Coupling of GeoModeller and FEFLOW:
A case study – Tunisian groundwater challenges addressed

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with

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4th European meeting on 3D geological modelling

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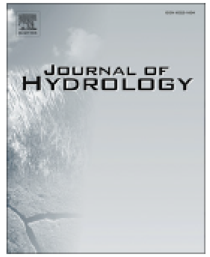

3D geological modeling of the Kasserine Aquifer System, Central Tunisia: New insights into aquifer-geometry and interconnections for a better assessment of groundwater resources

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4th European meeting on 3D geological modelling

Objective – rigorous groundwater resources assessment

GEOLOGICAL MODEL

- Consolidate and reconcile legacy data: all hydro-stratigraphic units of the KAS
- Build a verifiable 3D geological and structural model
- Honour primary geological observations

CONCEPTUAL MODEL

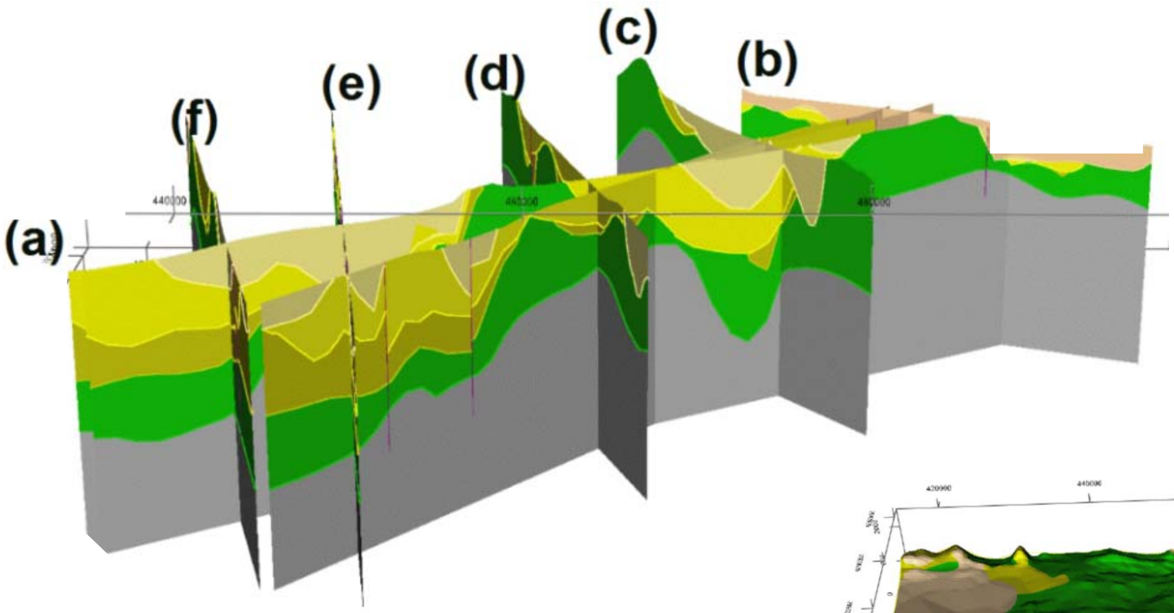
- Review characterisation of the aquifers
- View 3D locations of faults: compartments and connectivity
- Understand flow system including pathways, flow directions & springs
- Calculate aquifer volumetrics and estimate reserves

HYDROLOGICAL MODEL

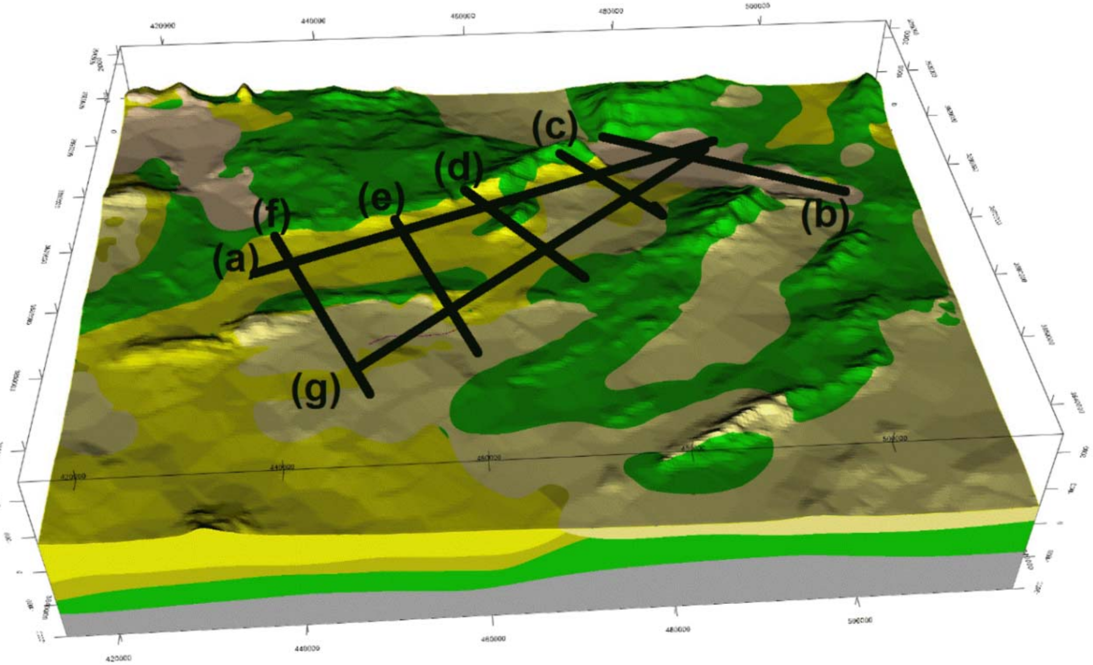
- Export the model as a fem mesh for numerical simulation in FELOW
- This final modelling phase is not presented today **in press*

Implicit 3D geological/structural model (KAS)

- Constrained on a regional scale
- Honours primary data
- Geolocated & includes the DEM
- ~100 km x ~75 km and 2 km(z)



- Plio-Quaternary
- Plio-Miocene (Upper Miocene)
- Middle Miocene sandstone
- Lower Miocene-Aquitanian
- Creteaceous Limestone
- Basement



Choice of GeoModeller software

- Can successfully model sparse geological contact observations (coupling structural data)

- Can constrain 3D geology from surface, with only shallow borehole data (or no drilling)

- Can employ a rules-based modelling approach: (a) relationships of the stratigraphic pile, and (b) chronological relationships of the fault network
  – are also employed as constraints of the model

- Needed to easily edit and re-compute for an updated model (when more data available)

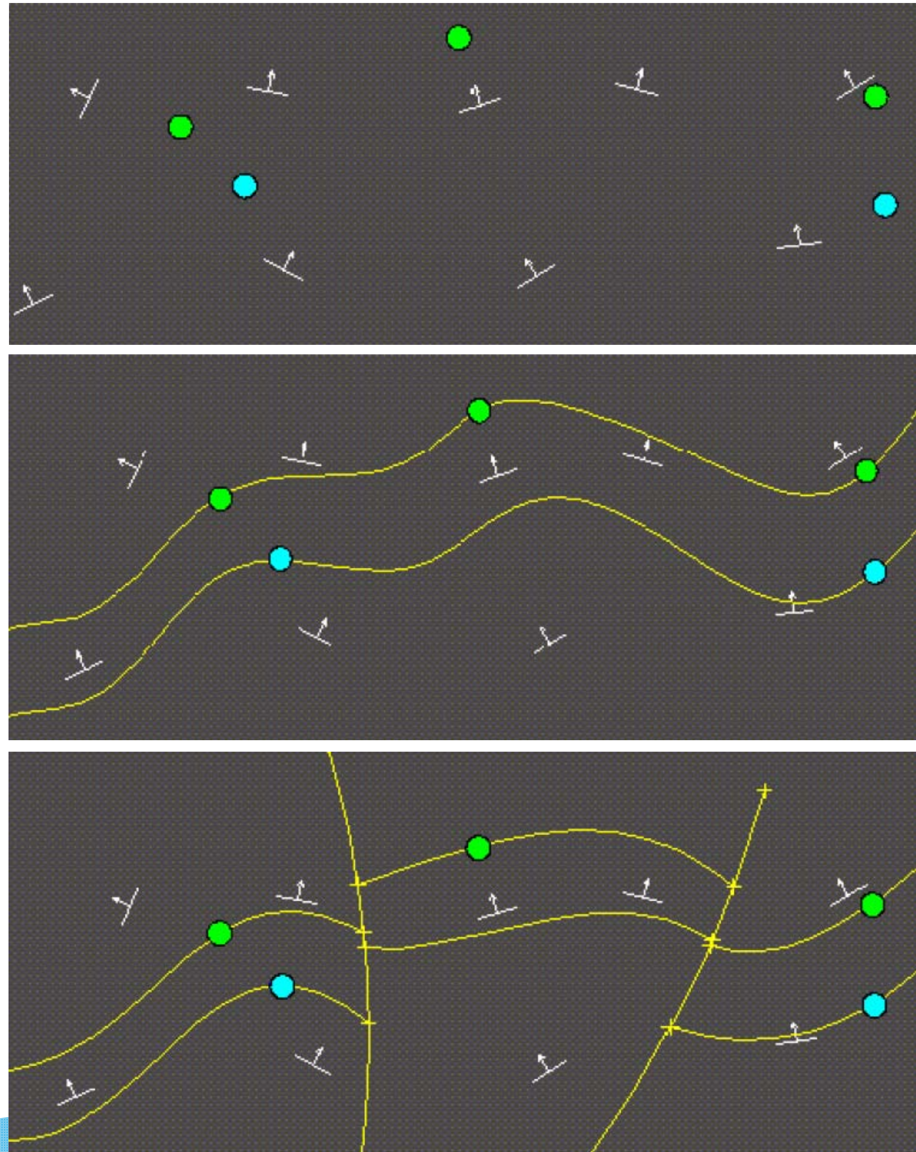
Future Considerations for the 3D model

- Needed seamless inter-operability with FEFLOW

- 2D/3D workspace to support multi-geophysics integration eg.,. add airborne EM, seismic, perform forward modelling of grav/mag direct from the 3D geology (a verification step)

GeoModeller - Potential field method of interpolation

- <u>3D implicit surfaces</u> constrained by contacts & structural data ***together***
  - "co-kriging" Lajaunie et al. 1997
  - a mathematical model
  - contacts belong to iso-potential surfaces of a 3D scalar field
  - dips are treated as gradients of the field
- 3D fault surfaces are solved same way
  (add discontinuous drift functions)



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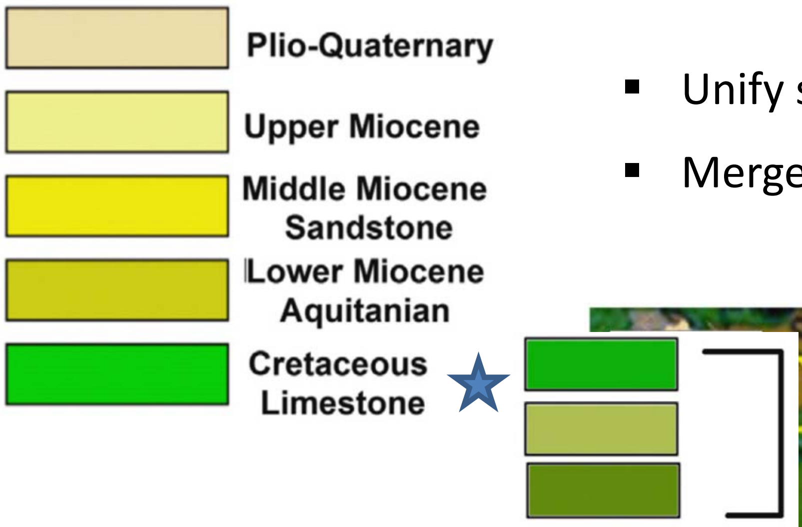
Data to build the KAS model

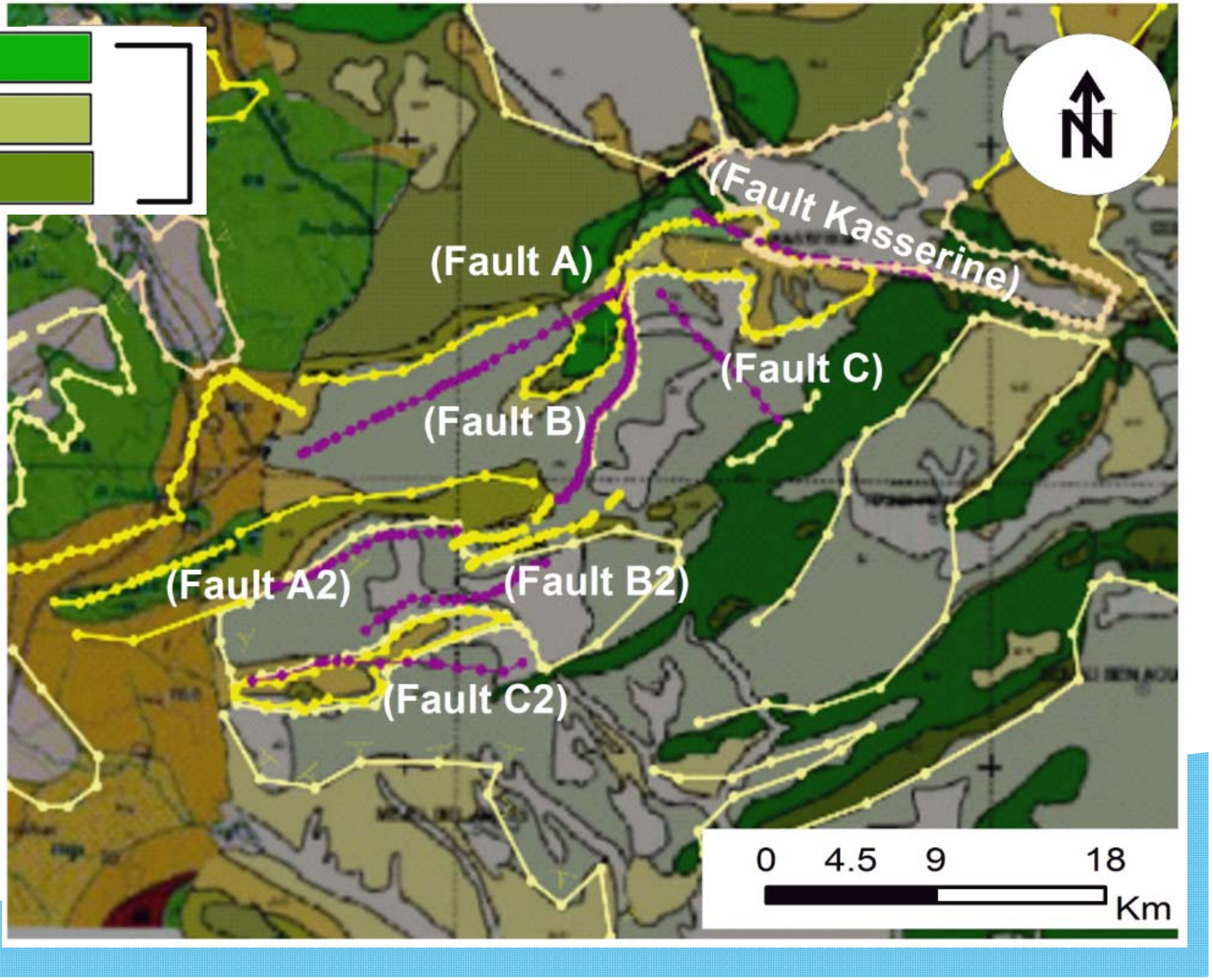
Data	Source	Note
Elevation	USGS	Digital elevation map
Geology	The National Office of Mine	Geological map of Feriana (1932) (scale 1:200000) Geological map of Tunisia (1958) (Scale 1:500000)
	Directorate of Trade, engineering and industry, Geological survey of Algeria	Geological map of Algeria (1952) (scale 1:500000)
	Khanfir	Geological map of Oum Ali-Thelepte (1980) (scale 1:200000)
	Khanfir	3 cross-sections (1980, 1983)
Well logs	General Management of Water Resources (DGRE) Regional Commission of Agricultural Development of Kasserine (CRDA) Tunisian National Oil Company (ETAP)	173 bores (47 used in the model)

Steps to build the KAS model



- Unify stratigraphic classification region-wide
- Merge some, but keep important hydro-stratigraphic units

- Geo-locate map images in the 3D workspace
- Digitize geological boundaries (contact points)
- Add dip/dip-direction data



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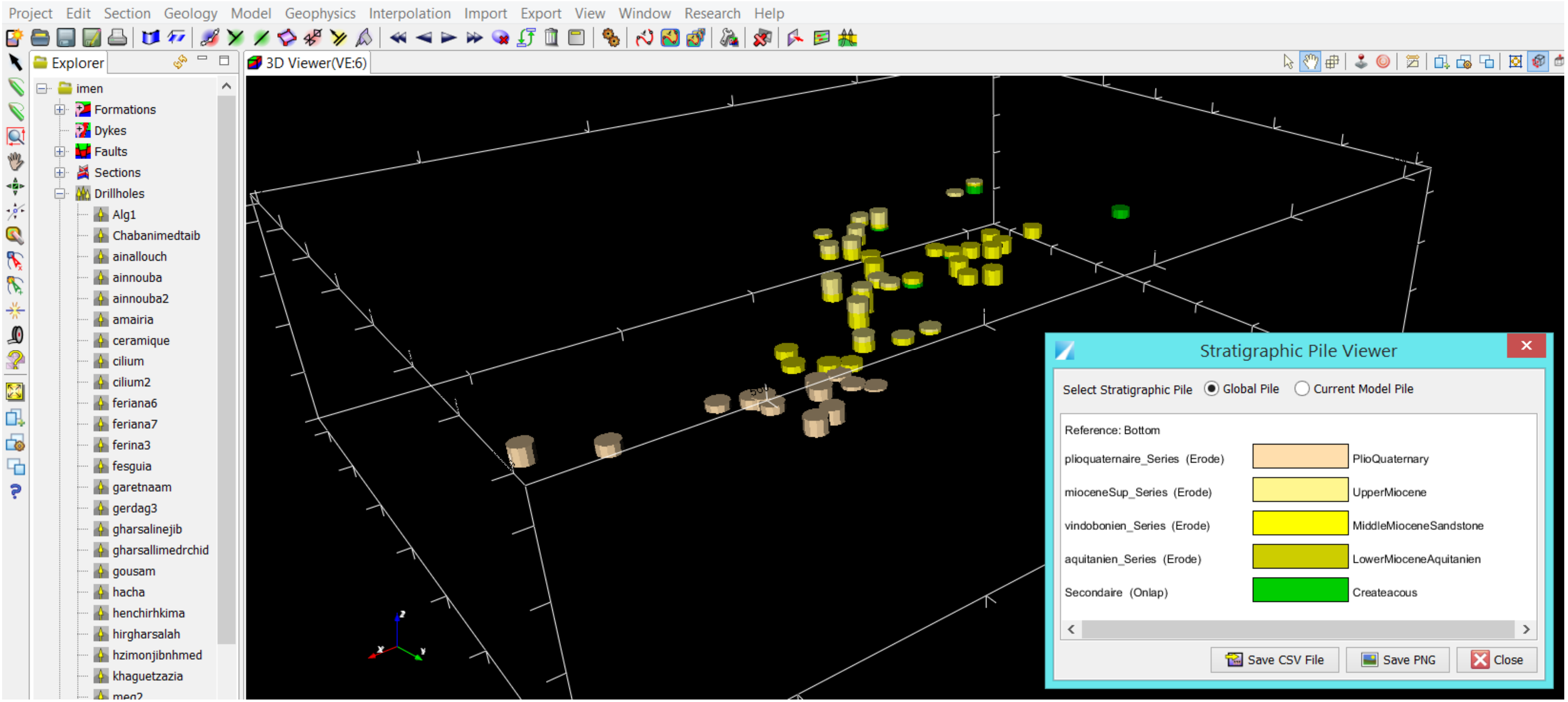
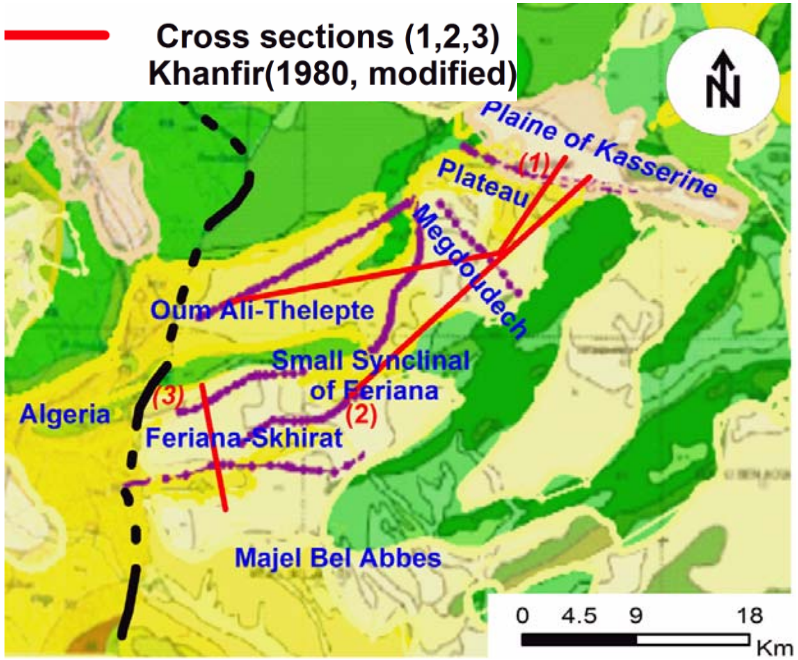
Steps to build the KAS model

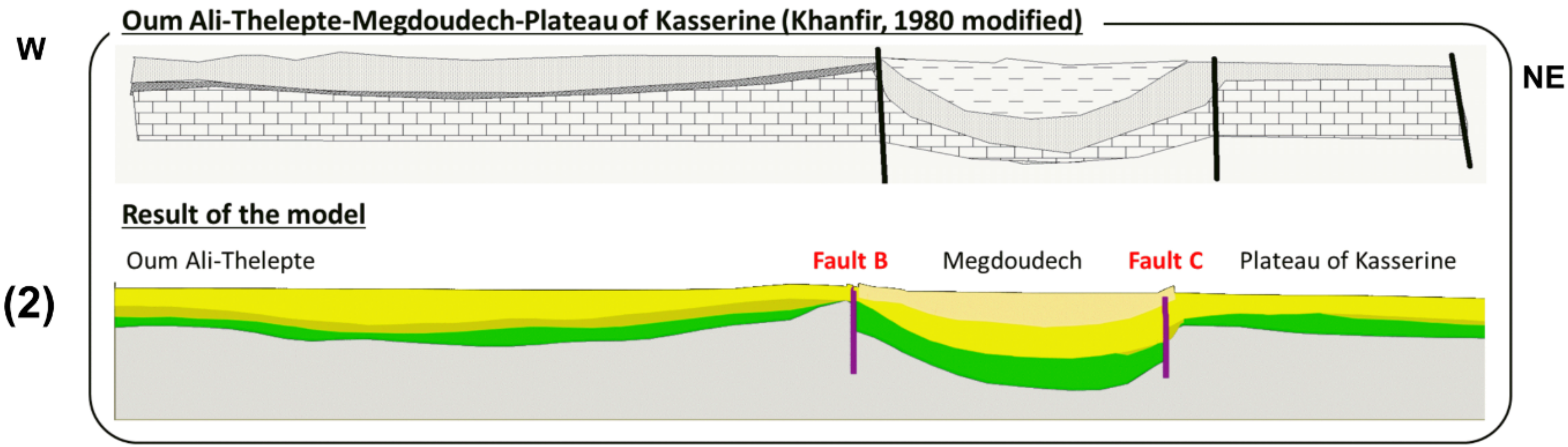
- Load most representative, deepest bores (only 47 of 173)
- Deepest is 500 m





Steps to build the KAS model

- Geo-locate interpreted cross-section
- Digitise the contacts and dips
- Compute & render the 3D model to 2D – check the fit



Review characterisation of the aquifers

From previous literature:

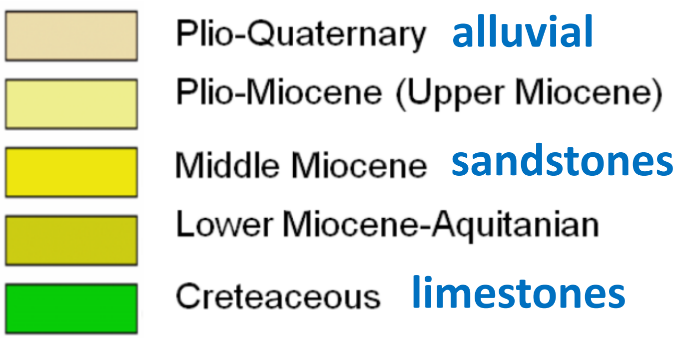
KAS comprises 5 hydrogeological units:
3 main aquifers, 2 interlayered aquitards

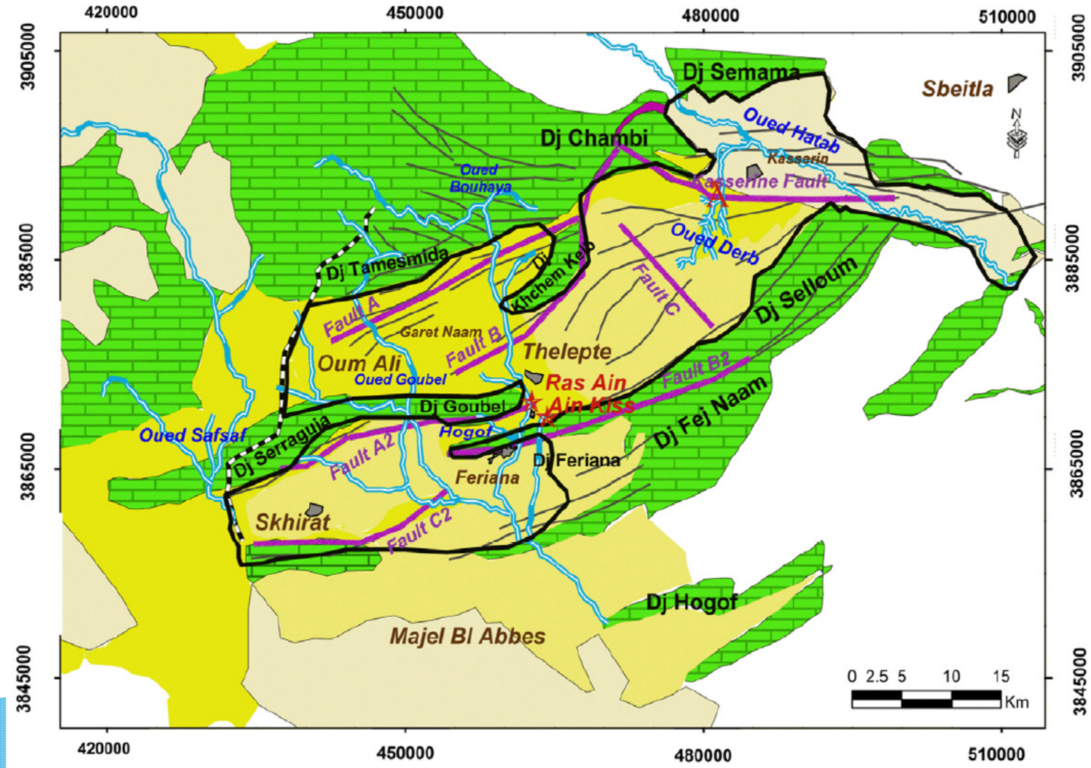
Surficial exposure:

Up-gradient aquifer system (west) = comprises mid-Miocene sandstones (10-300 m), is **unconfined**

Down-gradient system (central-east) = comprises Mio-Pliocene marls >400 m thick, hence the MM aquifer is **confined** here

Plio-Quaternary	Aquifer
Mio-Pliocene	Aquitard
Middle Miocene sandstone	Aquifer
Lower Miocene	Aquitard
Creteaceous (Abiod)	Aquifer
Basement	Basement





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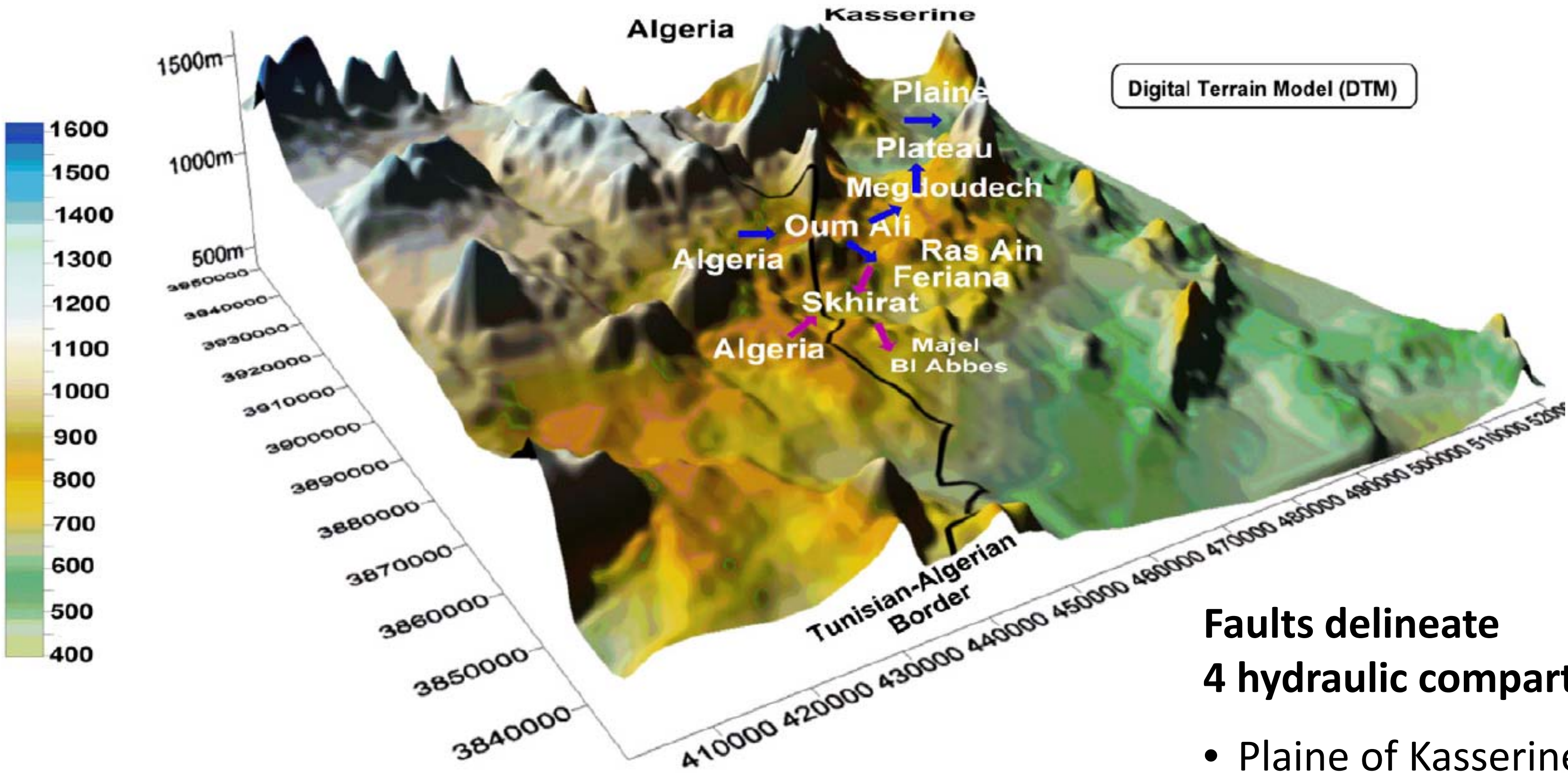
Review & revise: pathways and connectivity

KAS - Recharge occurs in the west (Algeria)

Water flow direction (Known)
Suggested water flow direction



Faults delineate
4 hydraulic compartments:

- Plaine of Kasserine
- Plateau of Kasserine
- Oum Ali-Thelepte
- Feriana-Skhirat

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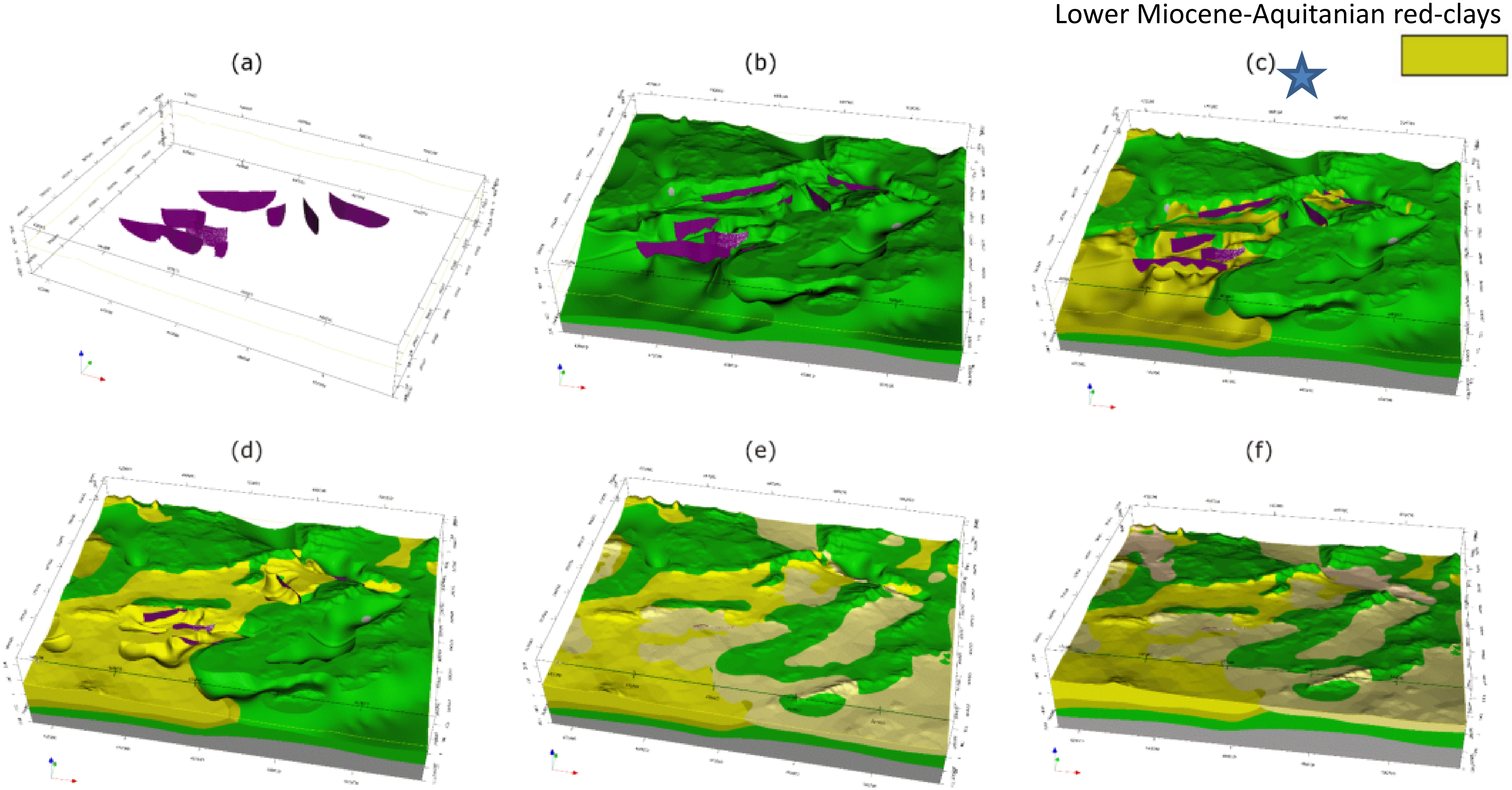
Review & revise: pathways and connectivity

- no springs in the west, where Lower Miocene aquitard (red clay) unit exists extensively

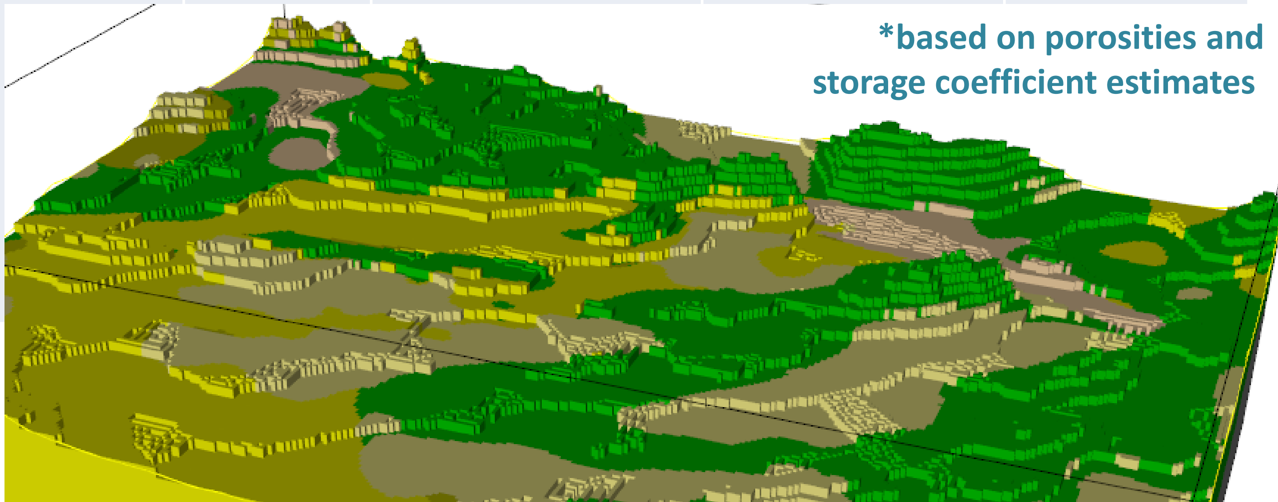
& hence the two older aquifers are proposed as *connected* east of here



Modelled metrics of the Kasserine Aquifer System

Lithology	Mapped and Modelled units		Reserve (geology volume) GeoModeller (m3)	% of the total model volume	*Resources (m3)
Alluviums,sands, sandstones, gravels, silts and sandy-clays	Plio-Quaternary	Aquifer	$7x\ 10^{10}$	2.2 %	$7x\ 10^{7}$ to $35x\ 10^{7}$
Conglomerate, clay, sandstone	Mio-Pliocene	Aquitard			
sand and sandstone with intercalated green and grey marl in the shallower sequences	Middle Miocene sandstone	Aquifer	$1x\ 10^{12}$	16 %	$11x\ 10^{9}$ to $55x\ 10^{9}$
clay, sandstone red clay with gypsum	Lower Miocene red clay	Aquitard			
Hilatus					
dolomitic limestone	Creteaceous limestones	Aquifer	$5.9x\ 10^{12}$	55 %	
thick mar, interbeddedwith thin limestone					
dolomite and claystone					
dolomite and claystone					
thin clay and marl interbedded with limestone and dolomite					

*based on porosities and storage coefficient estimates



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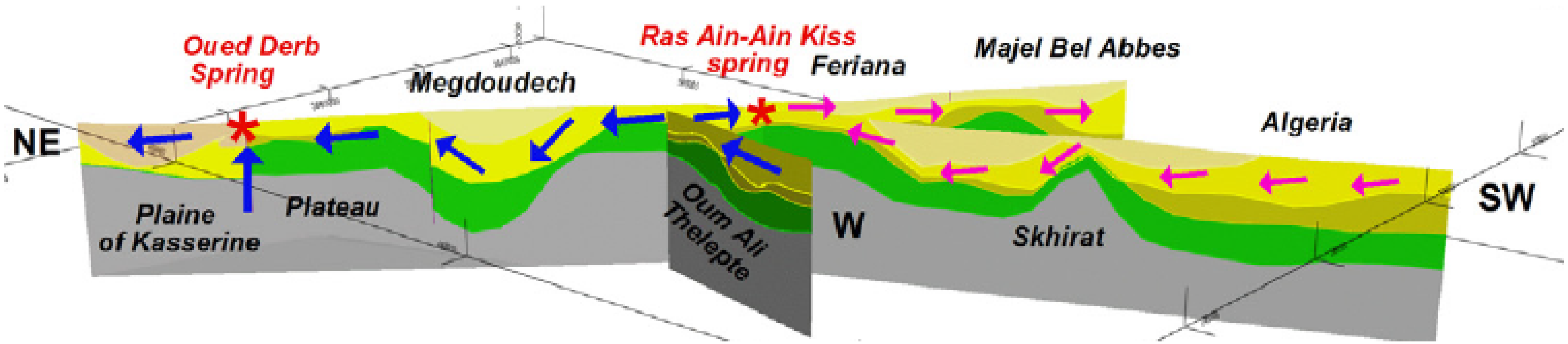
Further possible new findings:

Dual nature of faults - acting both as barriers to horizontal groundwater flow, and simultaneously as conduits for vertical flow

Two flow directions may occur within the KAS, at a small syncline near Feriana



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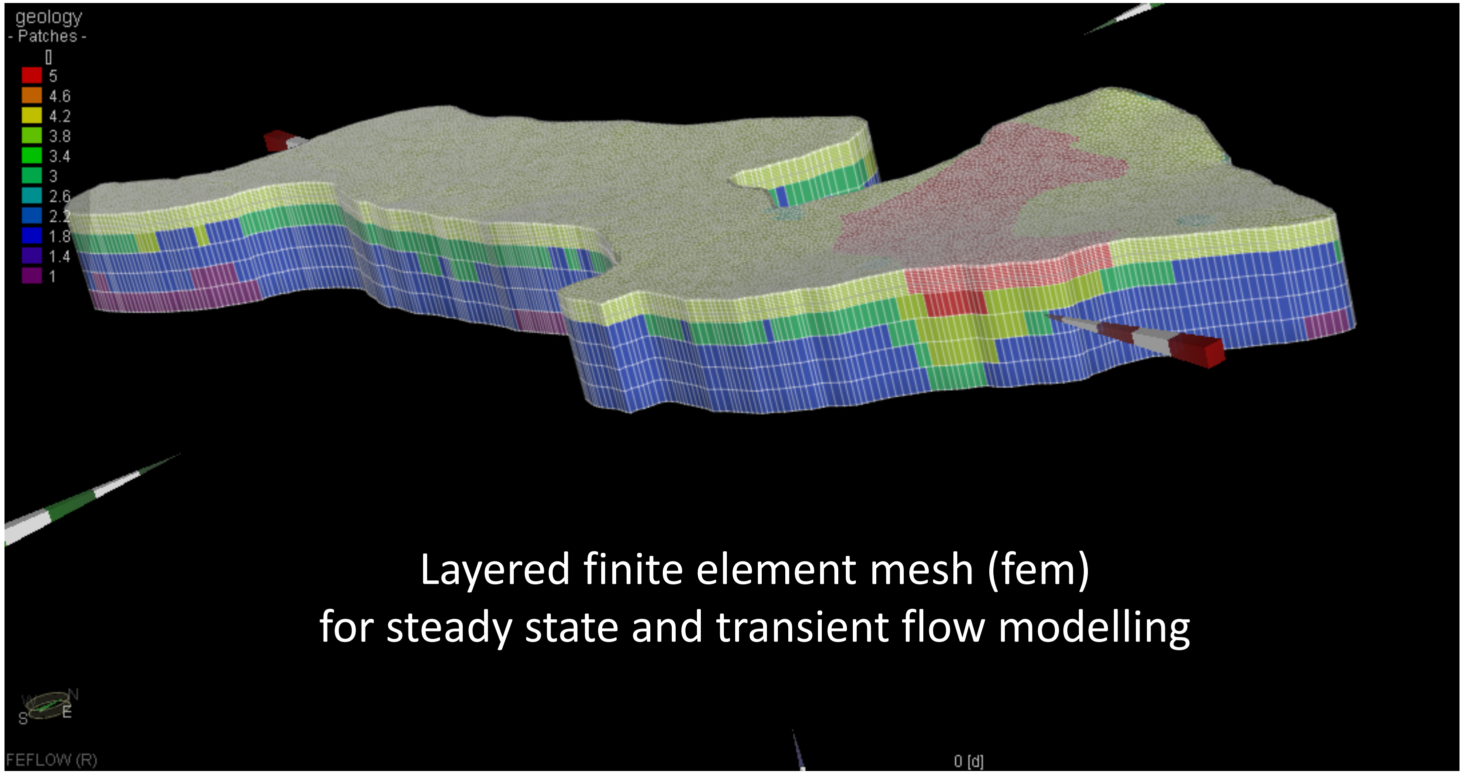
The KAS hydrological model – in 2017

Coupling GeoModeller and FEFLOW

Used GeoModeller's "Fill centroids" menu

- Add geology-identity to each element, of a pre-created mesh

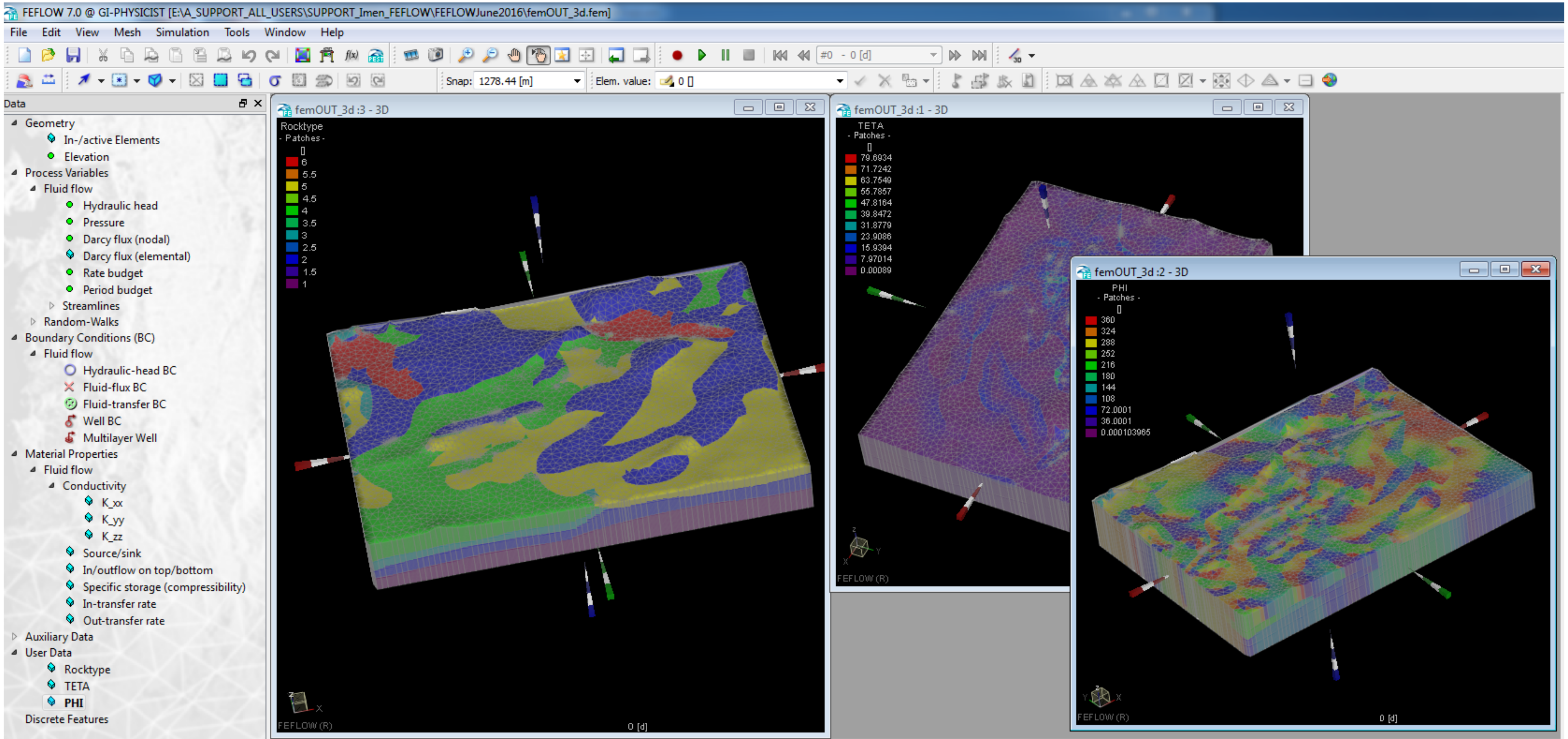


New possibilities ! GeoModeller v4

GeoModeller direct export:

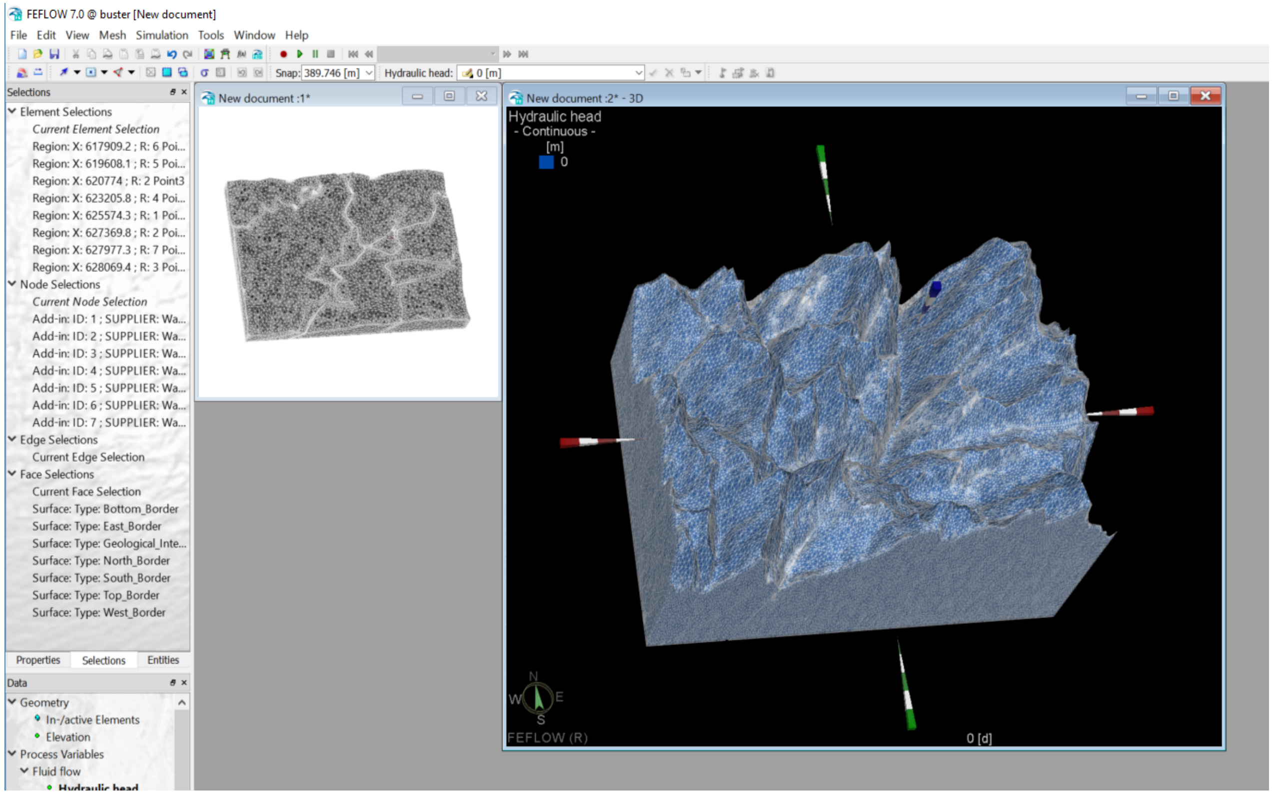
3-way attributed, adaptive, layered finite element meshes

1) Rock type
2) Dip & Azimuth – of the bedding orientation (contributing to anisotropic flow information)



New possibilities ! GeoModeller v4

GeoModeller direct export:
Fully unstructured finite element meshes
Supported by CGAL libraries for tetrahedral & triangulated meshing



- user-controls for adaptive mesh (coarse or fine per geology unit)
- Water tight & manifold
- thin bodies, pinch outs, dipping faults, limited faults

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Acknowledgements
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Imen Hassen
Fadoua Hamzaoui-Azaza
François Negro
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