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LARGE SCALE CONVECTIVE CIRCULATION IN THE LAKE CHAD BASIN.

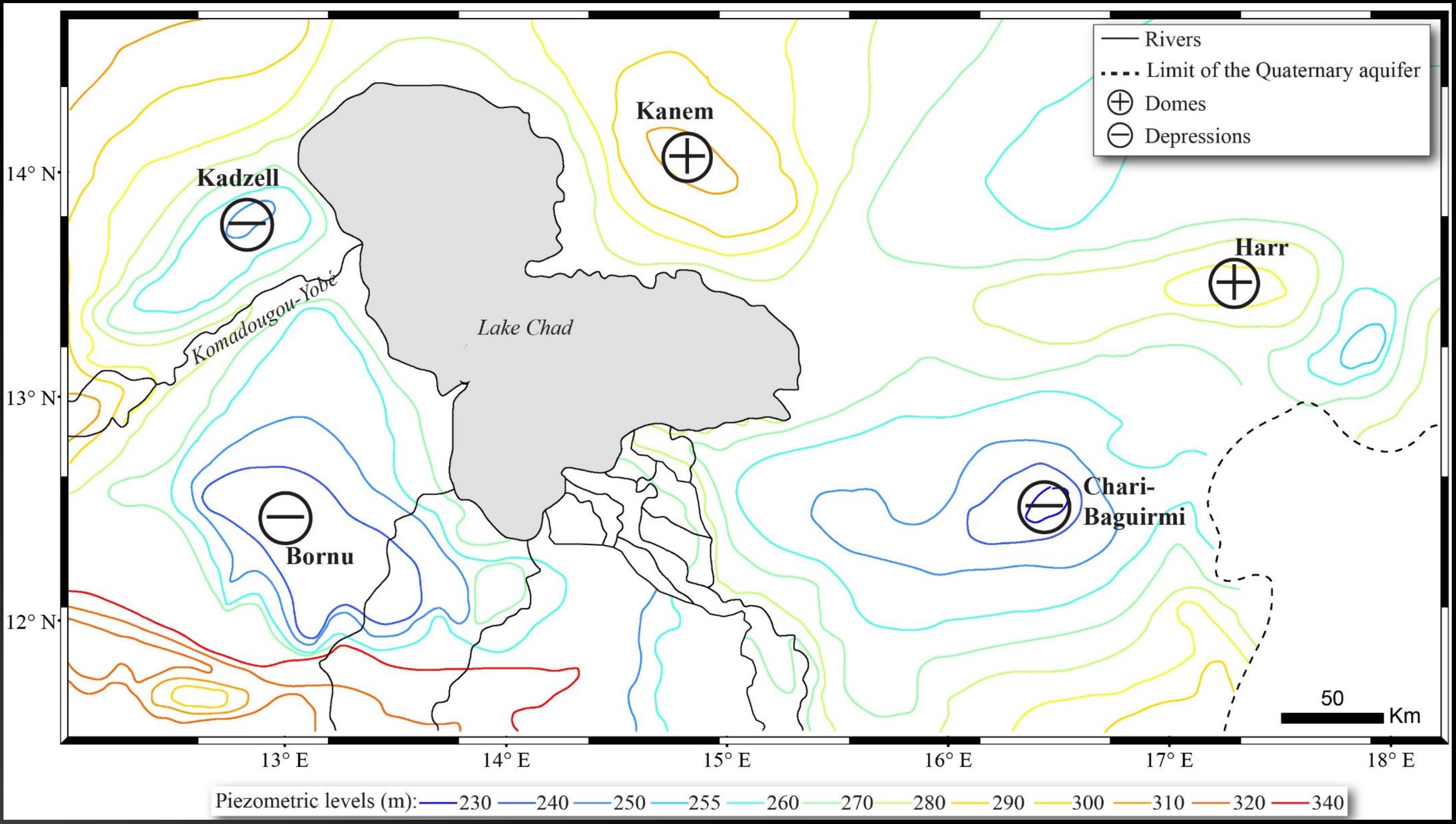
Teodolina Lopez

With the contributions of: R. Antoine, Y. Kerr, J. Darrozes, M. Rabinowicz, G. Ramillien, P. Genthon, A. Cazenave

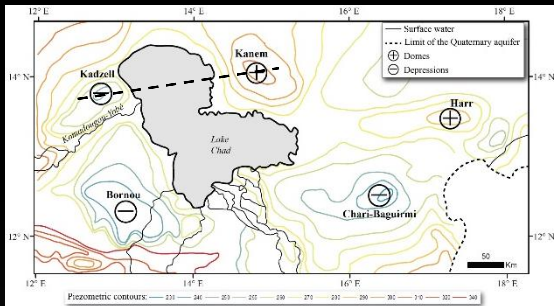
Lake Chad Basin

Phreatic Quaternary aquifer (QPA):

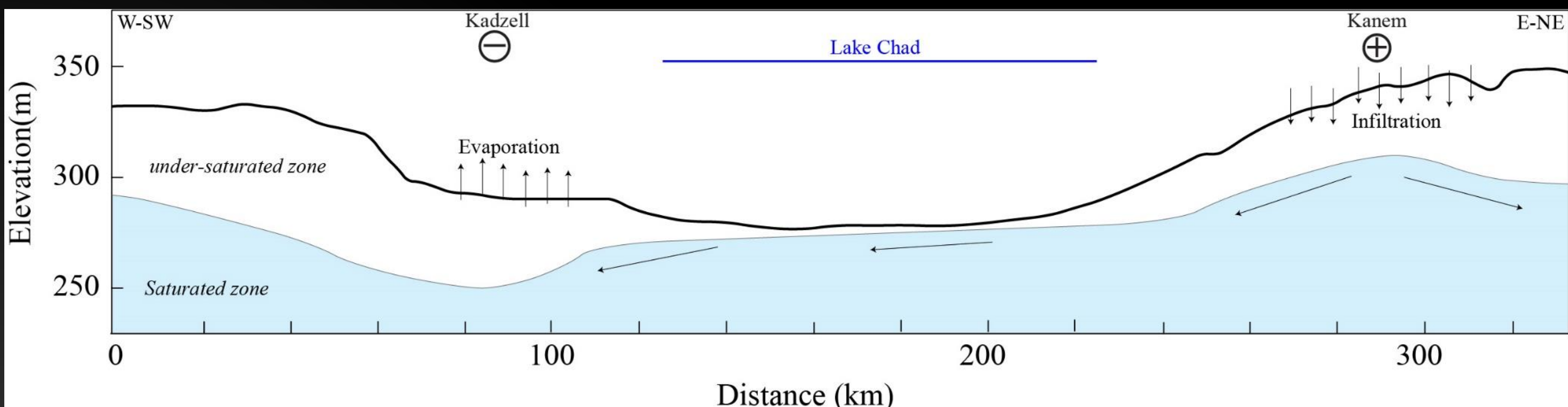
- characterised by closed piezometric domes and depressions.
- aquifer depth: ~10 m and ~60 m, respectively.



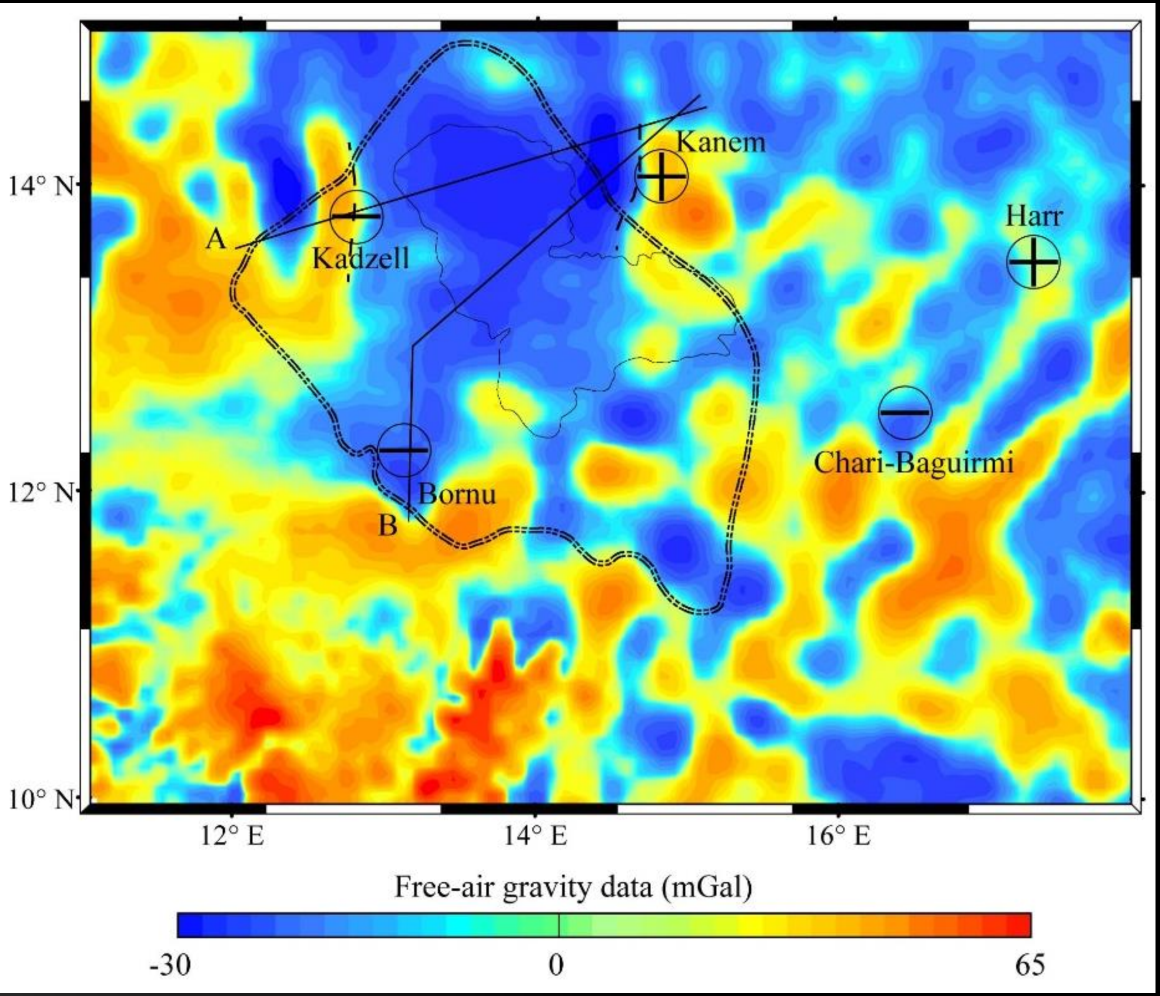
Main Hypothesis



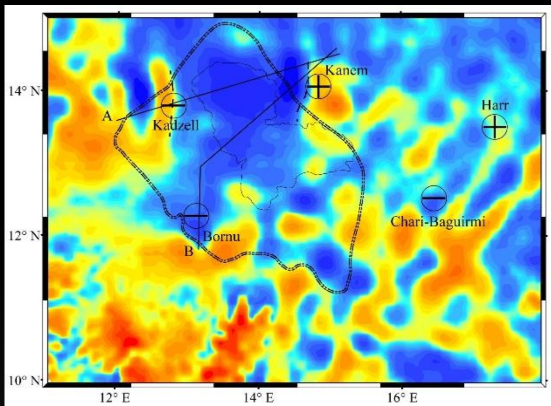
Excess losses by evapotranspiration above the depressions (Aranyossy and Ndiaye, 1993).



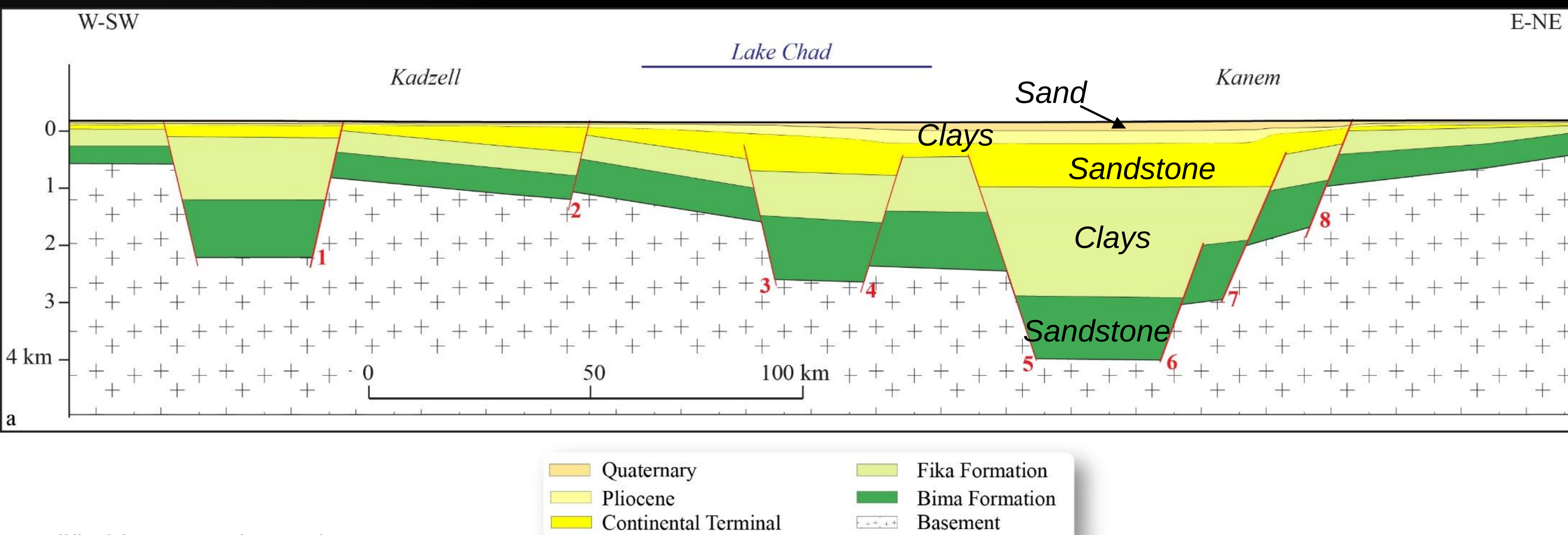
Free air (FA) gravity data map of the lake Chad basin (EGM 2012):



Correlation between the location of the piezometric anomalies and the limits of the basin.



At large-scale: - depression located above thin sequence,
- dome located above thick sequence.

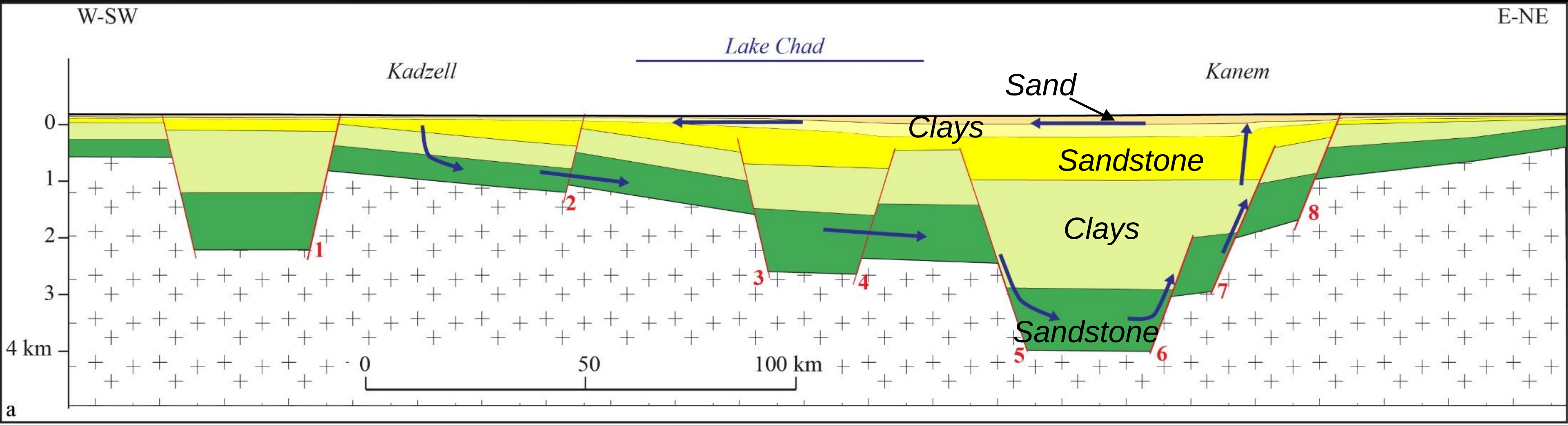


Modified from Pouclet et al, 1983

Four aquifers in the basin:

- Phreatic Quaternary aquifer,
- Pliocene aquifer,
- Continental Terminal aquifer,
- Continental Hammadian aquifer.

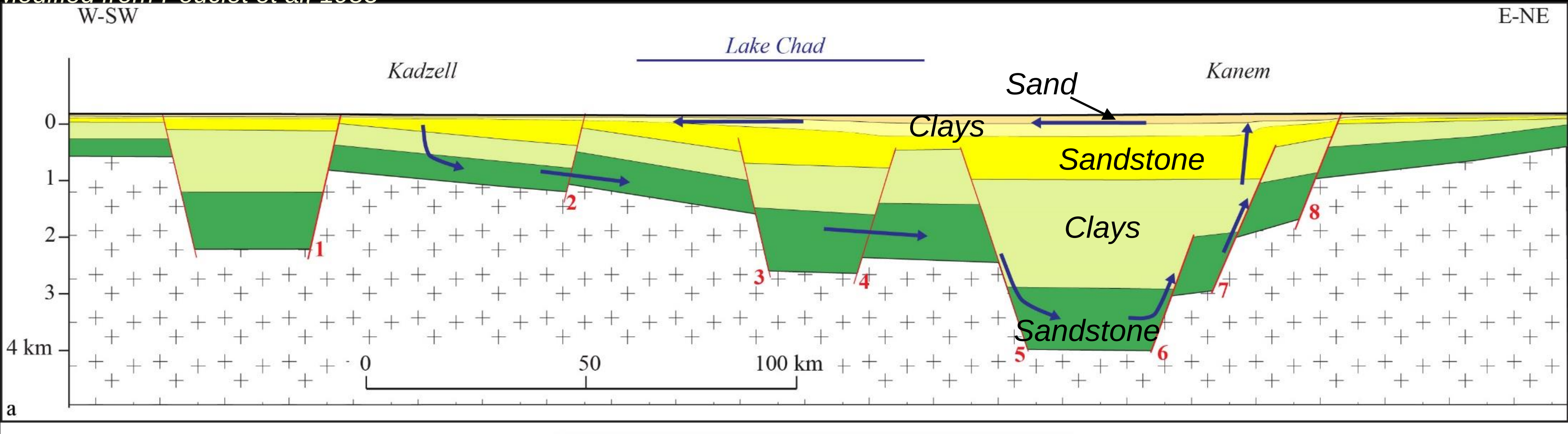
Hypothesis : Depressions and domes are the consequence of a thermally driven convection in the aquifers.



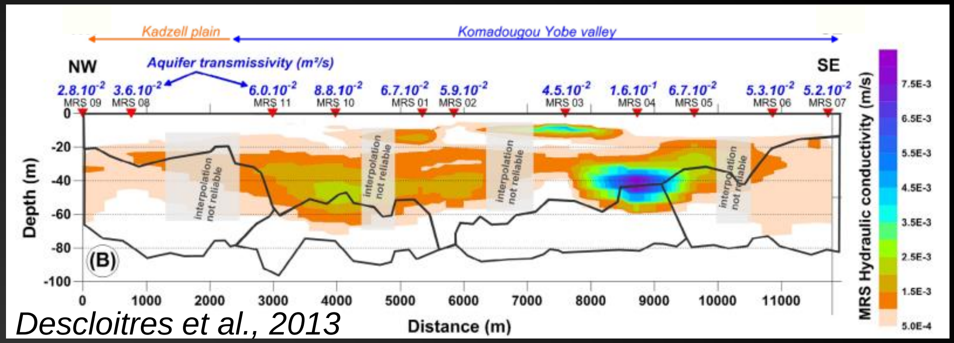
Modified from Pouclet et al, 1983

Presence of normal faults

Modified from Pouclet et al. 1983



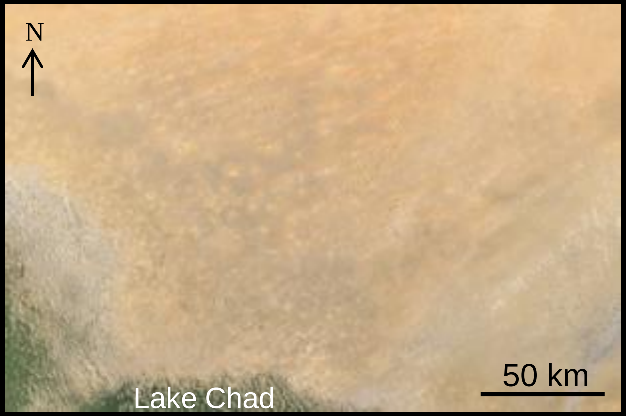
Kadzell depression



Descloitres et al., 2013

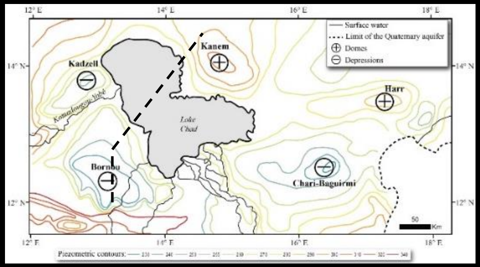
Presence of drains with a hydraulic conductivity of 7 10^{-3} m s^{-1} .

Kanem dome

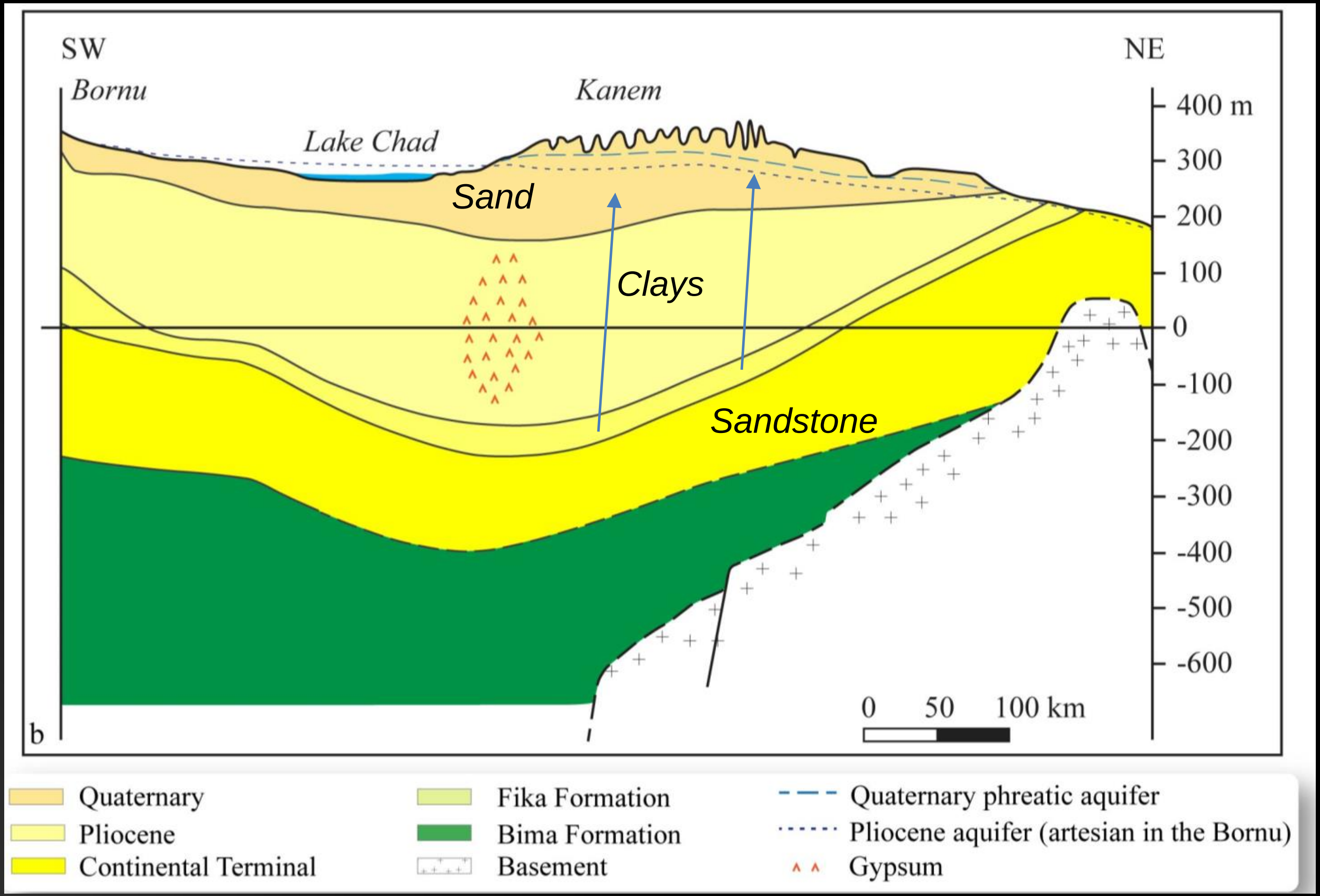


Layer of sand with an isotropic permeability between 10^{-11} to 10^{-10} m^2.

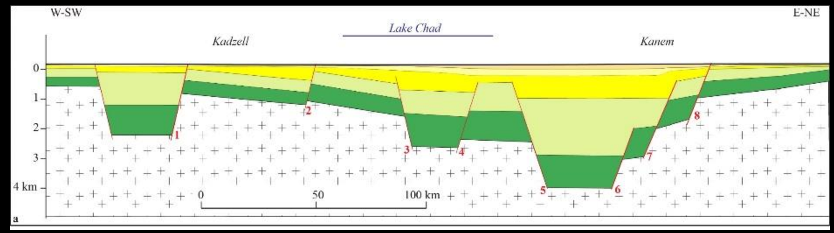
VERTICAL PERMEABILITY THROUGH CLAYS

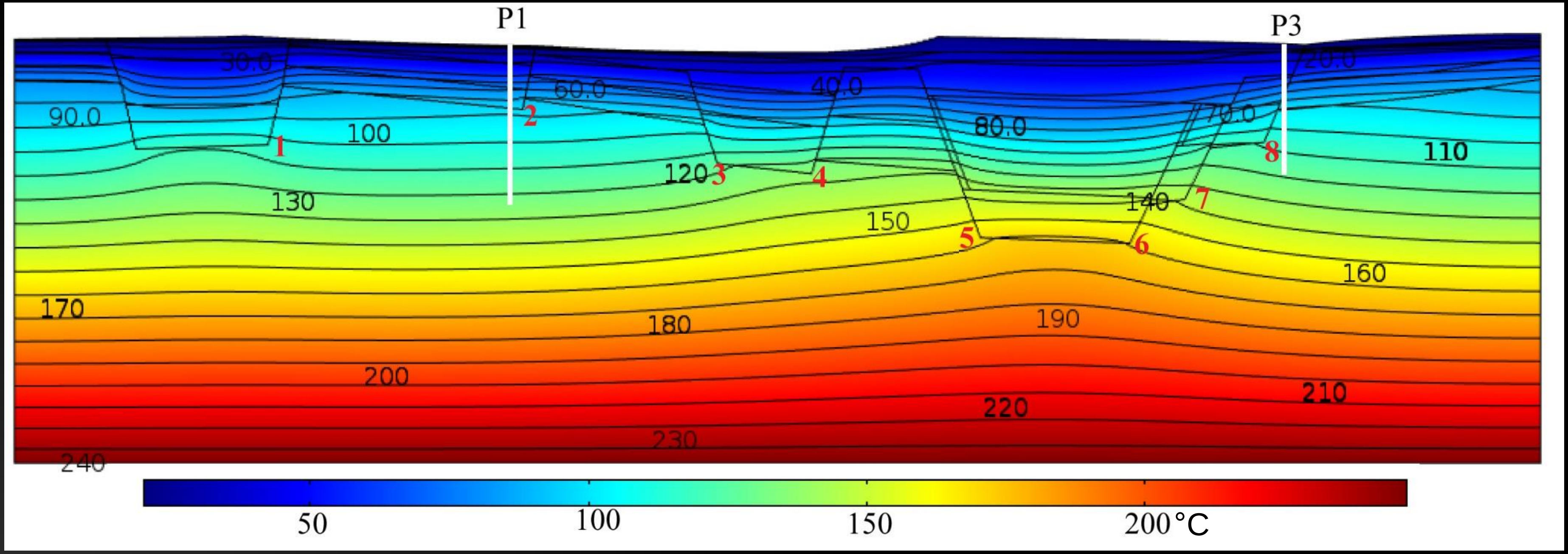


Artesian springs of Pliocene aquifer > clay-rich formation is fractured.



Modified from Schneider and Wolff, 1992

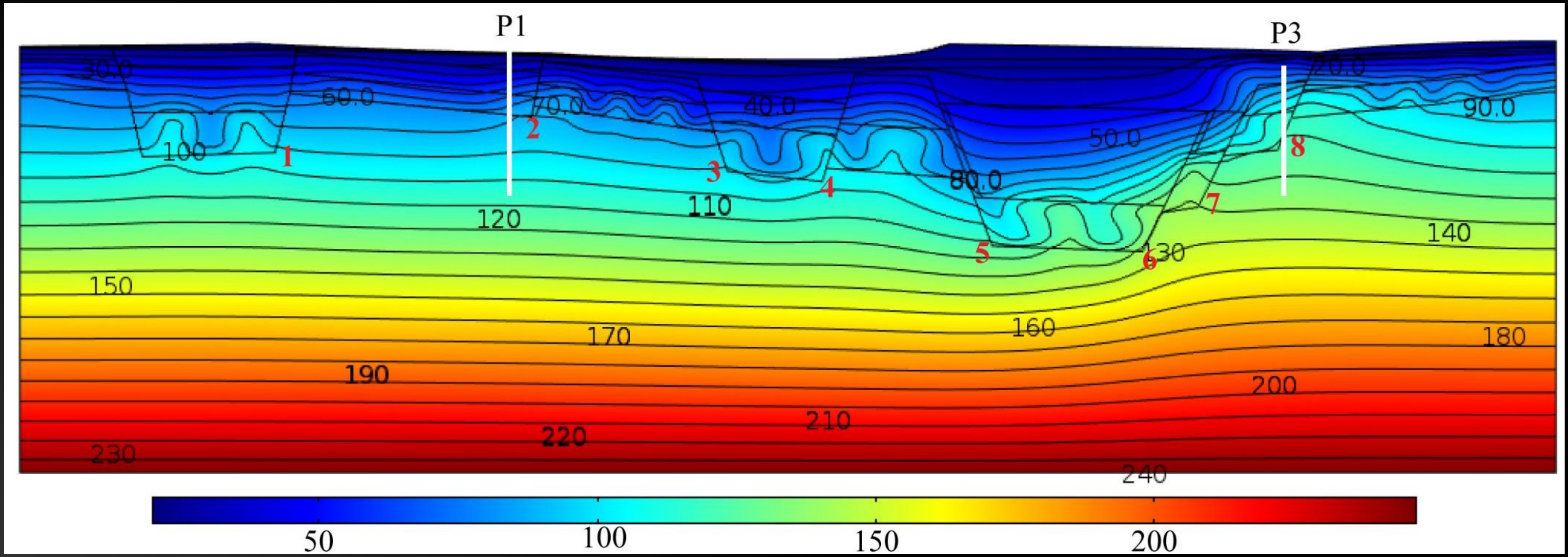




Large-scale slope of the conductive isotherms: convection is triggered whatever the Rayleigh number.

Vigour of the convection within the stratified porous media is characterised by the vertical Rayleigh number:

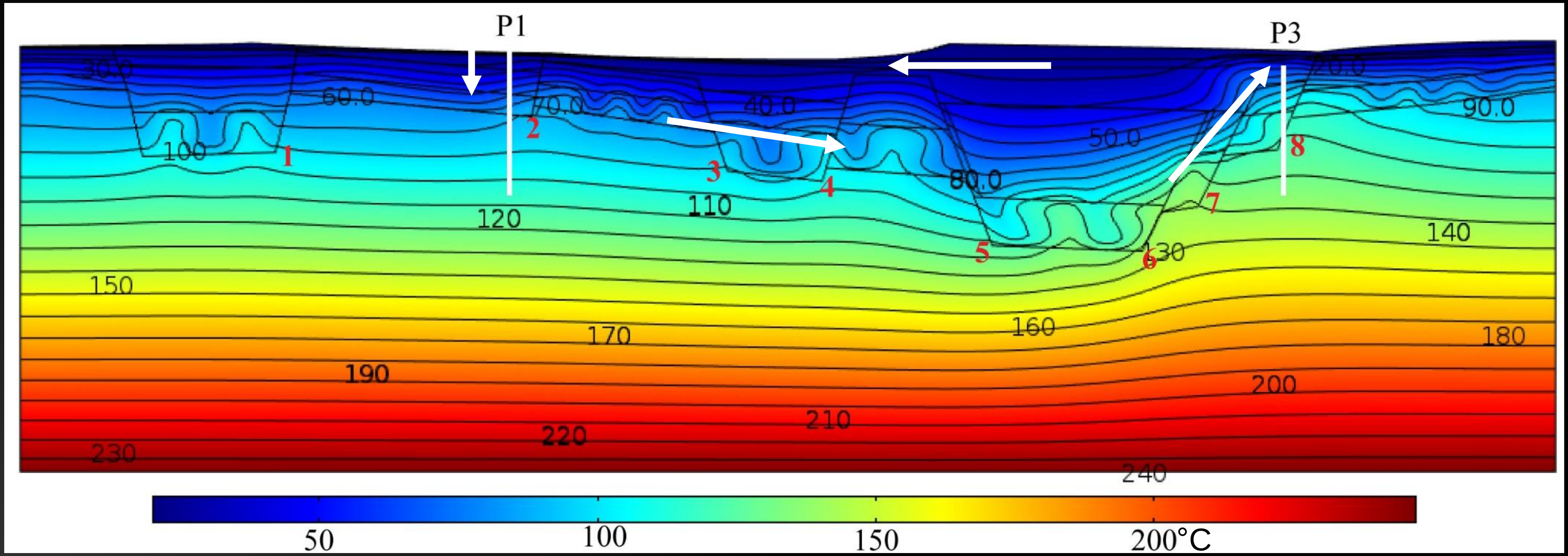
$$Ra = \frac{\alpha \rho g C_L K_Z}{\mu \lambda_{eq}} \gamma h^2$$



Snapshot of the convective field after ~500,000 yrs.

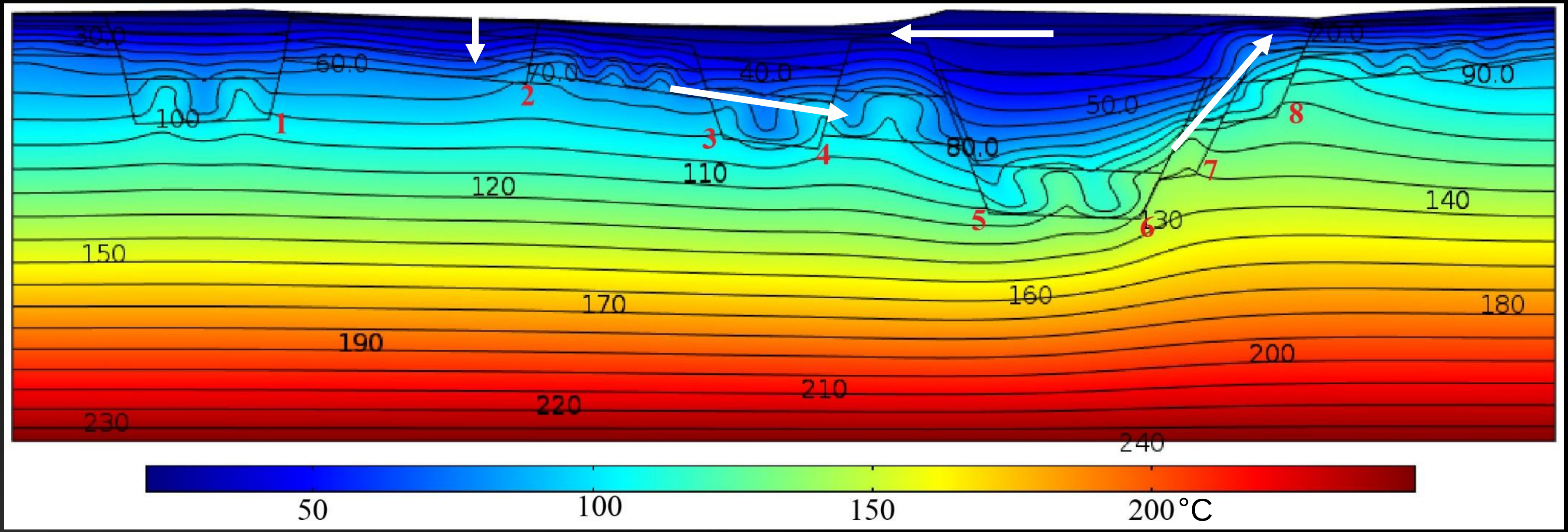
$$Ra = \frac{\alpha \rho g C_L K_Z}{\mu \lambda_{eq}} \gamma h^2 < \sim 40$$

Formation of a basin-wide convective cell.



Fluid velocity field $\vec{u}$ = (U_x, V_z) describe by the Darcy's law:

$$\vec{u} = -\frac{K}{\mu}\left(\overrightarrow{\nabla p} - \rho\vec{g}\right)$$



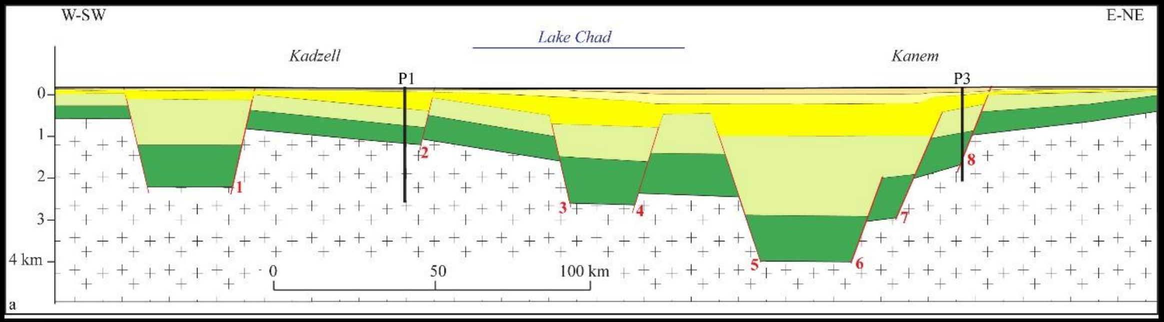
Vertical velocity

- descending current: 4 mm yr^{-1}
- ascending current: 4 cm yr^{-1}

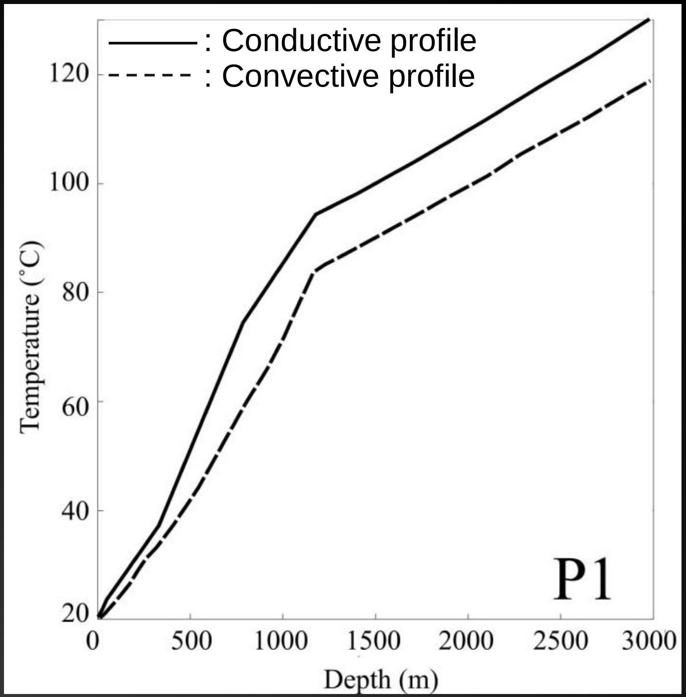
Horizontal velocity

- bottom current:10 cm yr^{-1}
- 7 cm yr^{-1}< top current < 39 cm yr^{-1}

THERMAL PROFILES

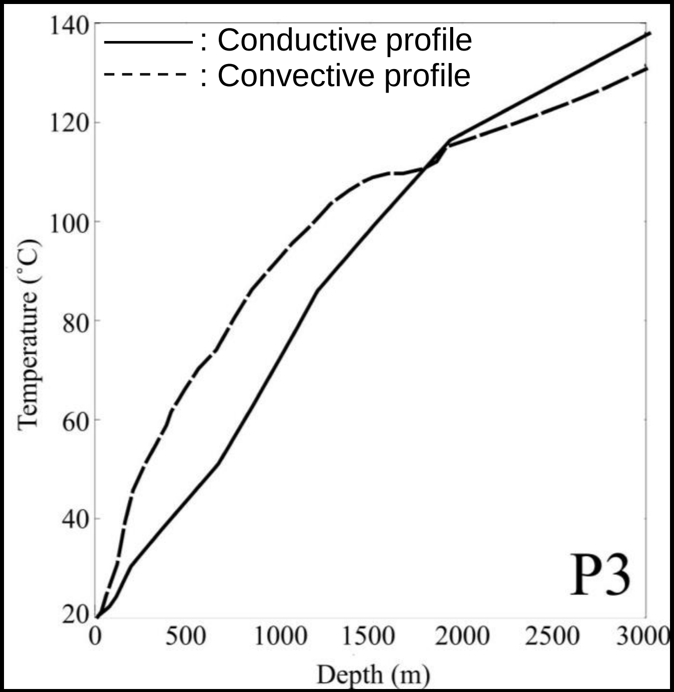


Kadzell



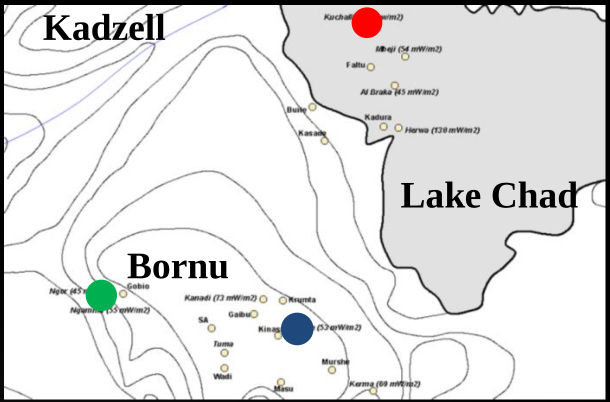
Thermal profile typical of a descending current

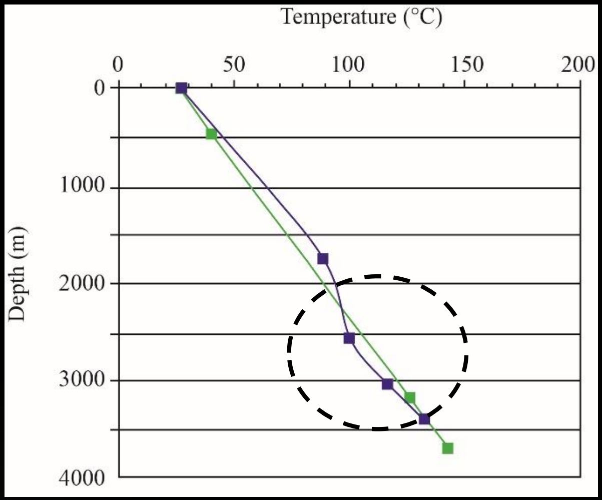
Kanem

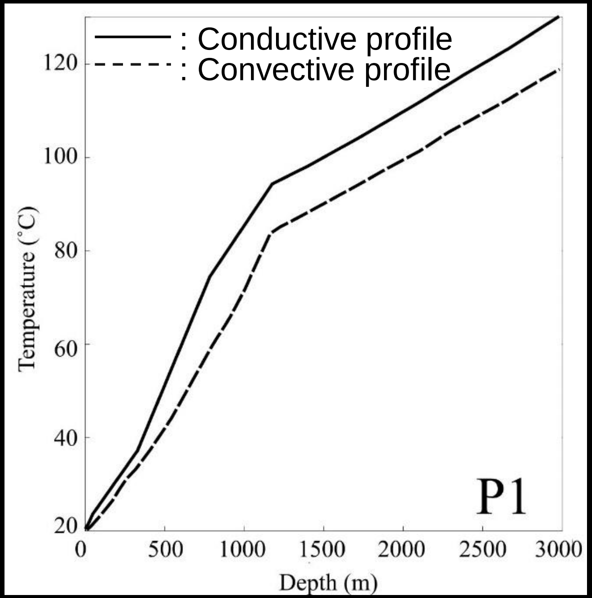


Thermal profile typical of an ascending current

THERMAL PROFILES FROM OIL WELL

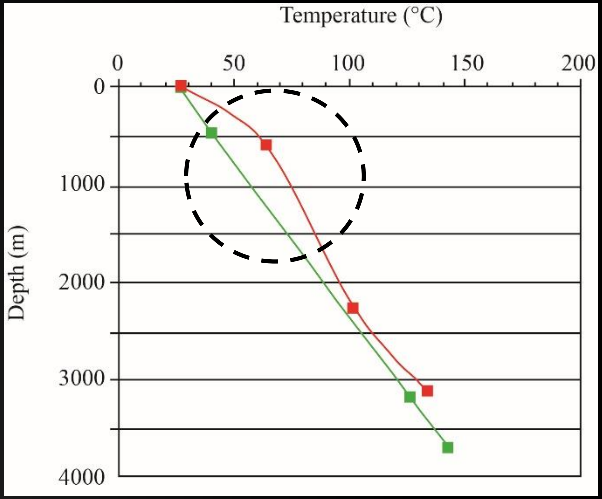




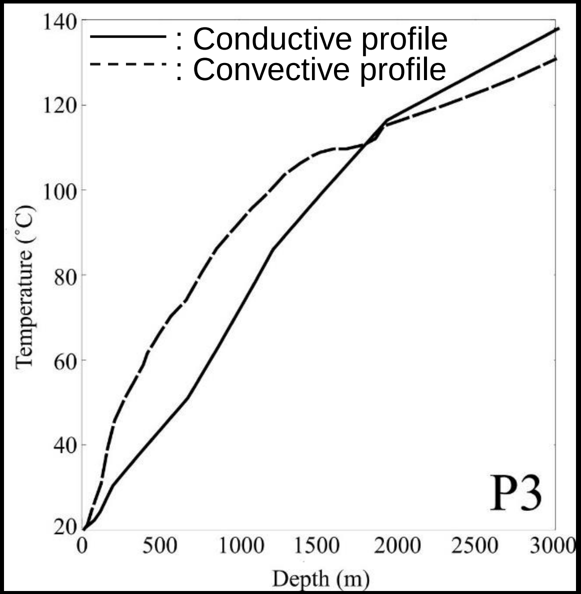


At first order:

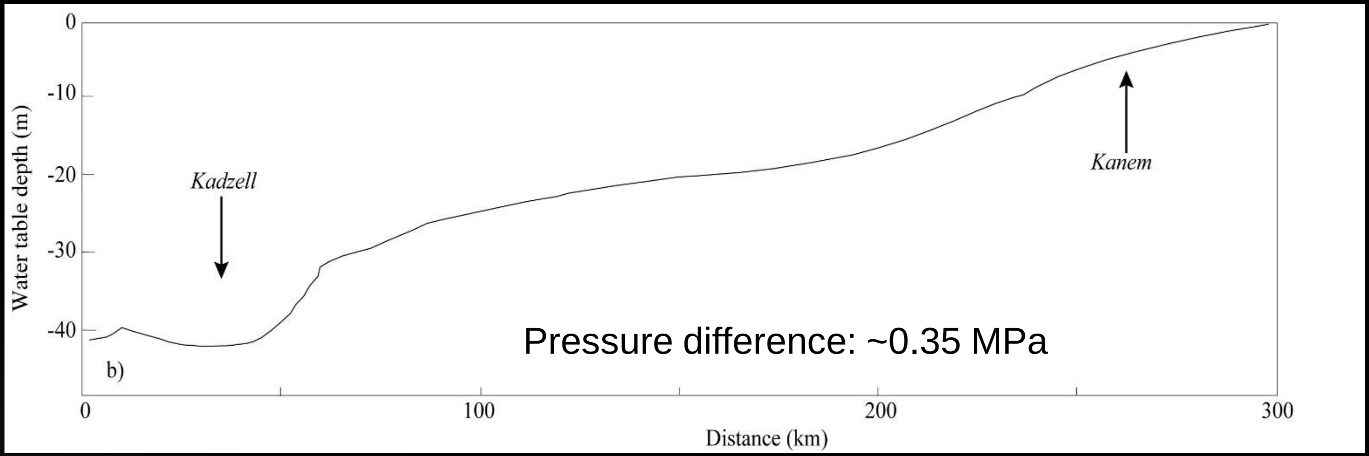
- Bornu depression associated with a cold descending current,
- Presence of a warm ascending current.

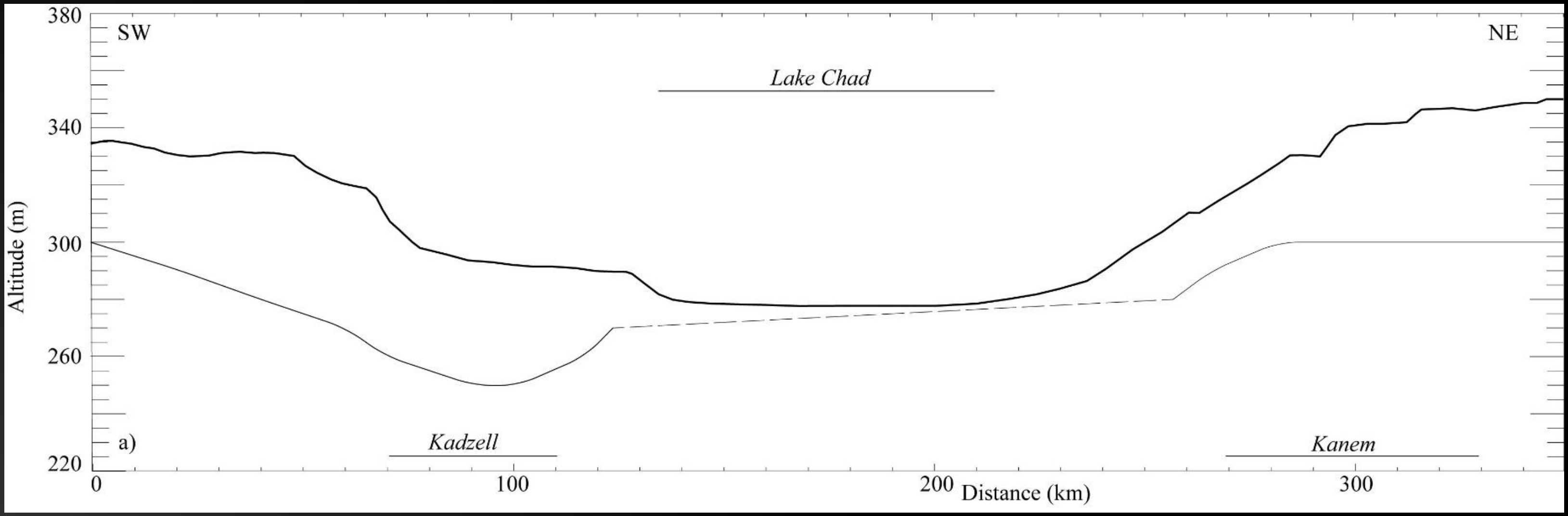


Modified from Nwankwo and Ekine, 2010



Water table topography





The water table derived from the convective model reproduces the observed water table.

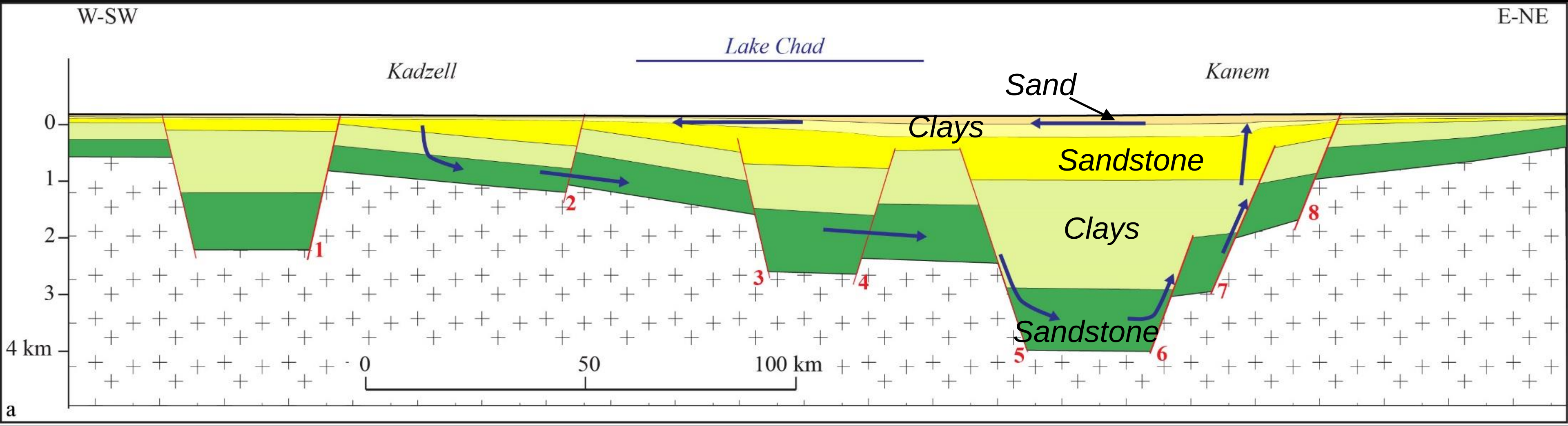
GEOCHEMISTRY

Total Dissolved Solid:

- Phreatic Quaternary aquifer > $CaHCO_3$ waters. — 164 mg L^{-1}
- Pliocene aquifer > $NaSO_4$ waters.
- Continental Terminal aquifer > $NaHCO_3$ waters.
- Continental Hammadian aquifer > NaCl waters.

(Pliocene, Continental Terminal and Continental Hammadian aquifers: 760 mg L^{-1})

Apparent absence of a notable vertical stratification of salinity > basin-wide circulation may be only driven by thermal gradients.



Variations of water chemistry:

- Anion exchanges,
- Presence of sulphate-reducing bacteria.

Conclusion

- The phreatic Quaternary aquifer (QPA) of the Lake Chad basin presents piezometric anomalies; correlated with the sedimentology of the basin (depressions are associated with thin sedimentary sequence).

- The lack of gradient vertical salinity and the presence of vertical permeability permit the development of a basin-wide thermally driven convective circulation.

- The variation of chemistry between aquifers can be explained by two processes in clay-rich deposits:
    - Anion exchanges,
    - Sulphate-reducing bacteria.

Our convective model predicts the water table topography of the QPA:
- Depressions are associated to a cold descending current,
- Domes are associated to a warm ascending current.

THANKS FOR YOU ATTENTION

Lake Chad seen from Apollo 7