Accurate groundwater flow modelling closely linked to constrained 3D geology: A case study from Tunisia

Imen Hassen[1]

with

Helen Gibson[2]

Fadoua Hamzaoui-Azaza

François Negro

Khanfir Rachid and Rachida Bouhlila

1 Laboratory of Modeling in Hydraulics and Environment (LMHE), National Engineering School of Tunis, University of Tunis El Manar, Tunisia

2 Intrepid Geophysics, Brighton, Victoria 3186, Australia

INTREPID GEOPHYSICS

Journal of Hydrology 539 (2016) 223–236

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

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

Imen Hassen [a,*], Helen Gibson [b], Fadoua Hamzaoui-Azaza [c], François Negro [d], Khanfir Rachid [e], Rachida Bouhlila [a]

[a] *Laboratory of Modeling in Hydraulics and Environment (LMHE), National Engineering School of Tunis, University of Tunis El Manar, BP 37, Belvedere, 1002 Tunis, Tunisia*
[b] *Intrepid Geophysics, Suite 110, 3 Male Street, Brighton, Victoria 3186, Australia*
[c] *Research Unit of Geochemistry and Environmental Geology, Department of Geology, Faculty of Mathematical, Physical and Natural Sciences, University of Tunis El Manar, Tunis, Tunisia*
[d] *CHYN (Centre of Hydrogeology and Geothermics), Neuchâtel University, Rue Emile Argand 11, CH-2000 Neuchâtel, Switzerland*
[e] *General Directorate of Water Resources, 43 Mannoubia Street, 1008 Tunis, Tunisia*

INTREPID GEOPHYSICS

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
- Include the fault systems

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

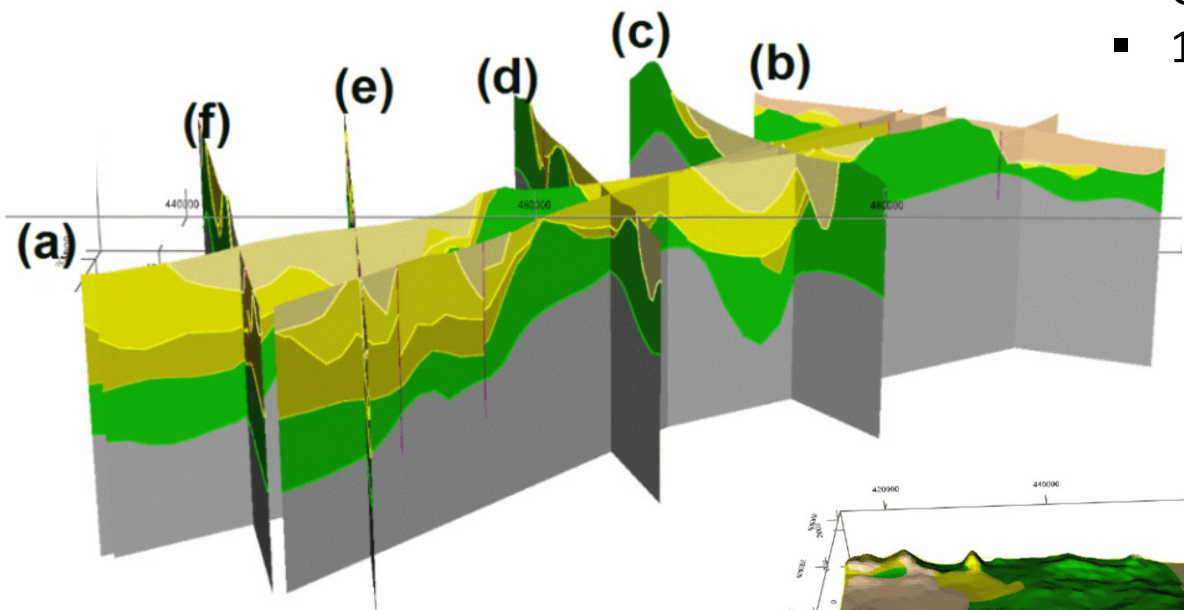
- Export the model as a fem mesh for numerical simulation in FELOW
- (This final modelling phase is not presented today)

INTREPID GEOPHYSICS

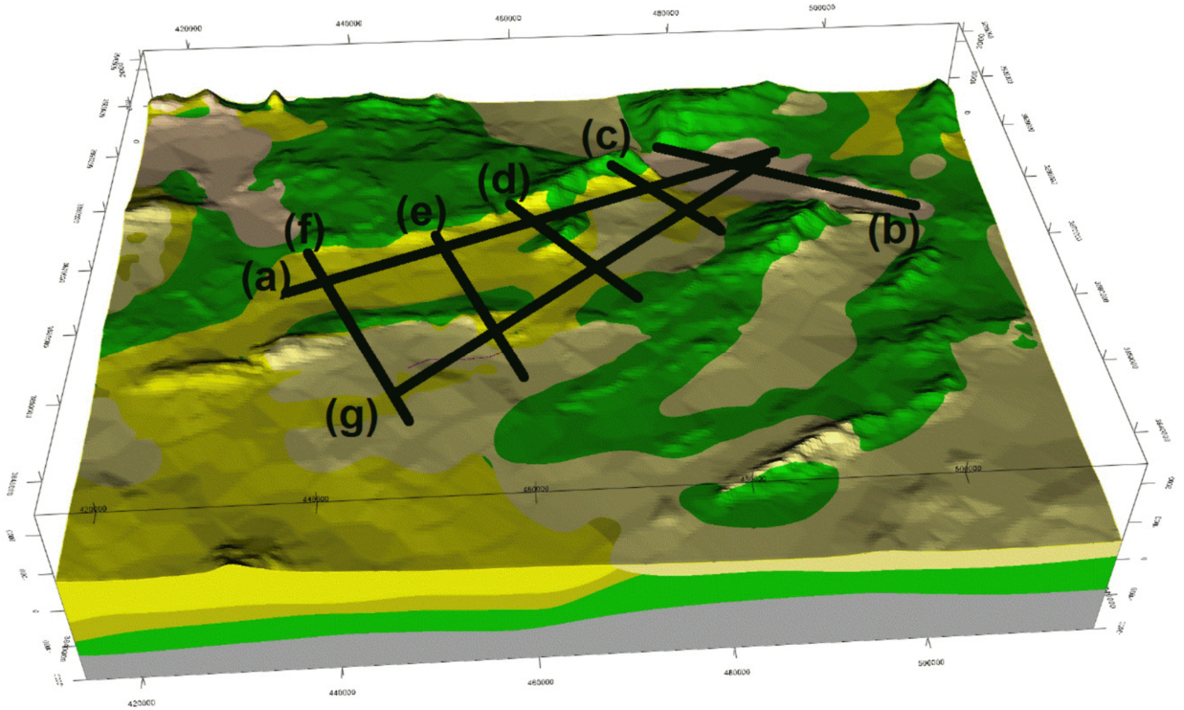
Implicit 3D geological/structural model (KAS)

- constrained on a regional scale, honoring primary data

- Geolocated & includes the DEM
- 102 km x 76 km and 2 km(z)



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



INTREPID GEOPHYSICS

Choice of GeoModeller software

- Needed to model sparse geological observations (need to couple structural data constraints)

- to constrain 3D geology with only shallow borehole data (or no drilling at all)

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

- Apply a rules-based modelling approach: (1) relationships of the stratigraphic pile, and (2) chronological relationships of the fault network
  – are both employed as constraints of the model

Future considerations (know these before you begin!):

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

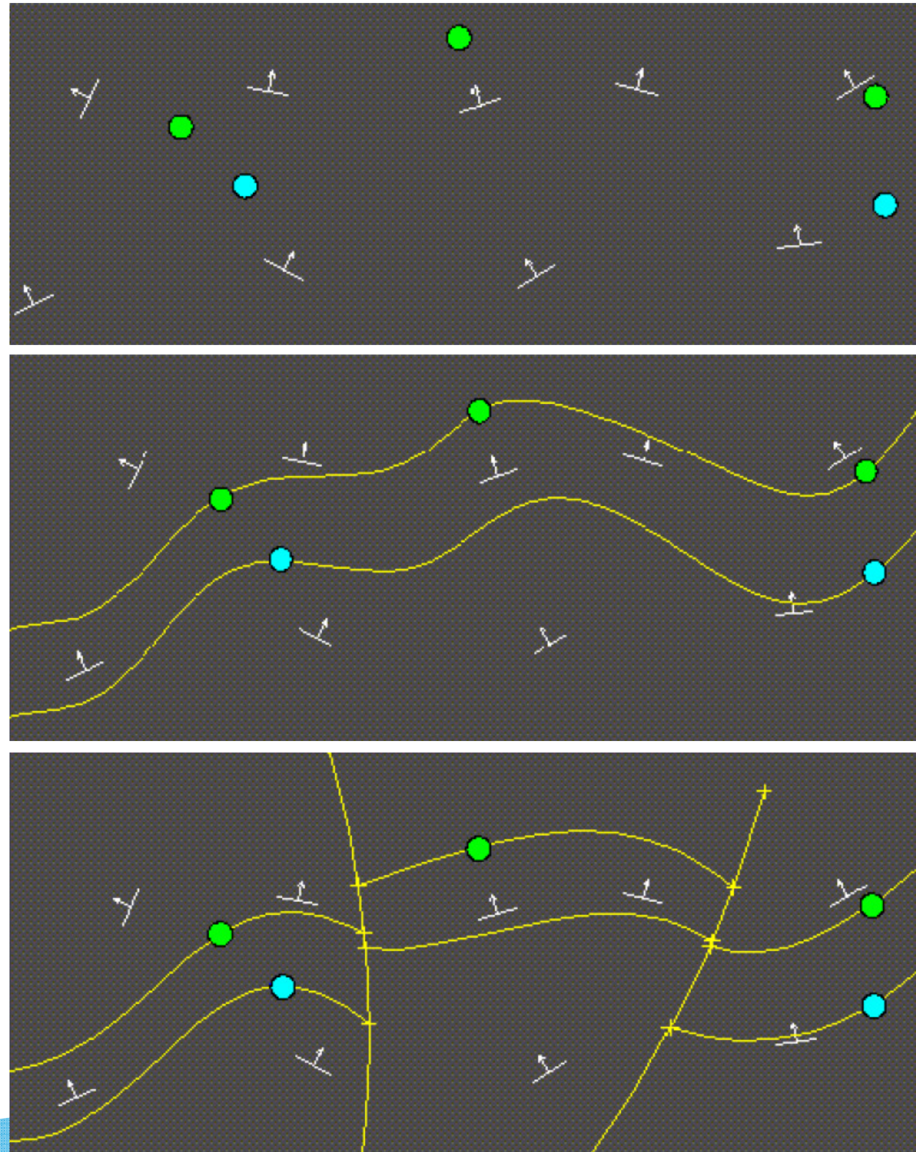
-needed seamless inter-operability with FEFLOW

GeoModeller - Potential field method of interpolation

- 3D implicit surfaces 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 built same way
  (add discontinuous drift functions)



INTREPID GEOPHYSICS

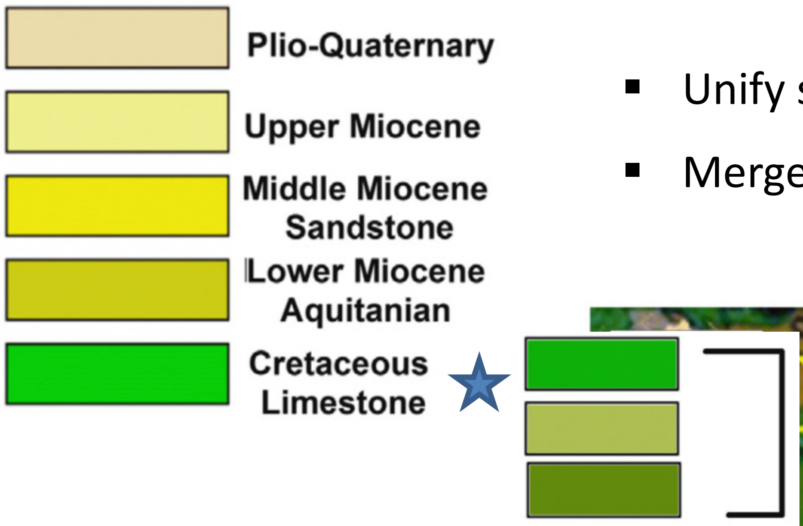
Data	Source	Note
Elevation	USGS	Digital elevation map
Geology	The National Office of Mine Directorate of Trade, engineering and industry, Geological survey of Algeria Khanfir	Geological map of Feriana (1932) (scale 1:200000) Geological map of Tunisia (1958) (Scale 1:500000) Geological map of Algeria (1952) (scale 1:500000) 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)

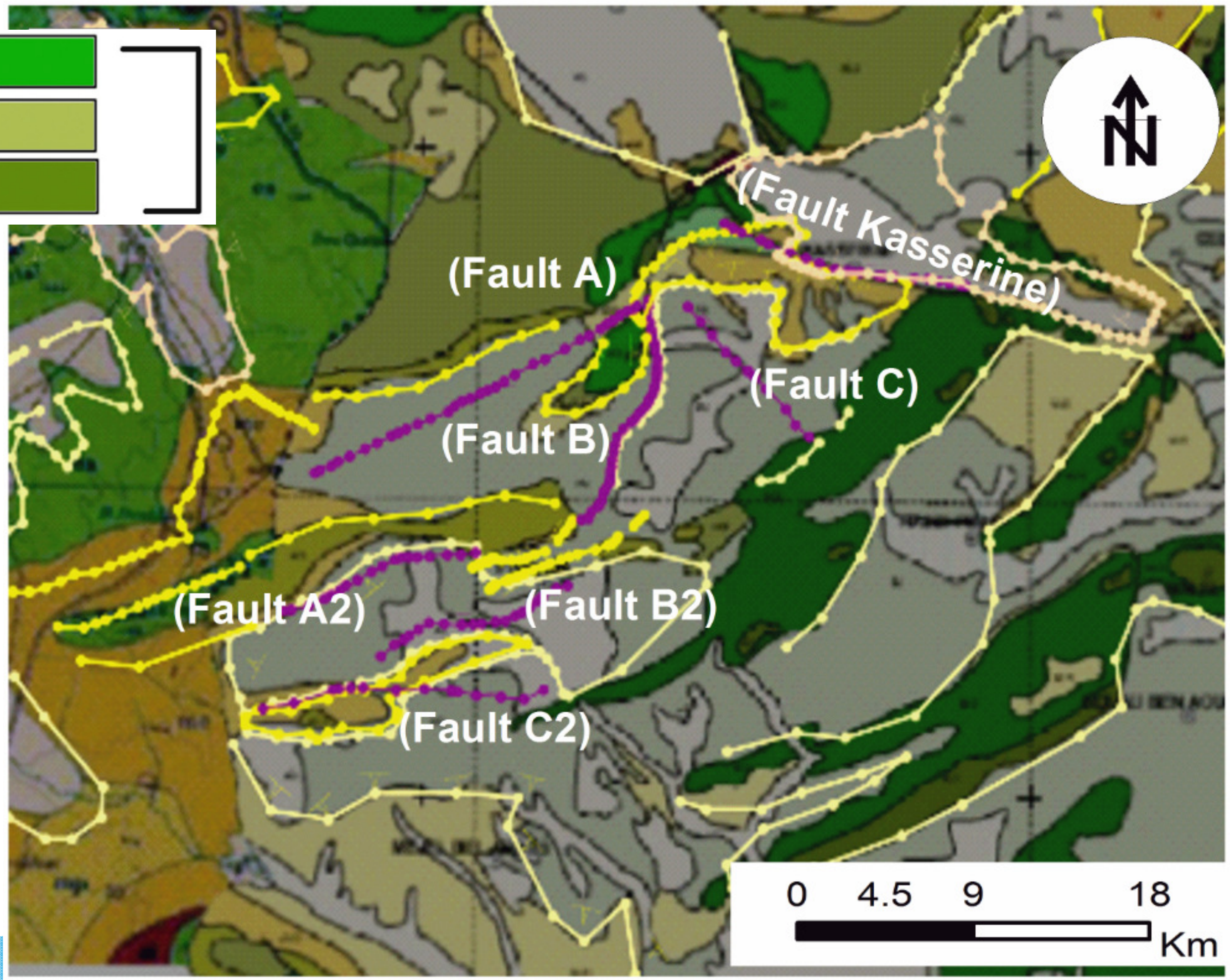
INTREPID GEOPHYSICS

Data to build the KAS model

Steps to build the KAS model

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



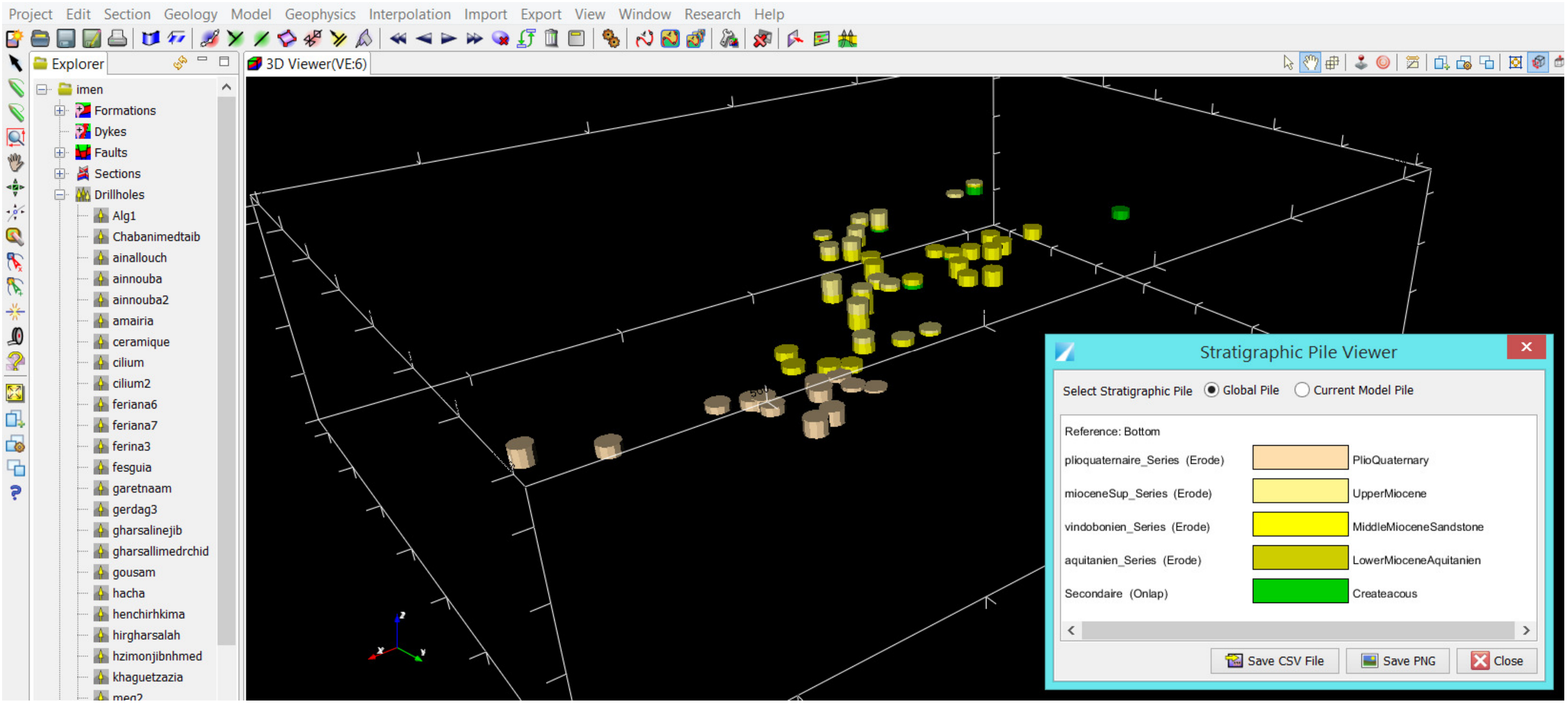


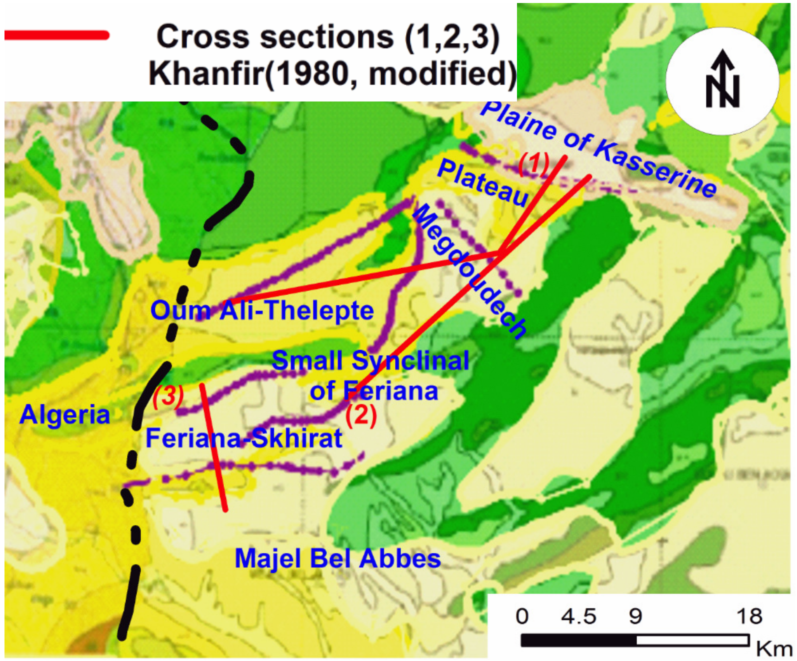
- Geo-locate map images in the 3D workspace
- Digitize geological boundaries (contact points)
- Add dip/dip-direction data

INTREPID GEOPHYSICS

Steps to build the KAS model

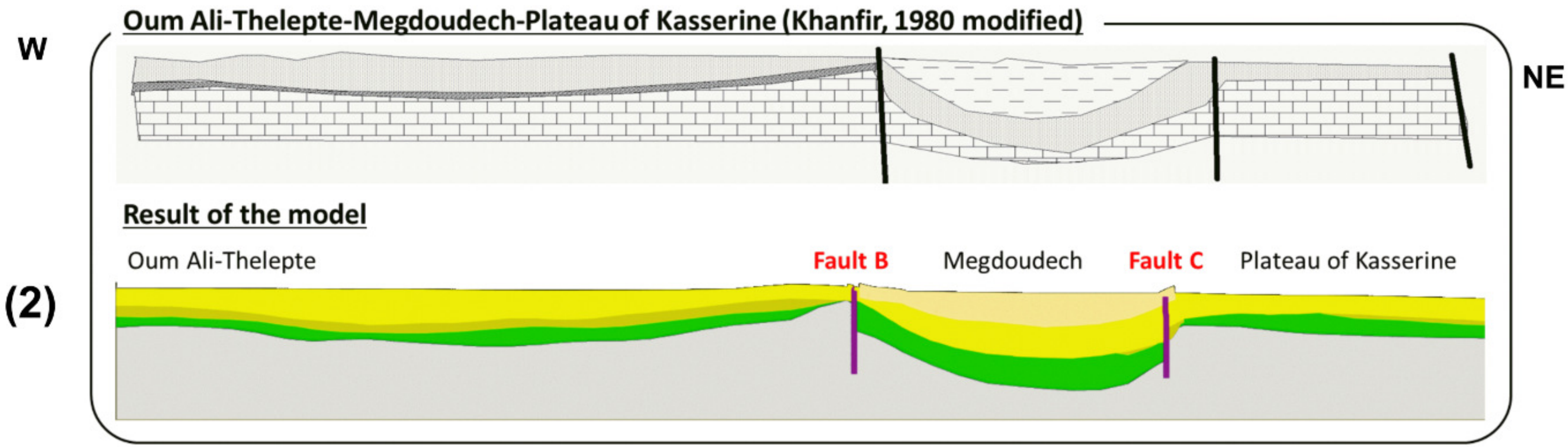
- Load most representative, deepest bores (only 47 of 173)
- Deepest is 500 m





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



INTREPID GEOPHYSICS

Review characterisation of the aquifers

From previous literature:

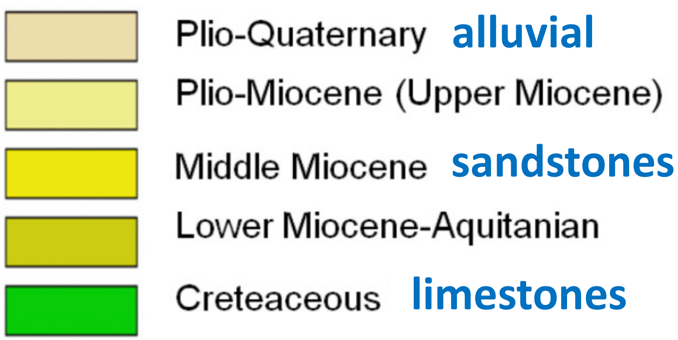
KAS multi-layered, comprising 5 hydrogeological units
3 main aquifers, 2 interlayered aquitards

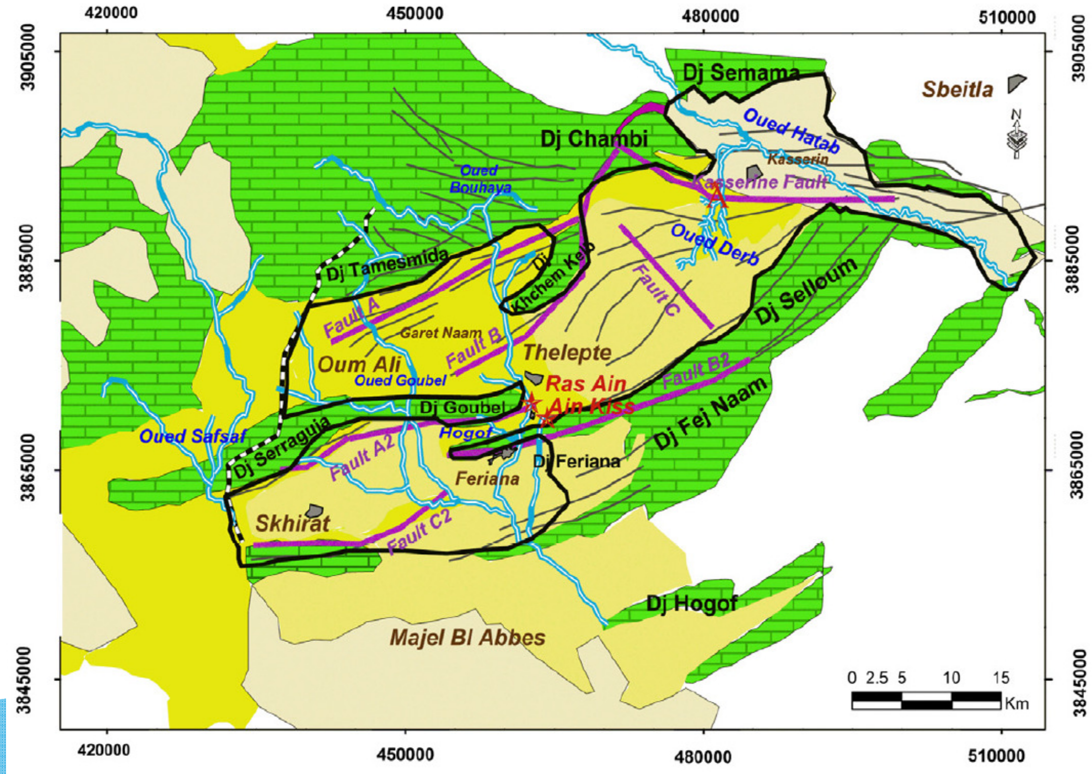
Surficial exposure:

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

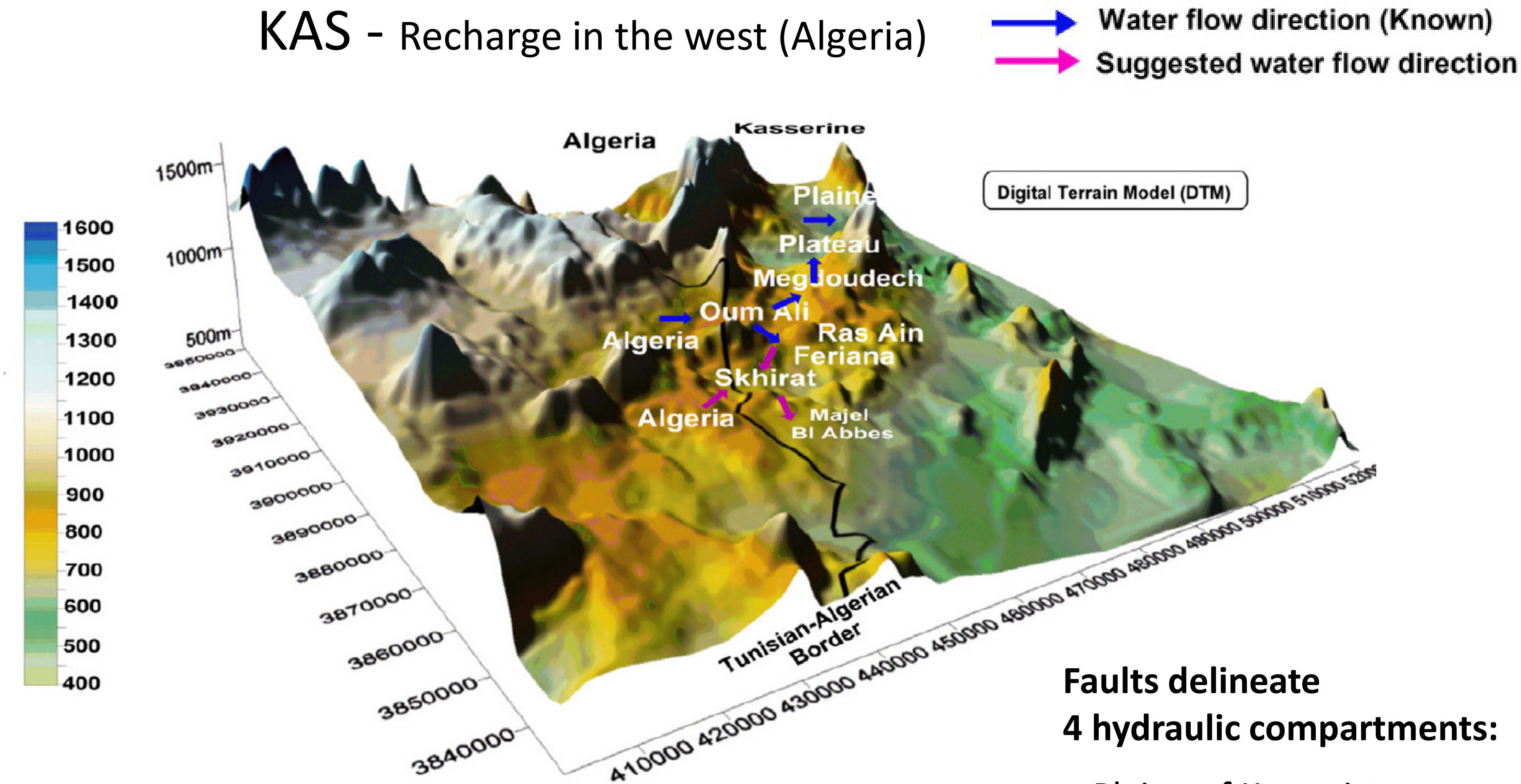




INTREPID GEOPHYSICS

Review & revise: pathways and connectivity (1)

KAS - Recharge in the west (Algeria)



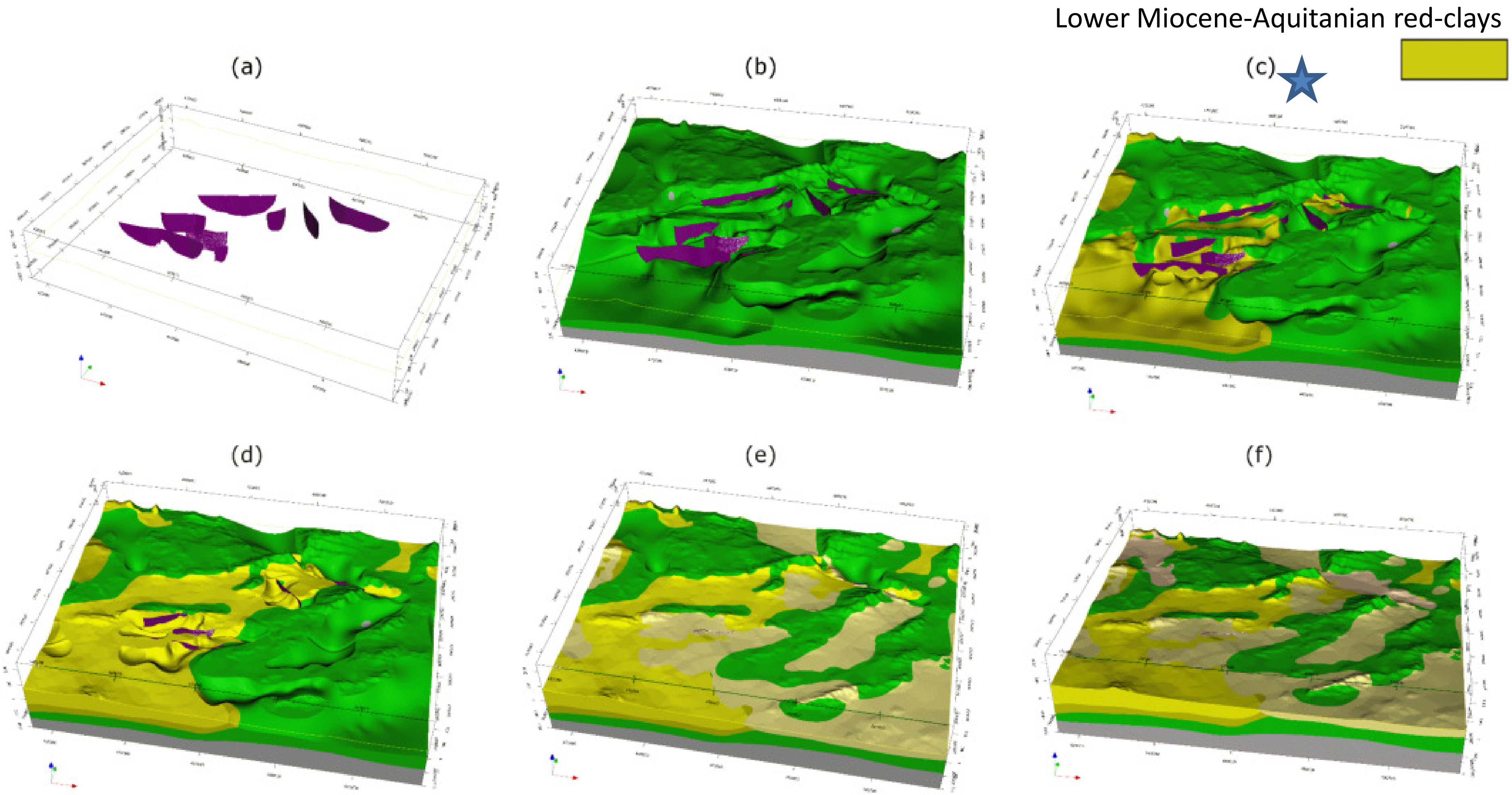
Faults delineate
4 hydraulic compartments:

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

INTREPID GEOPHYSICS

Review & revise: pathways and connectivity (1)

e.g., no springs in the west / where Lower Miocene aquitard - red clay unit exists
& 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	Lower Miocene red clay	Aquitard			
red clay with gypsum					
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					

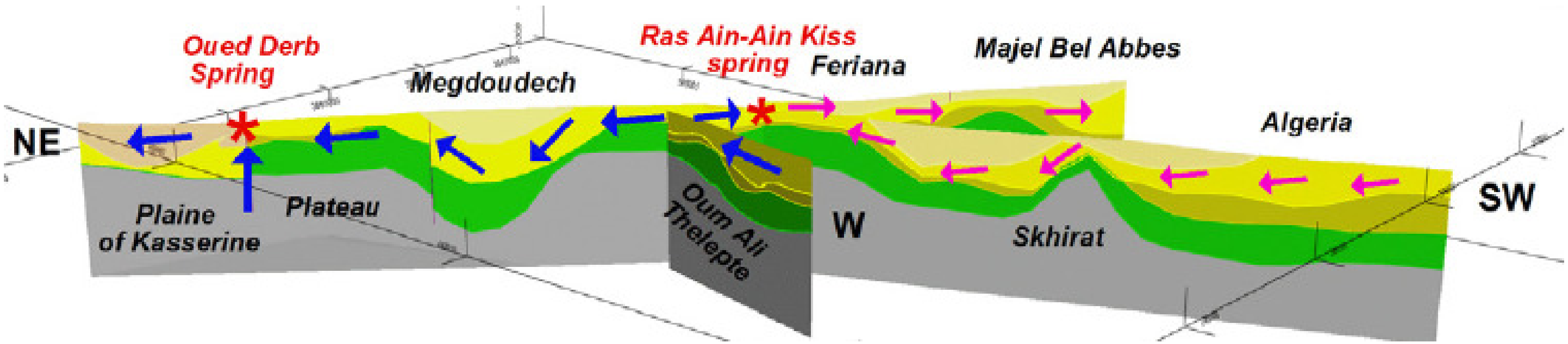
*based on porosities and storage coefficient estimates

INTREPID GEOPHYSICS

Further possible new findings:

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

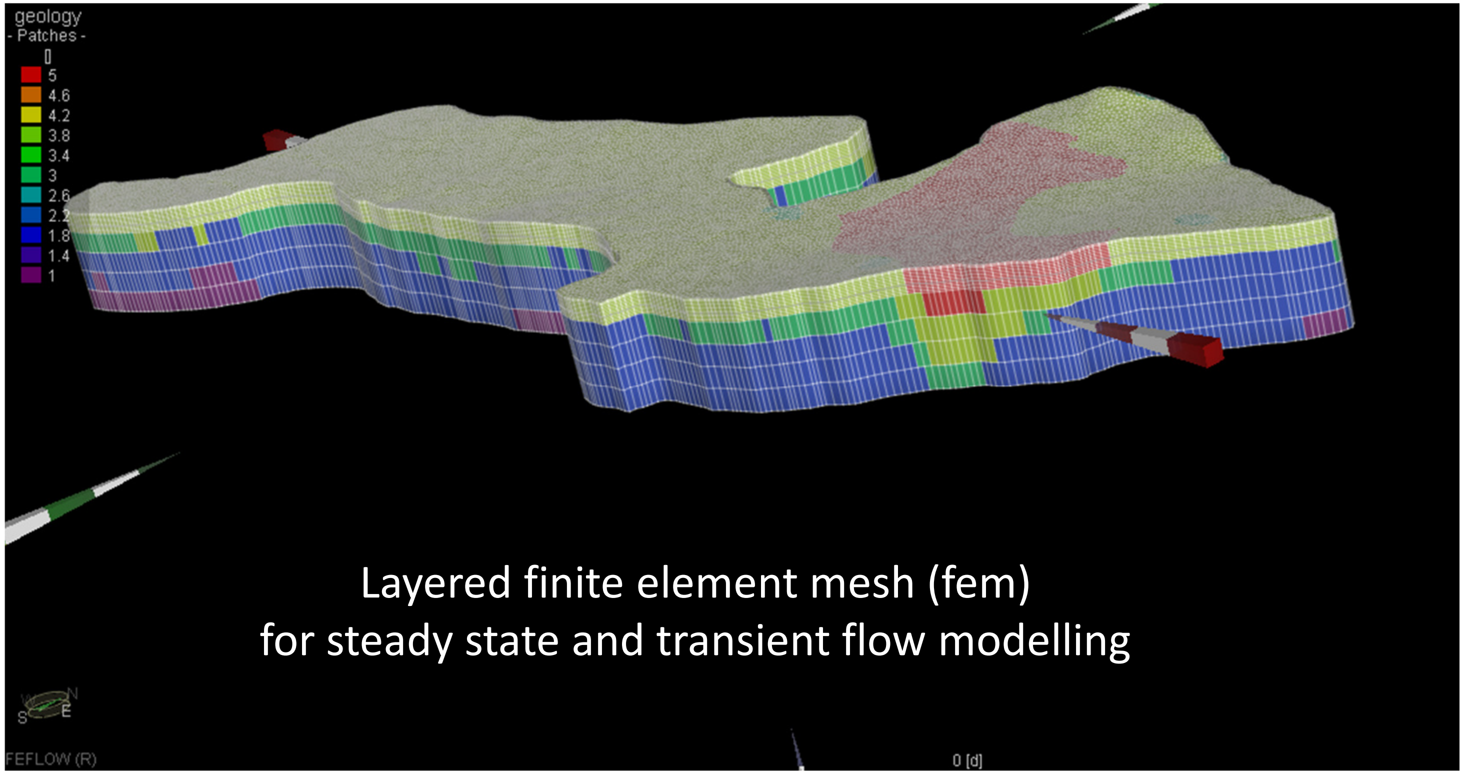
Two flow directions may occur within the KAS, at a small syncline near Feriana



INTREPID GEOPHYSICS

Coupling GeoModeller and FEFLOW

The hydrological model



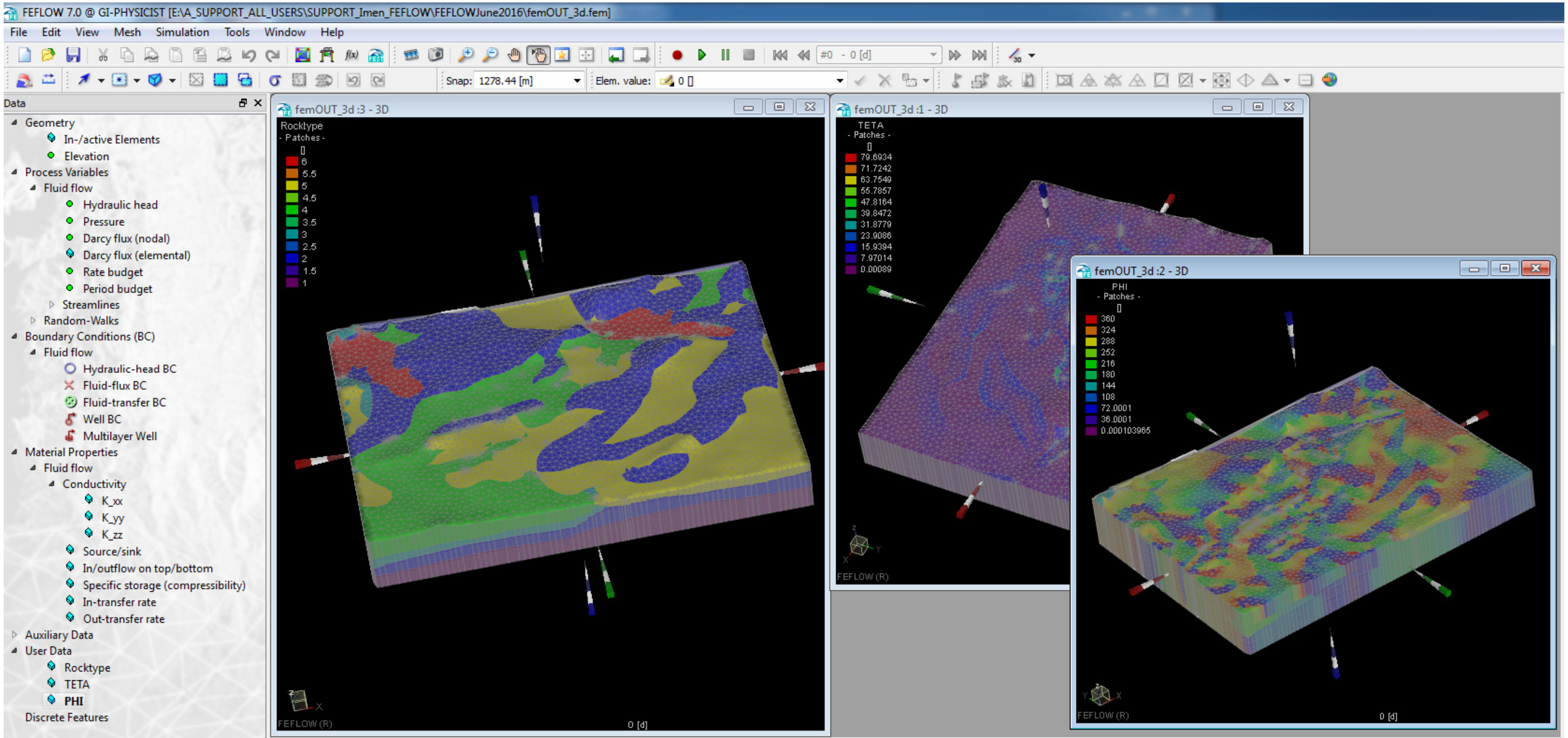
By pre-creation of a FEFLOW layered finite element mesh, then introduction of the geology-identity to each cell GeoModeller (Menu called fill FEFLOW centroids)

.

INTREPID GEOPHYSICS

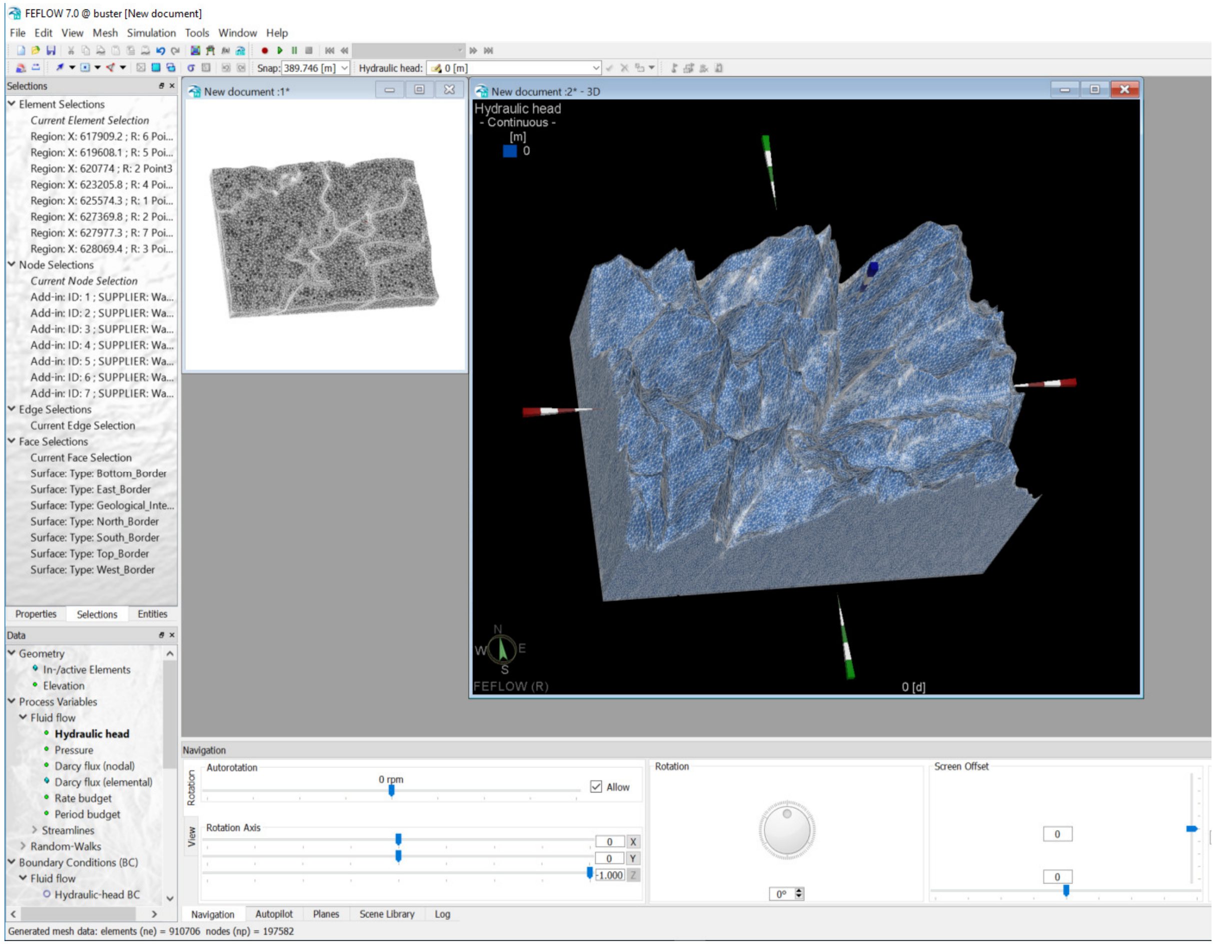
GeoModeller direct export: layered fem

Name	Date modified	Type	Size
femOUT_3d.fem	10/07/2017 5:12 PM	FEM File	111,312 KB
femOUT_triangles.data	10/07/2017 5:03 PM	DATA File	1,614 KB



Result is a 3-way attributed layered fem

Fully unstructured meshes export from GeoModeller



- With CGAL libraries for tetrahedron meshing
- user- controls for adaptive mesh (coarse or fine per geology unit)
- Water tight & manifold
- thin bodies, pinch outs, dipping faults (spatially limited or infinite faults)
- 30x reduction in the computational simulation problem: By much reduced # of equations for elements & nodes – detail where you want it

INTREPID GEOPHYSICS

Acknowledgements
to my co-authors:

Imen Hassen
Fadoua Hamzaoui-Azaza
Françоis Negro
Khanfir Rachid

Thank you

Helen Gibson *helen@intrepid-geophysics.com*

INTREPID GEOPHYSICS