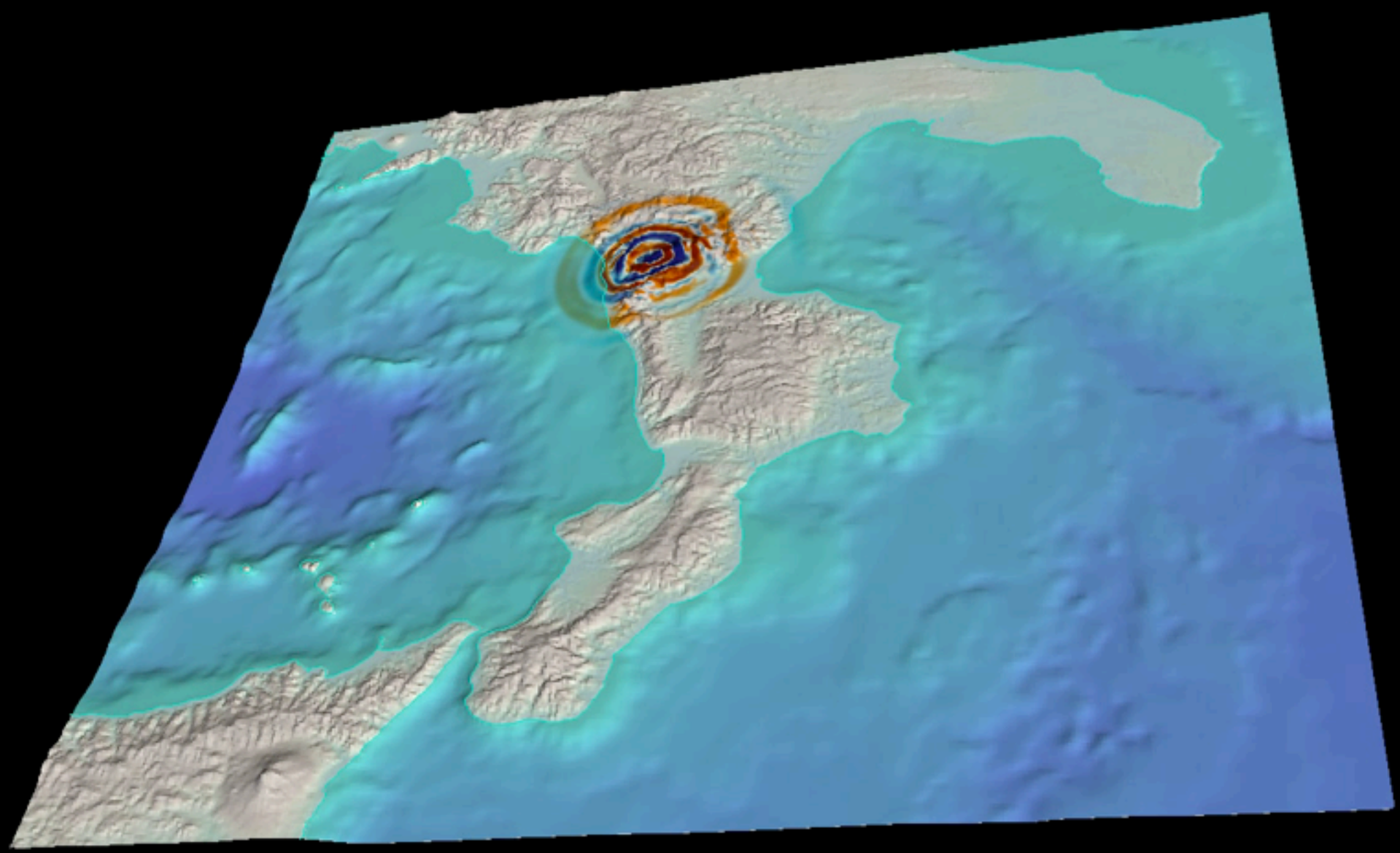

Italy div

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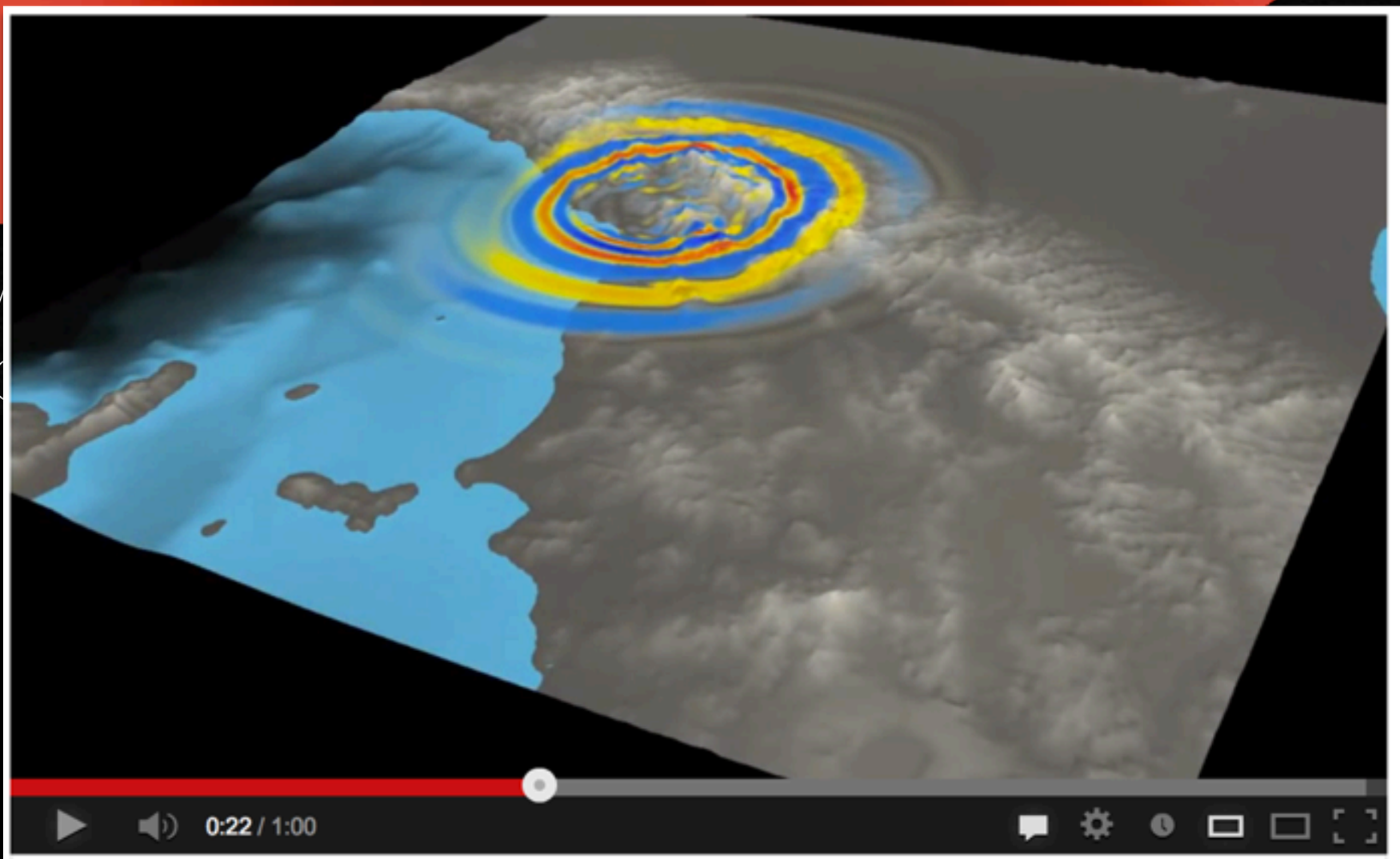

0:22 / 1:00

21.Giugno.2013 Animazione terremoto Ml 5.2 nella Lunigiana

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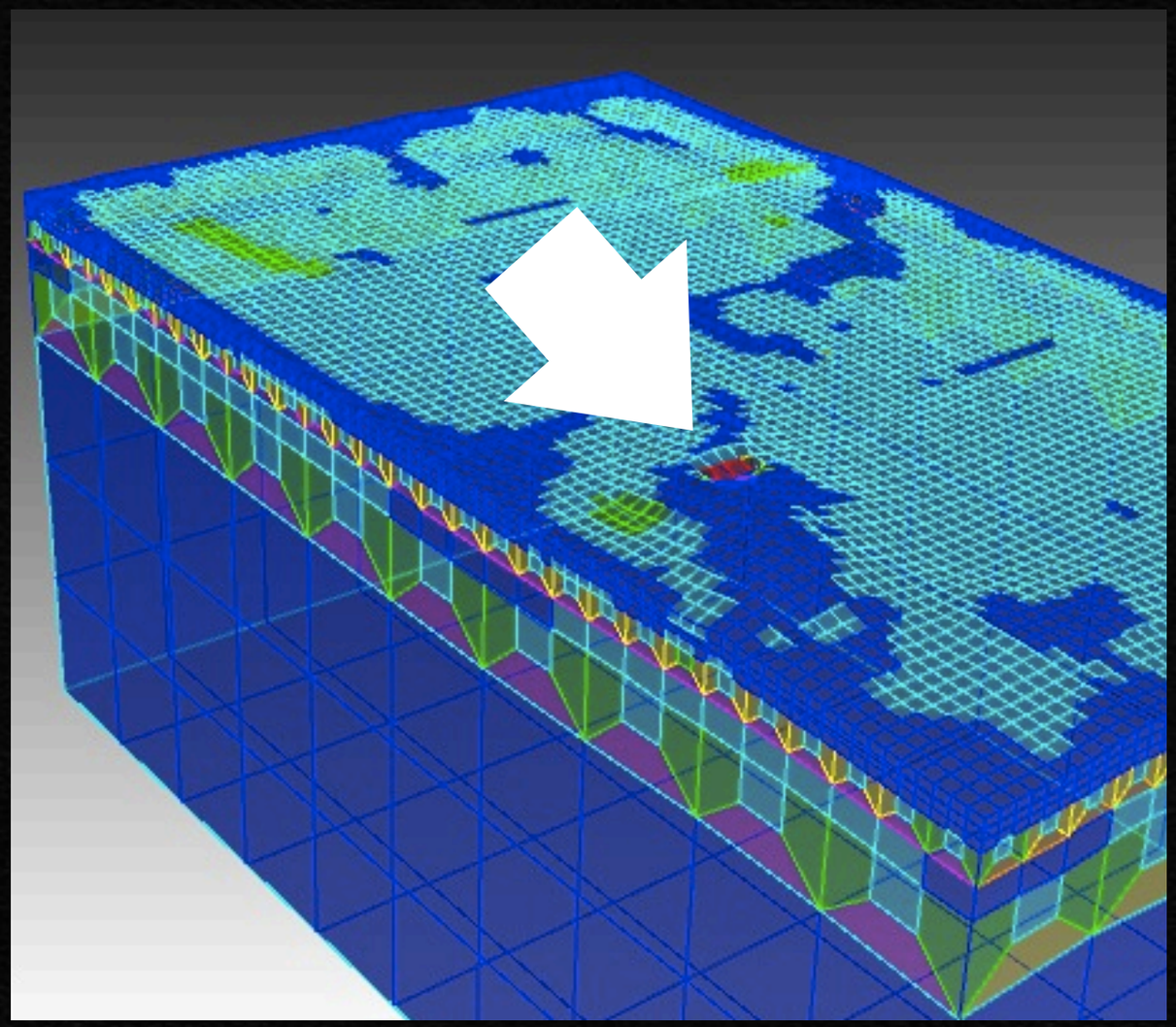
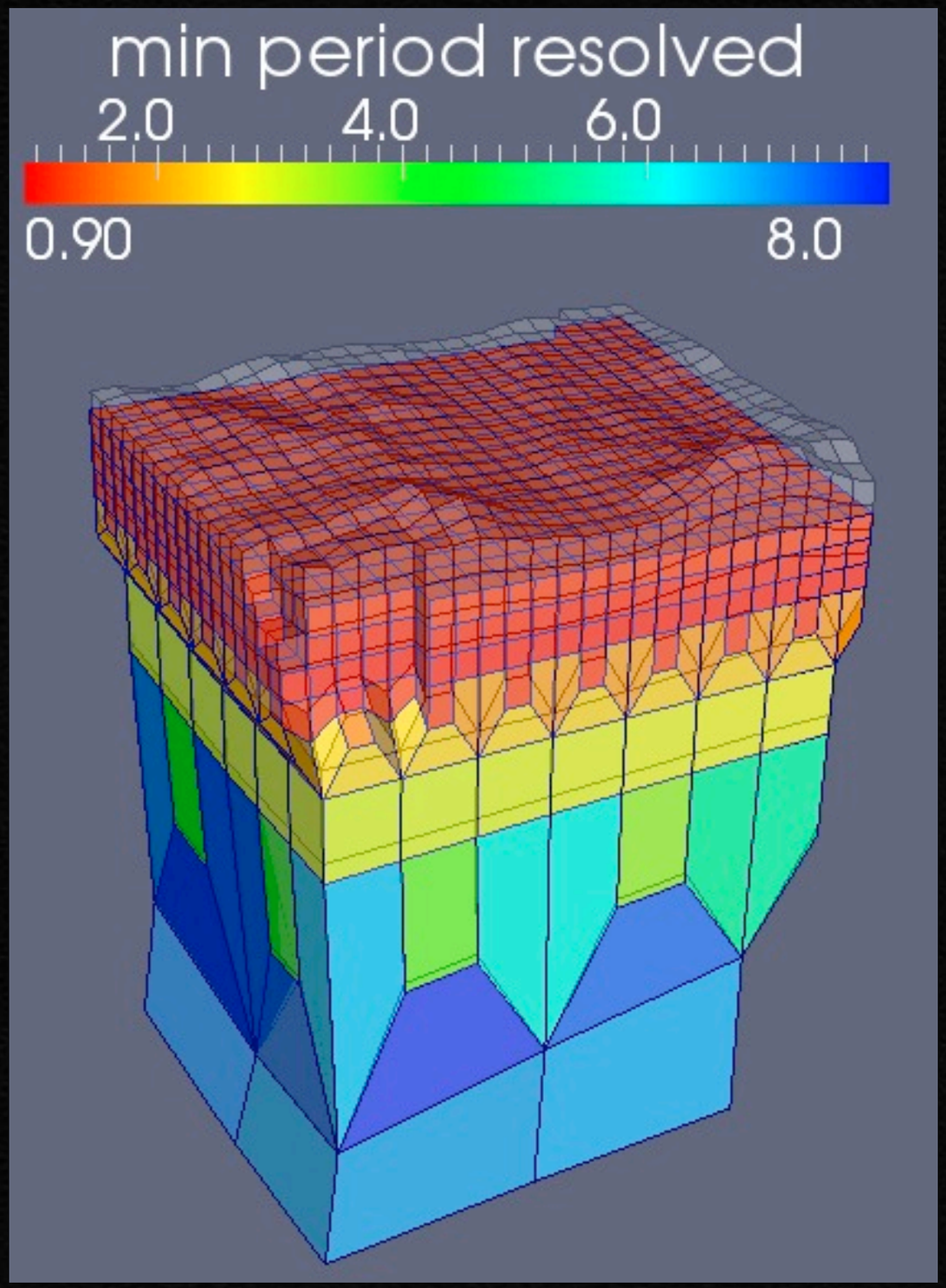
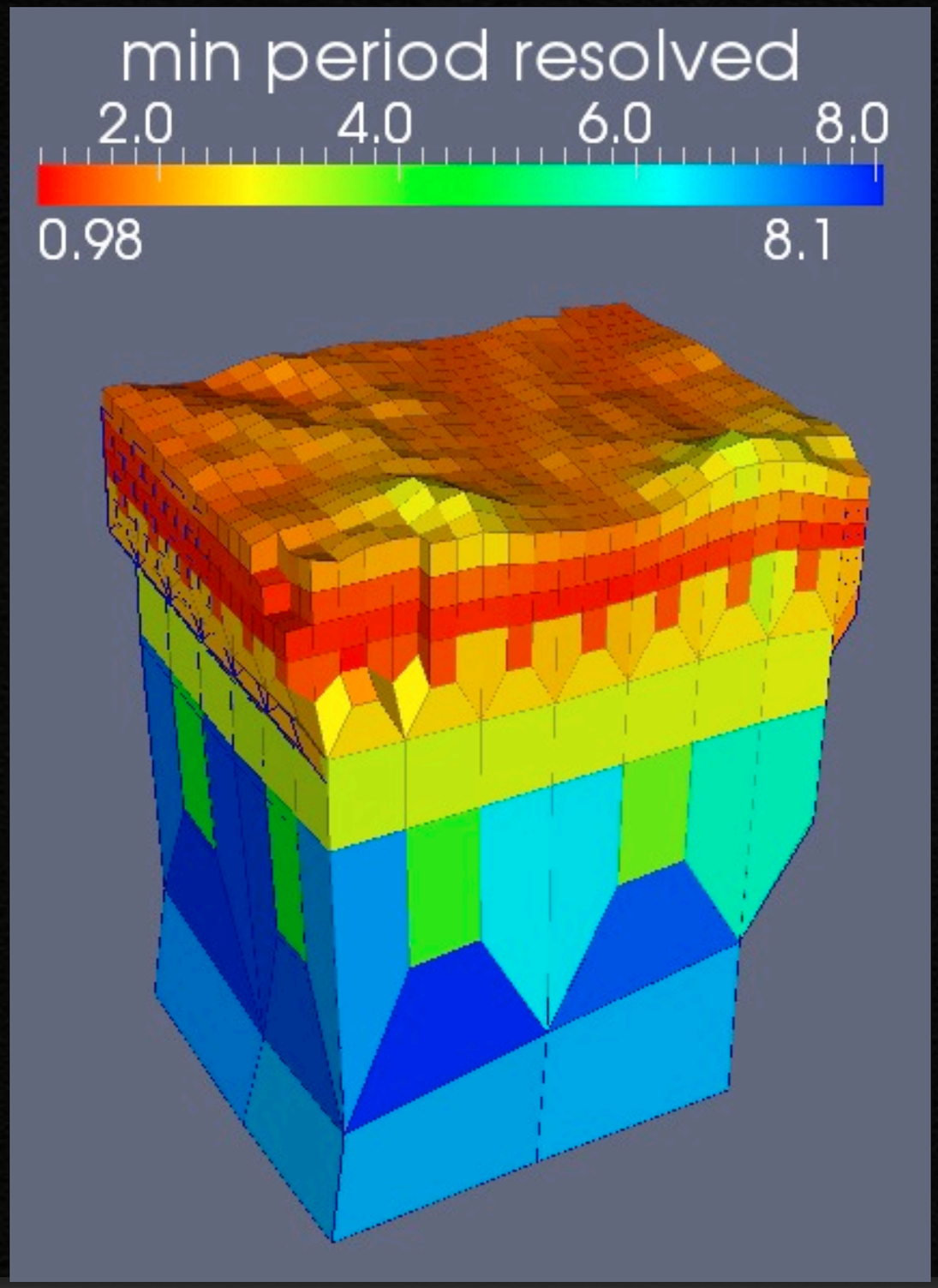
SHAKEmovie: Animazione della propagazione sulla superficie terrestre delle onde sismiche generate dal terremoto di Ml 5.2 delle ore 12.33 del 21 giugno 2013 in Lunigiana.

meshing - control Δt (S.California)



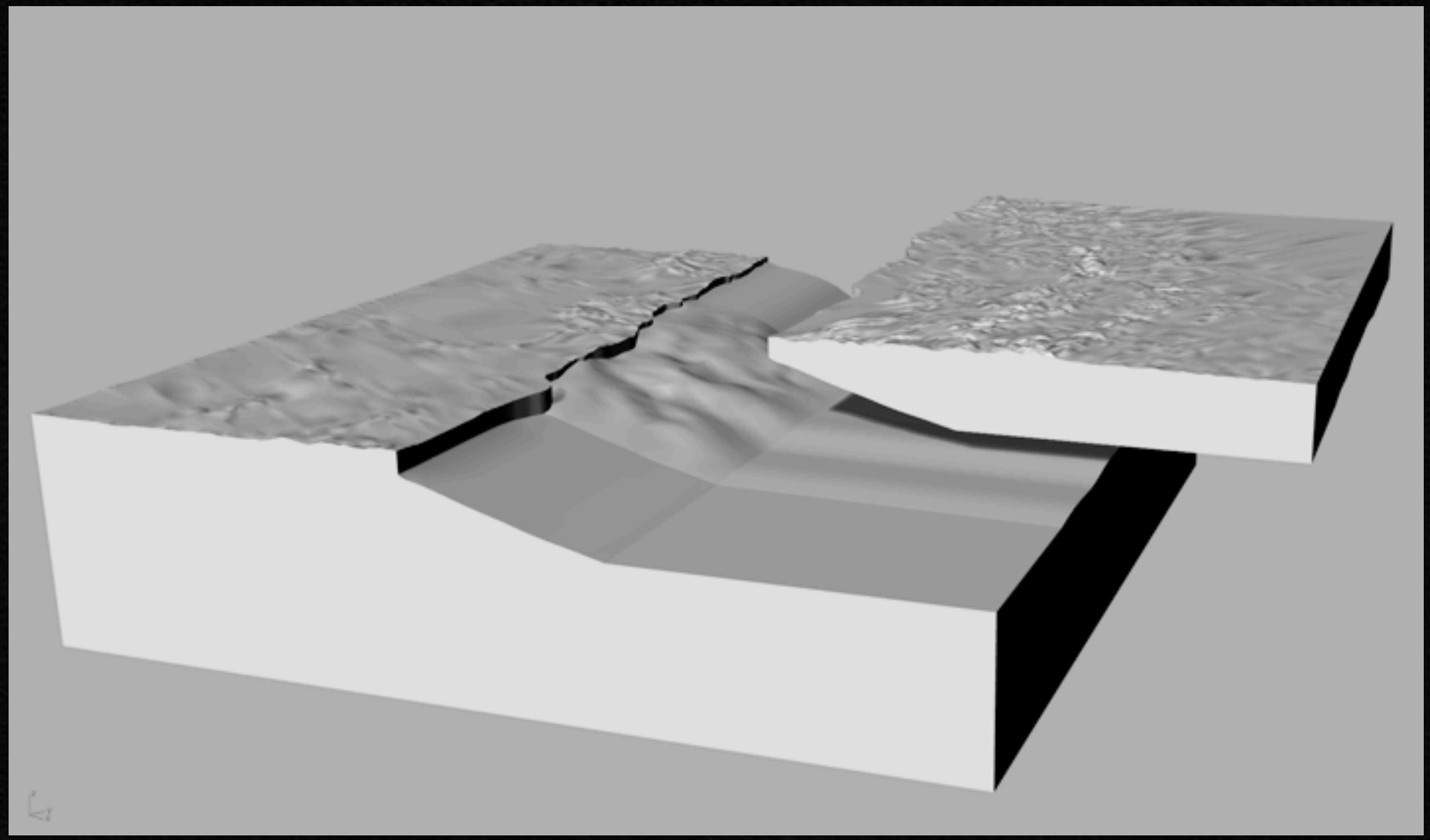
meshing - control resolution (Alaska)





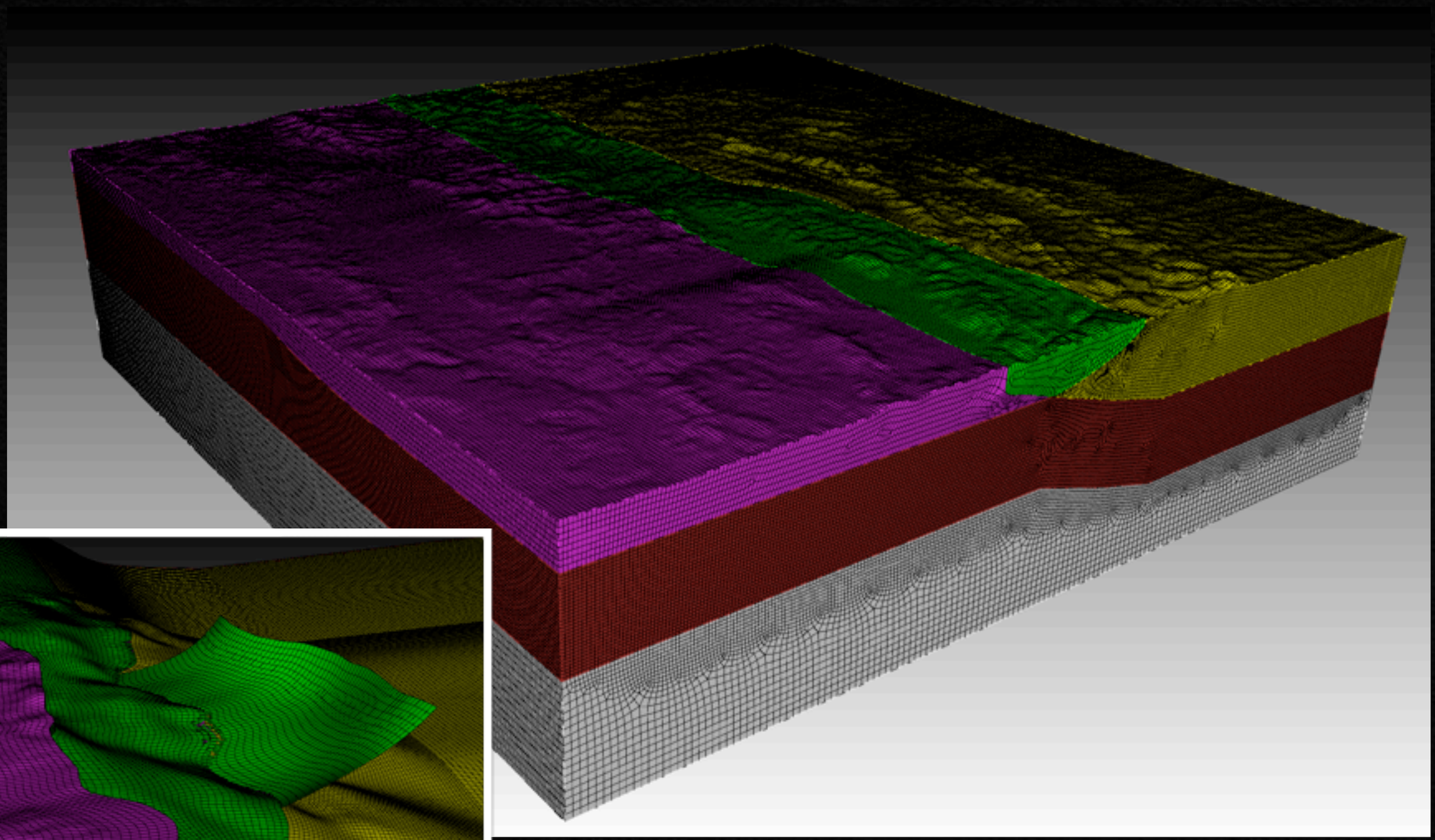
meshing - control resolution (Alaska)

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