The use of anisotropy of magnetic susceptibility and brittle mesostructures analysis to investigate the tectonic evolution of the oriental Atlas. Case study of the southern edge of the Tunisian trough, NW Tunisian Atlas

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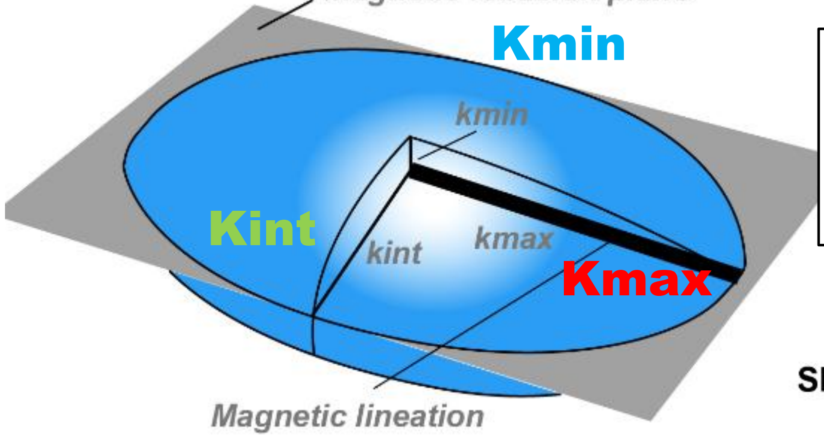
2025/05/16

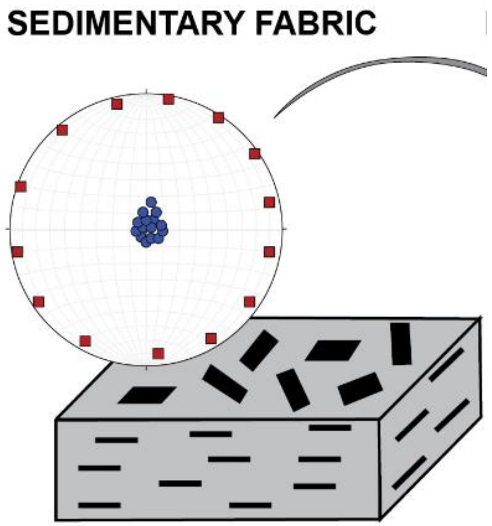
AMS (Anisotropy of Magnetic Susceptibility)



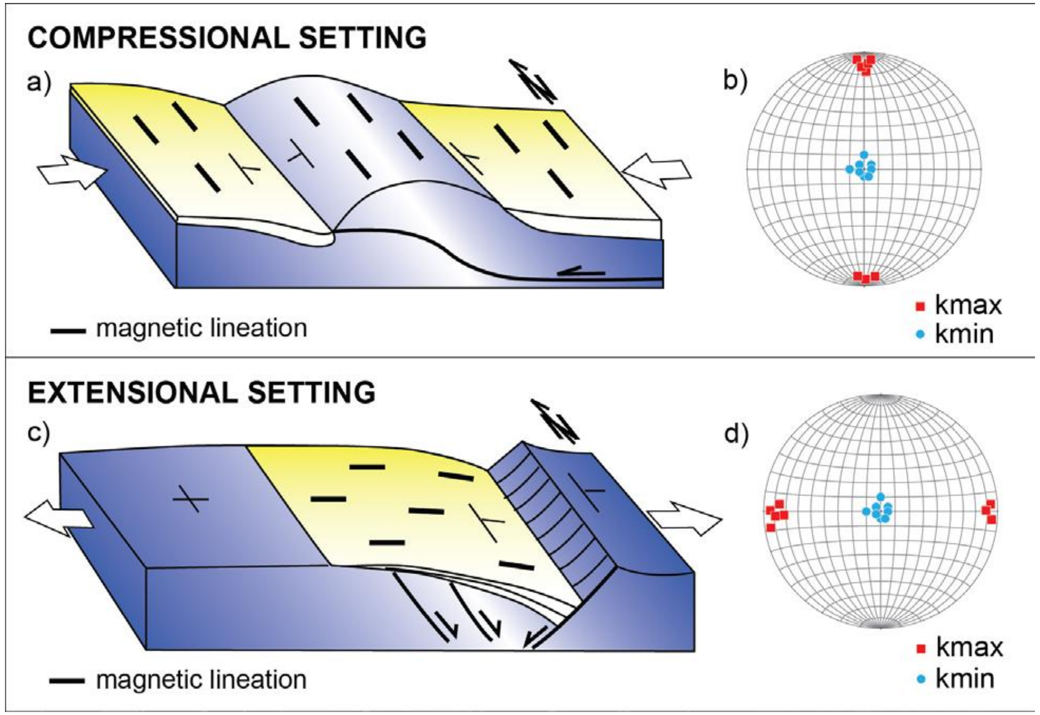
Kmax: mineral grains aligned along the direction of maximum magnetic properties

Kmin: direction of minimum magnetic properties

- In sedimentary rocks, this fabric is often controlled by the preferred orientation of platy minerals, like clays, which align during deposition or compaction.



Misorientation of basal planes of platy minerals, contained on horizontal bedding surfaces

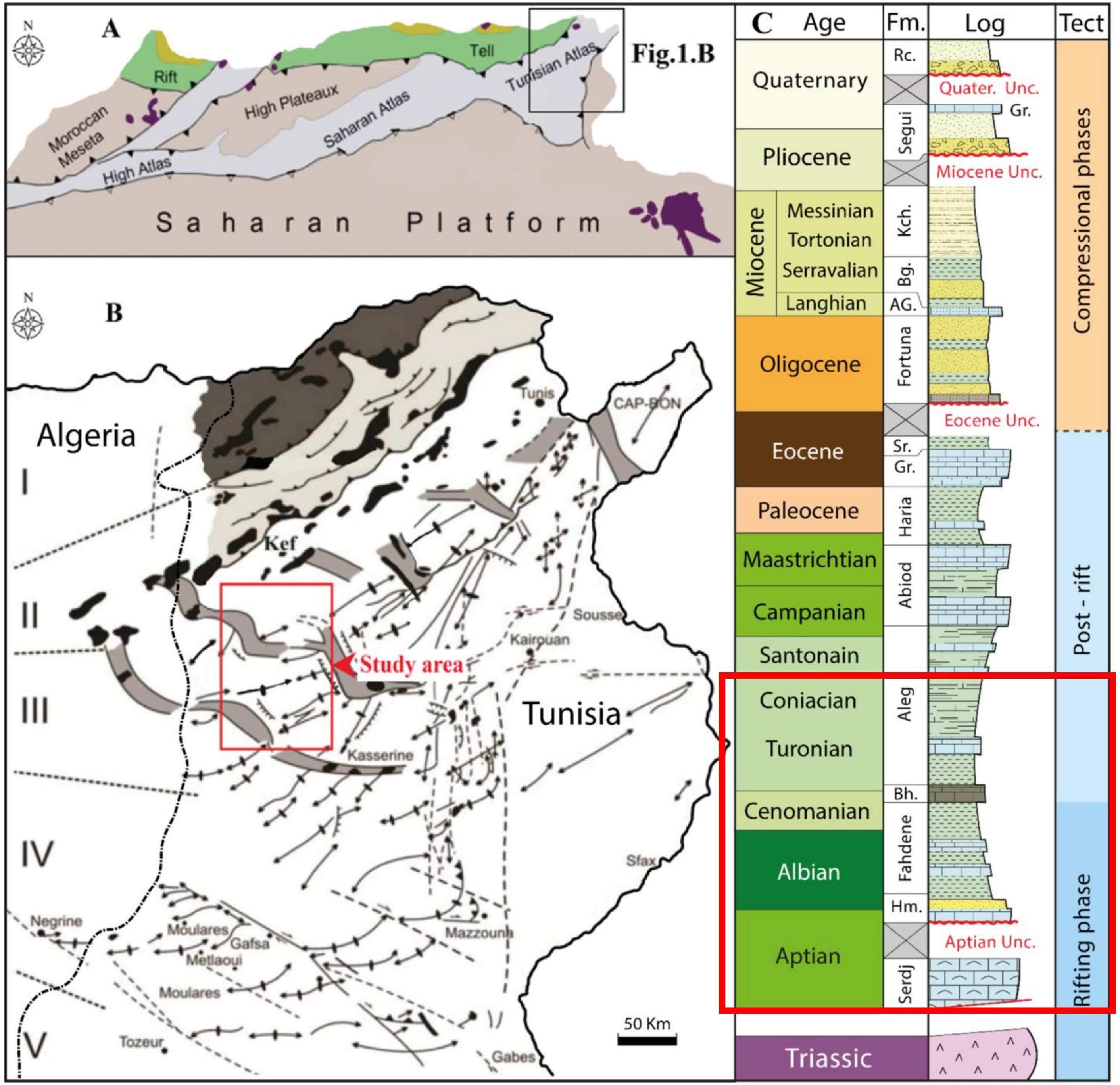


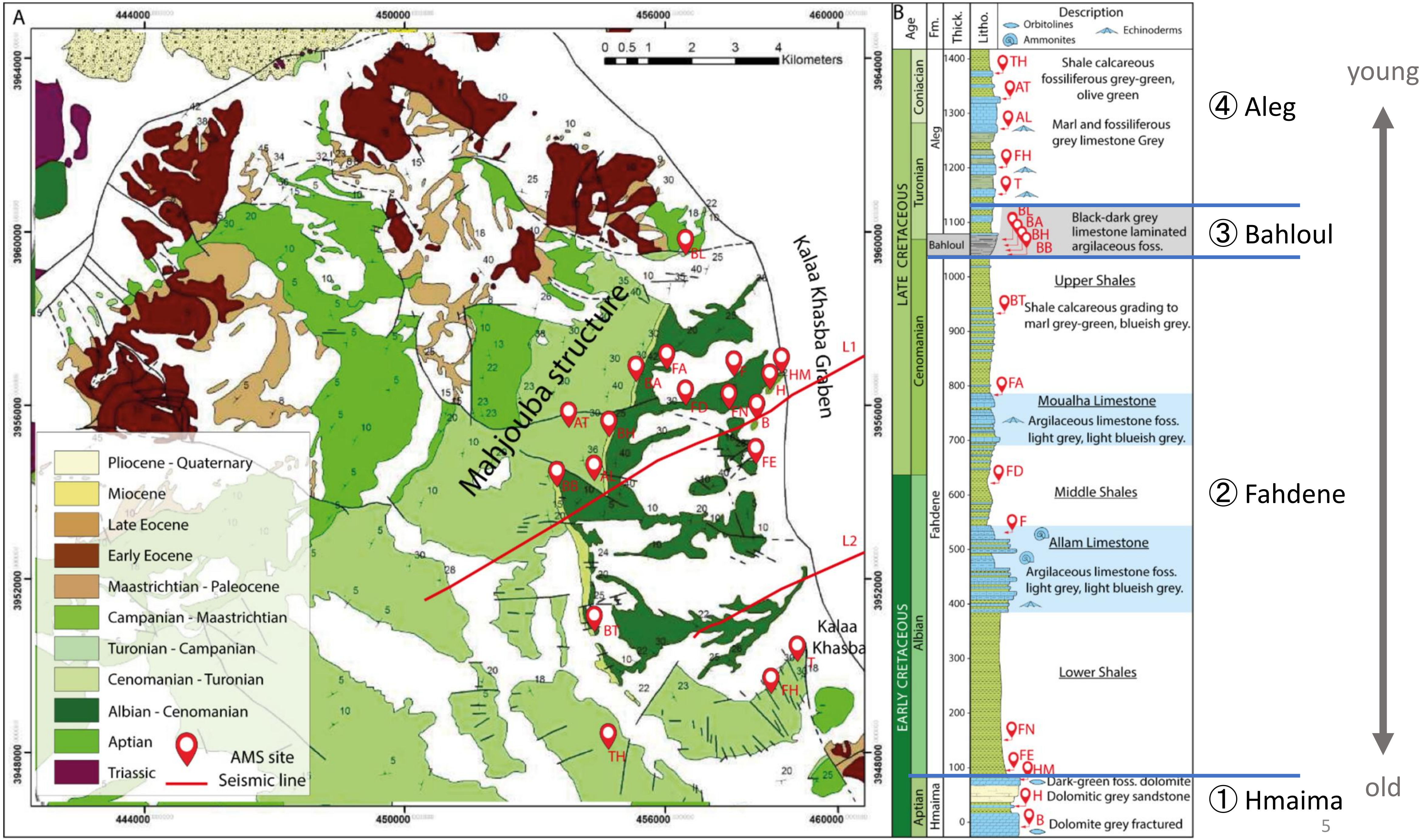
(Ruth Soto,2013)

Introduction

- AMS (Anisotropy of Magnetic Susceptibility) is a rock fabric analysis technique study rock fabrics through the preferred orientation of magnetic minerals.
- In this study, which focuses on sedimentary rocks, the AMS fabric is primarily controlled by clay minerals aligned during deposition or compaction.
- It focuses on the northwestern Tunisian Atlas, which records extensional and compressional tectonic phases.
- The aim is to evaluate the reliability of AMS directions against structural markers.

Study area


A
Fig.1.B
Rift
Tell
Tunisian Atlas
Moroccan Meseta
High Plateaux
Saharan Atlas
High Atlas
Saharan Platform
B
Algeria
Tunisia
Tunis
CAP-BON
Kef
Sousse
Kairouan
Study area
Kasserine
Sfax
Negrine
Moulares
Gafsa
Metlaoui
Mazzouna
Tozeur
Gabes
I
II
III
IV
V
50 Km
C
Age
Fm.
Log
Tect
Quaternary
Pliocene
Miocene
Messinian
Tortonian
Serravalian
Langhian
Oligocene
Eocene
Paleocene
Maastrichtian
Campanian
Santonain
Coniacian
Turonian
Cenomanian
Albian
Aptian
Triassic
Rc.
Segui
Kch.
Bg.
AG.
Fortuna
Sr.
Gr.
Haria
Abiod
Aleg
Bh.
Fahdene
Hm.
Serdj
Quater. Unc.
Gr.
Miocene Unc.
Eocene Unc.
Aptian Unc.
Compressional phases
Post - rift
Rifting phase


A
B
Kilometers
0 0.5 1 2 3 4
444000
450000
456000
460000
3964000
3960000
3956000
3952000
3948000
Mahjouba structure
Kalaa Khasba Graben
Kalaa Khasba
L1
L2
Pliocene - Quaternary
Miocene
Late Eocene
Early Eocene
Maastrichtian - Paleocene
Campanian - Maastrichtian
Turonian - Campanian
Cenomanian - Turonian
Albian - Cenomanian
Aptian
Triassic
AMS site
Seismic line
Age
Fm.
Thick.
Litho.
Description
Orbitolines
Ammonites
Echinoderms
LATE CRETACEOUS
EARLY CRETACEOUS
Coniacian
Turonian
Cenomanian
Albian
Aptian
Aleg
Bahloul
Fahdene
Hmaima
Shale calcareous fossiliferous grey-green, olive green
Marl and fossiliferous grey limestone Grey
Black-dark grey limestone laminated argilaceous foss.
Upper Shales
Shale calcareous grading to marl grey-green, blueish grey.
Moualha Limestone
Argilaceous limestone foss. light grey, light blueish grey.
Middle Shales
Allam Limestone
Argilaceous limestone foss. light grey, light blueish grey.
Lower Shales
Dark-green foss. dolomite
Dolomitic grey sandstone
Dolomite grey fractured
④ Aleg
③ Bahloul
② Fahdene
① Hmaima
young
old

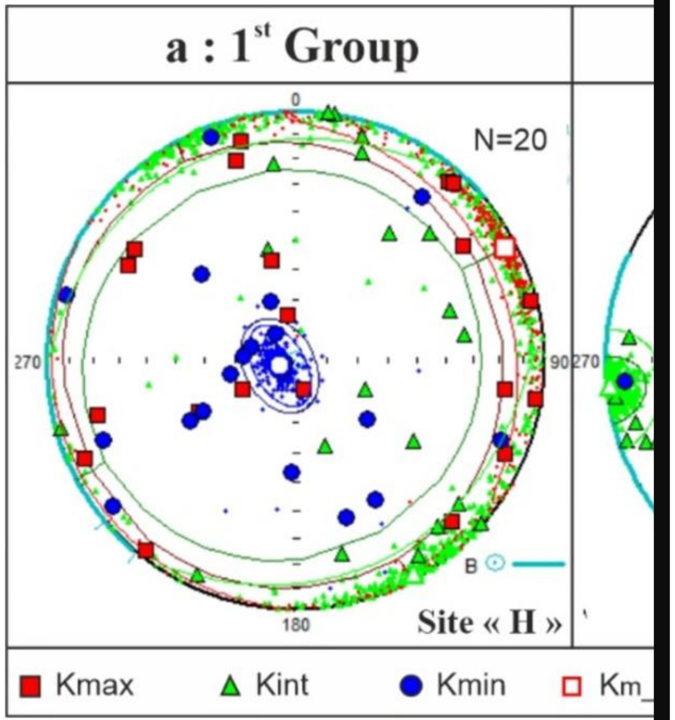
Methods

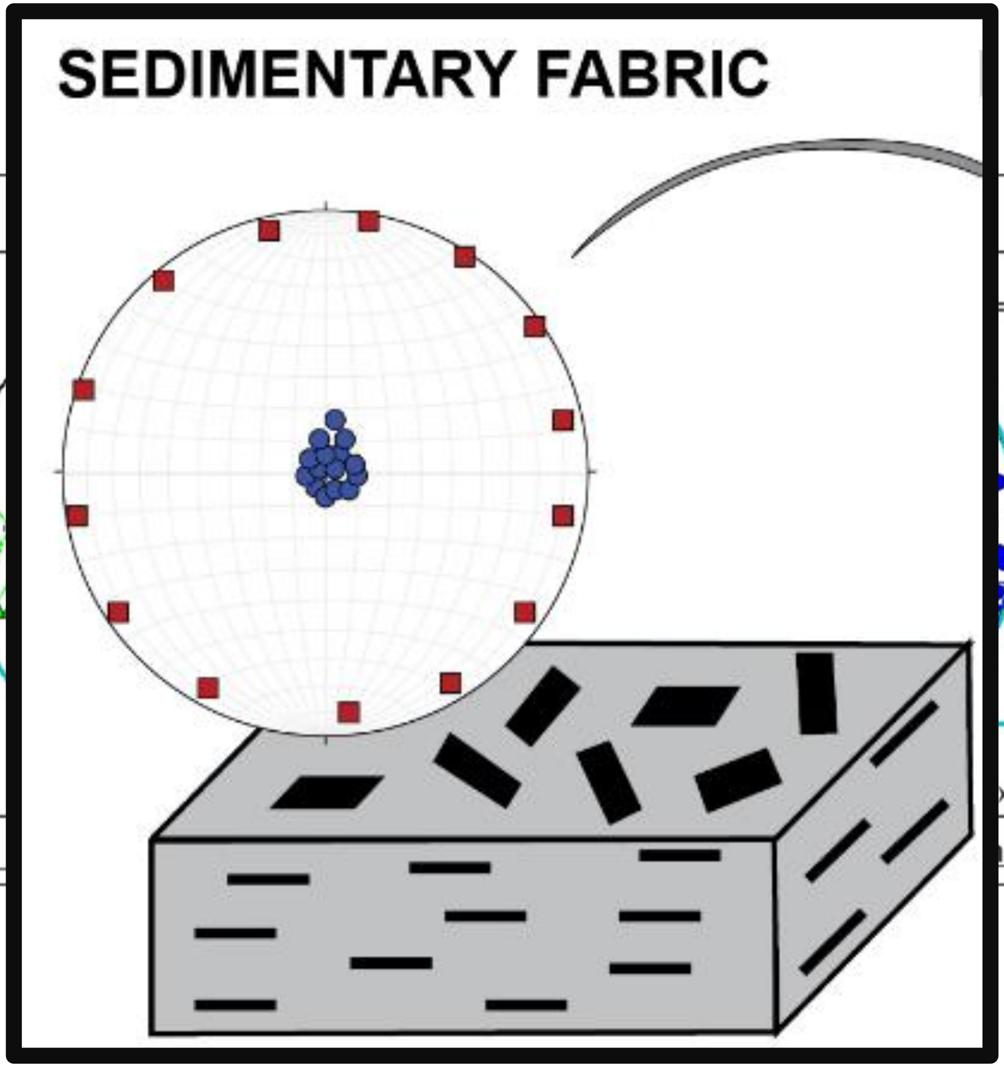
- **AMS analysis**:
  - Measure Kmax/Kint/Kmin axes to define magnetic fabrics
  - Identify 4 fabric types (sedimentary, normal, inverse, undefined)
- **Structural analysis**:
  - Measure faults and veins in the field
  - Stress tensor inversion to compare with AMS results

Result 1 – AMS fabric classification

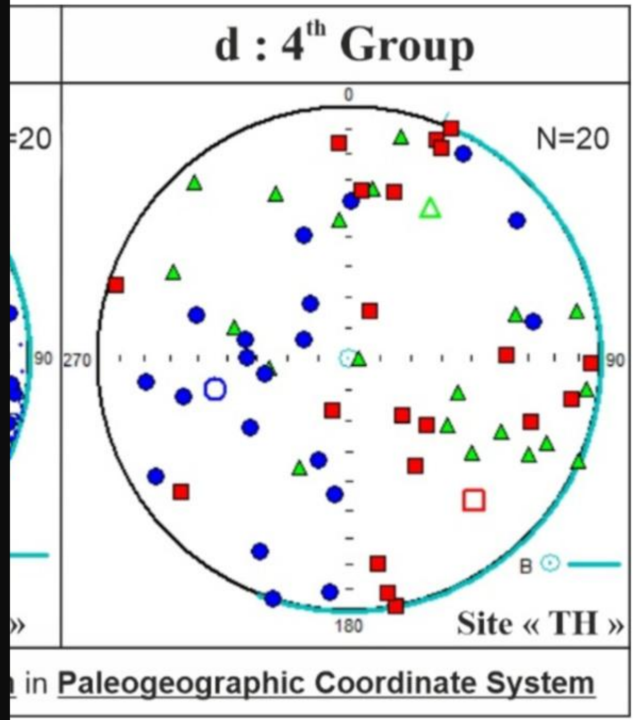
Kmax, Kint, Kmin

Sedimentary





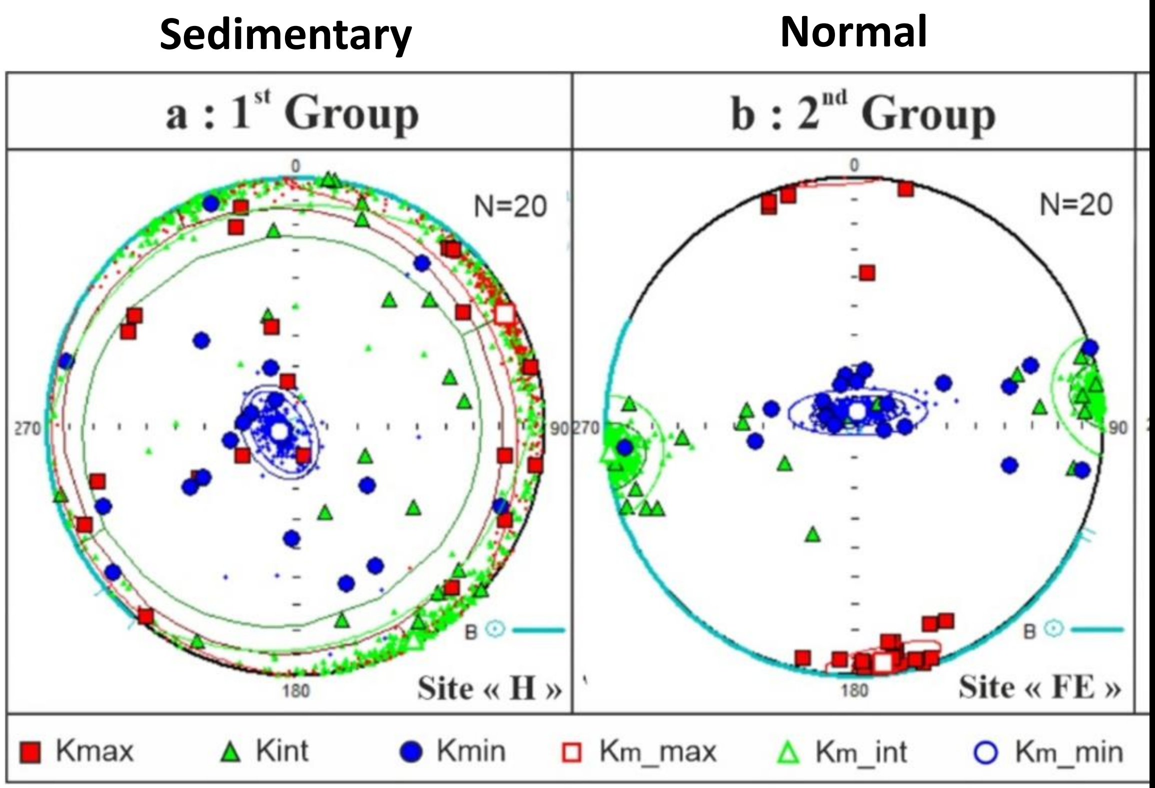
Undefined

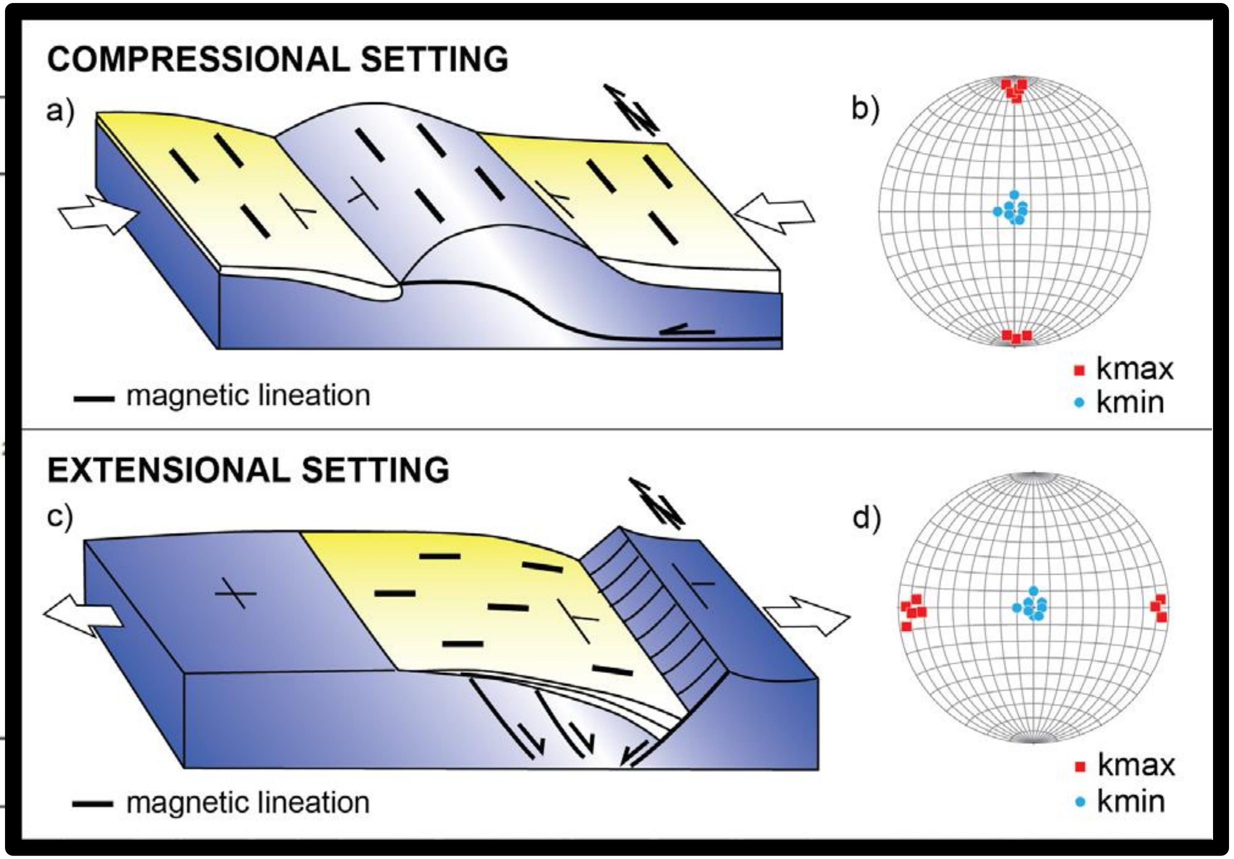


- **Kmin**: vertical
- **Kmax** don’t have a specific direction.

Result 1 – AMS fabric classification

Kmax, Kint, Kmin



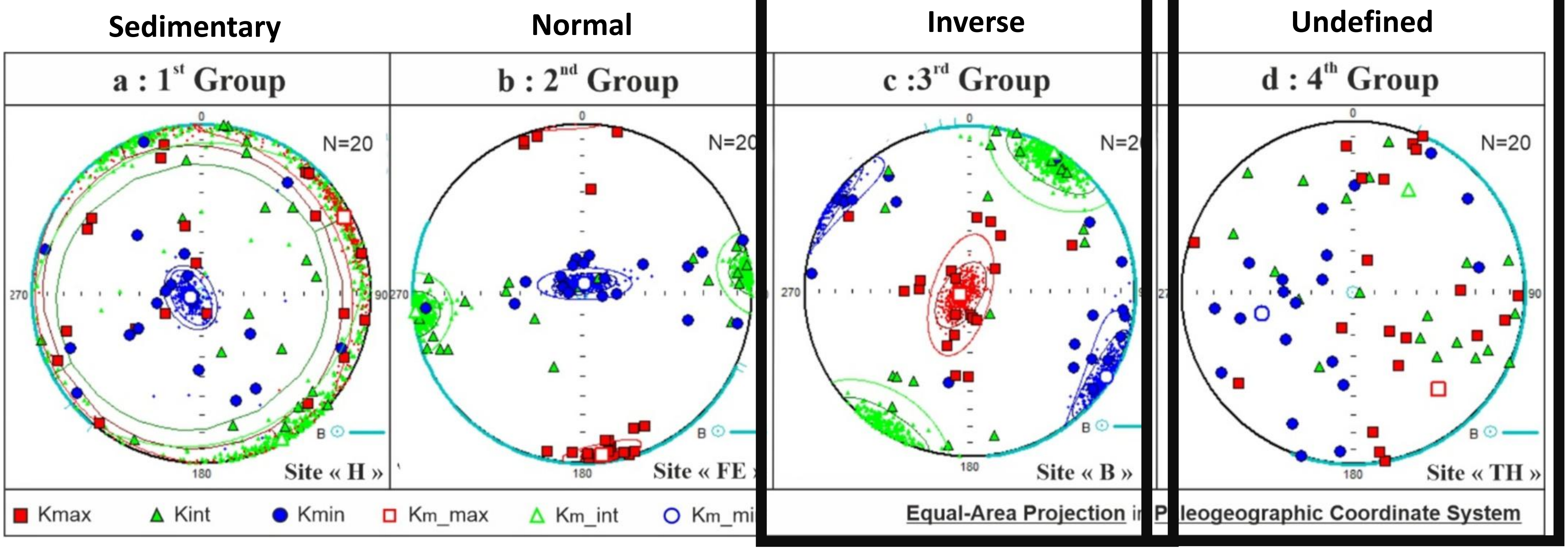


- **Kmin**: vertical
- **Kmax** don't have a specific direction.

- **Kmin**: vertical
- **Kmax** parallel to the bedding plane.

Result 1 – AMS fabric classification

Kmax, Kint, Kmin



- **Kmin**: vertical
- **Kmax** don't have a specific direction.

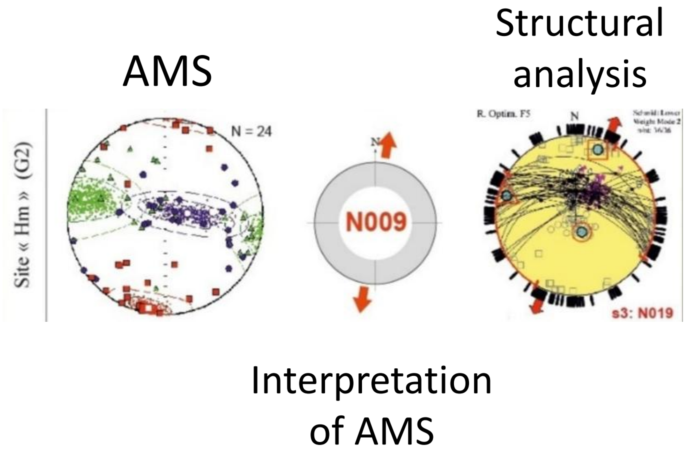
- **Kmin**: vertical
- **Kmax** parallel to the bedding plane.

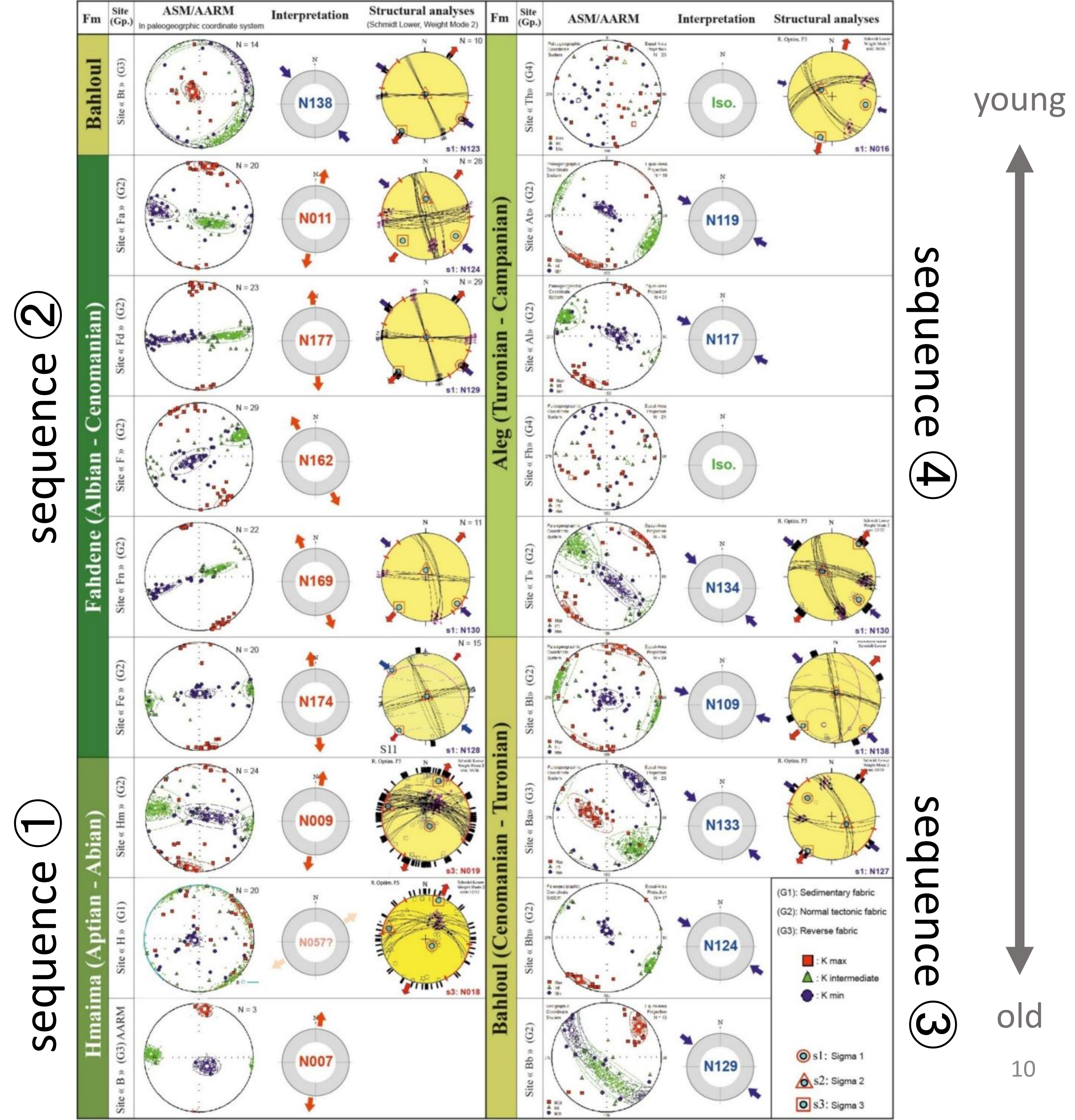
- **Kmax** shows in unexpected direction.

- All points are scattered.

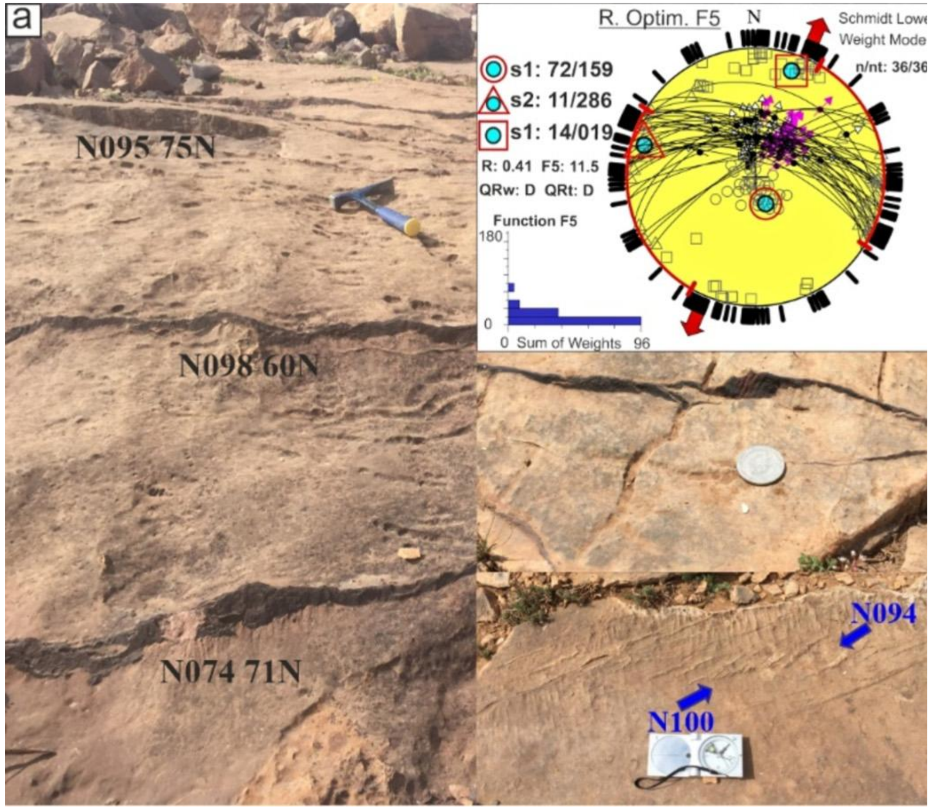
Result 2

AMS & Structural data

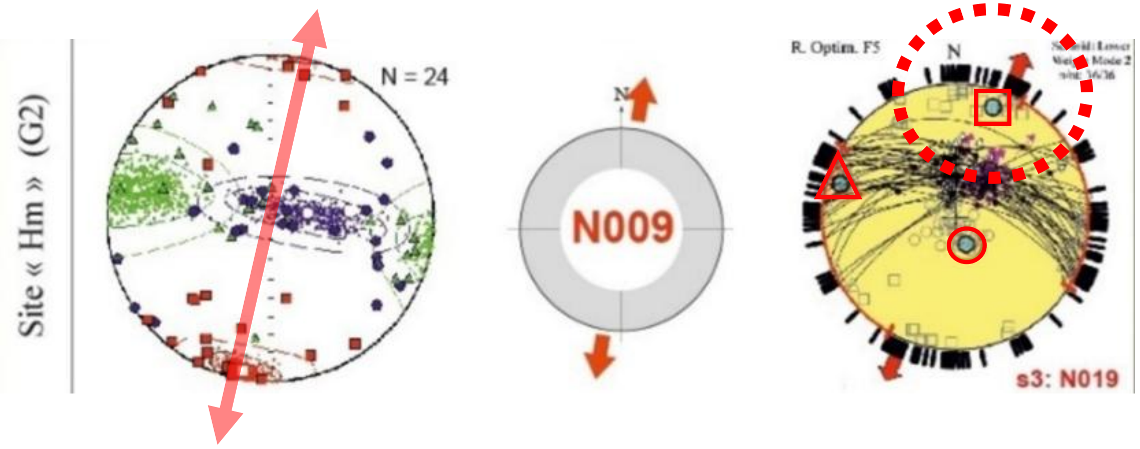




Result 2 - AMS & Structural data



Sigma 1 = Largest principle stress



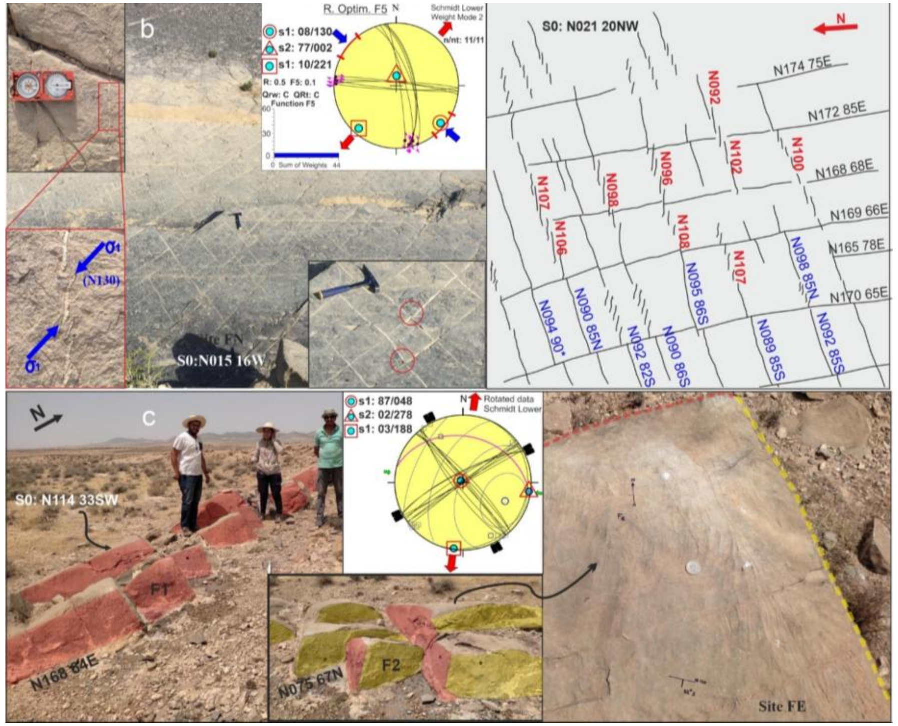
Kmax, Kint, Kmin

Sequence ①

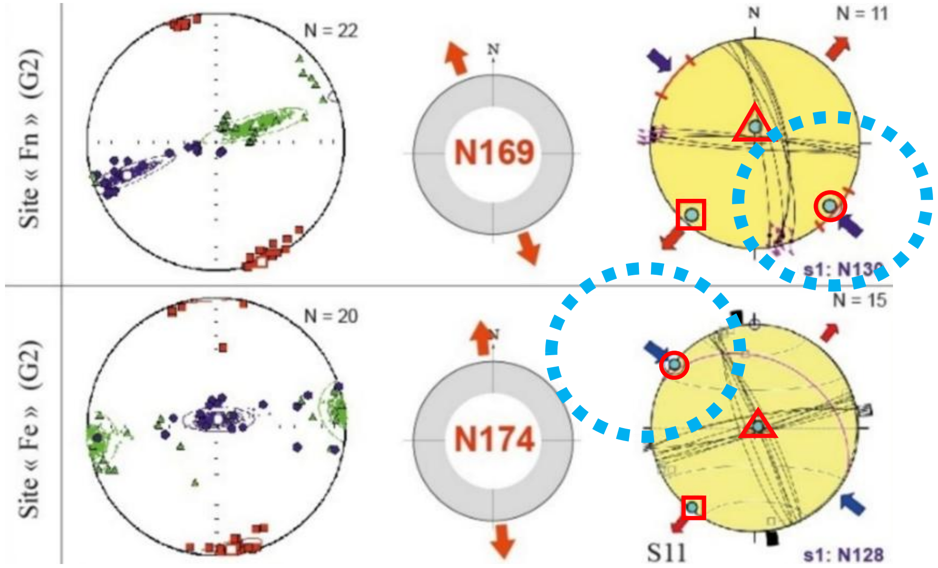
- E–W normal faults
- Sigma 1 is almost vertical.

Kmax aligned with sigma 3 & sigma 1 is vertical
→ compressional setting

Result 2 - AMS & Structural data



Sigma 1 = Largest principle stress



- Sigma 1
- Sigma 2
- Sigma 3

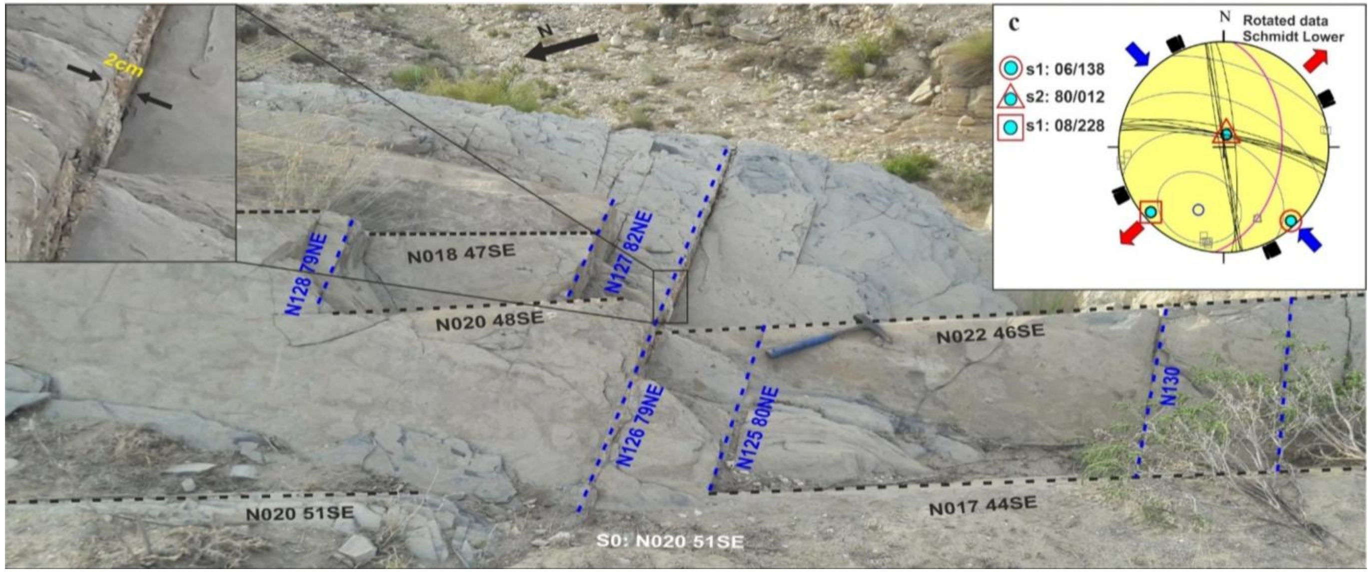
Kmax, Kint, Kmin

Sequence ②

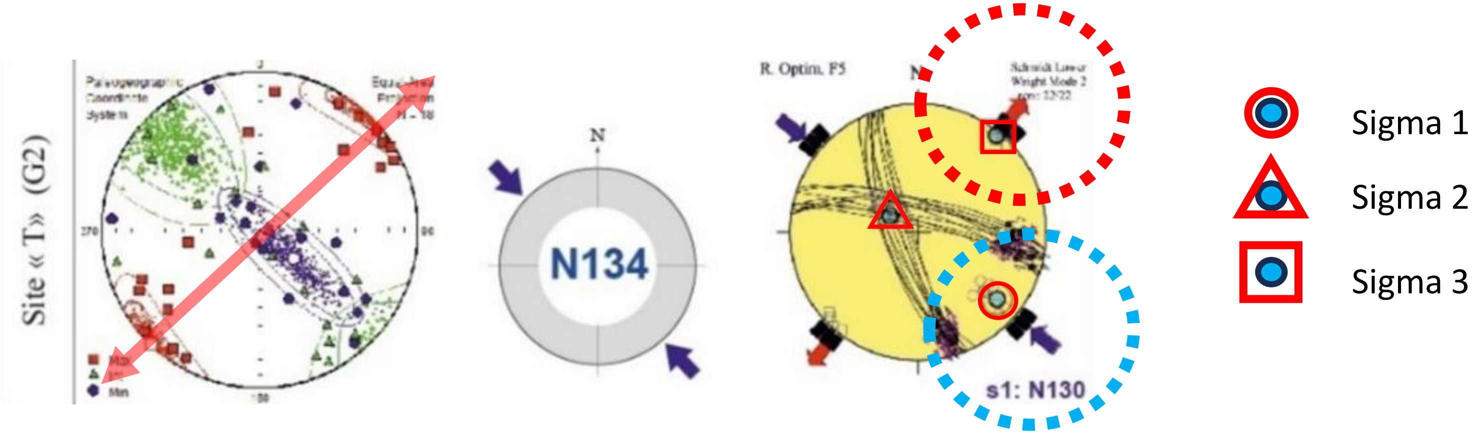
- 2 sets of conjugates
- Compression: N-S
- later period: NW-SE

- AMS shows a normal fabric, but Kmax axes misaligned with σ_3 → early extension signal preserved

Result 2 - AMS & Structural data



Sigma 1 = Largest principle stress



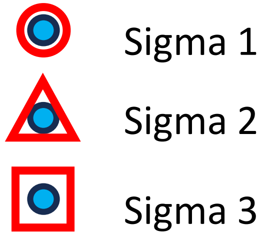
Sequence ③

- conjugate fractures reflect a NW–SE compressional regime

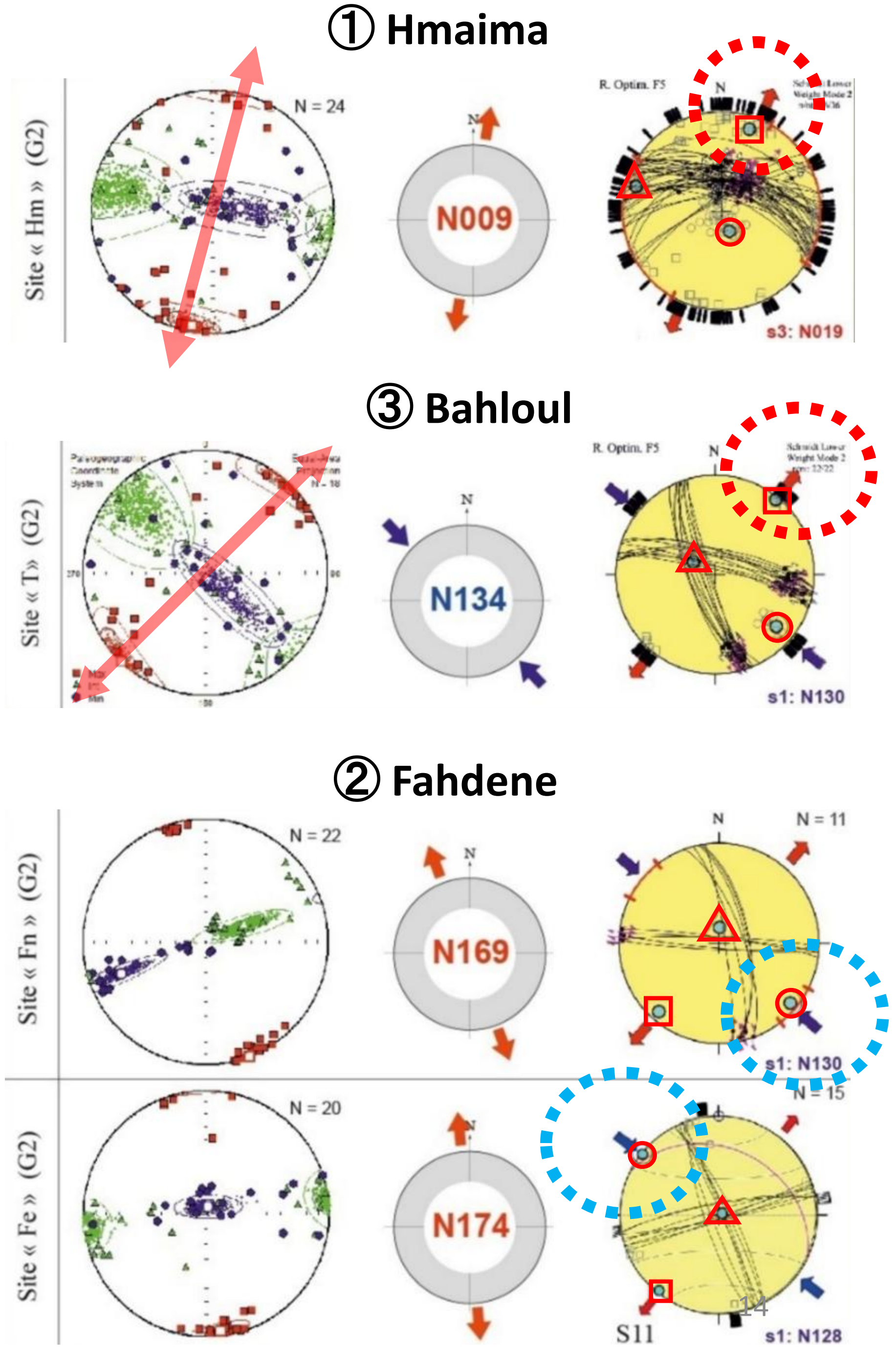
Kmax, Kint, Kmin

Discussions

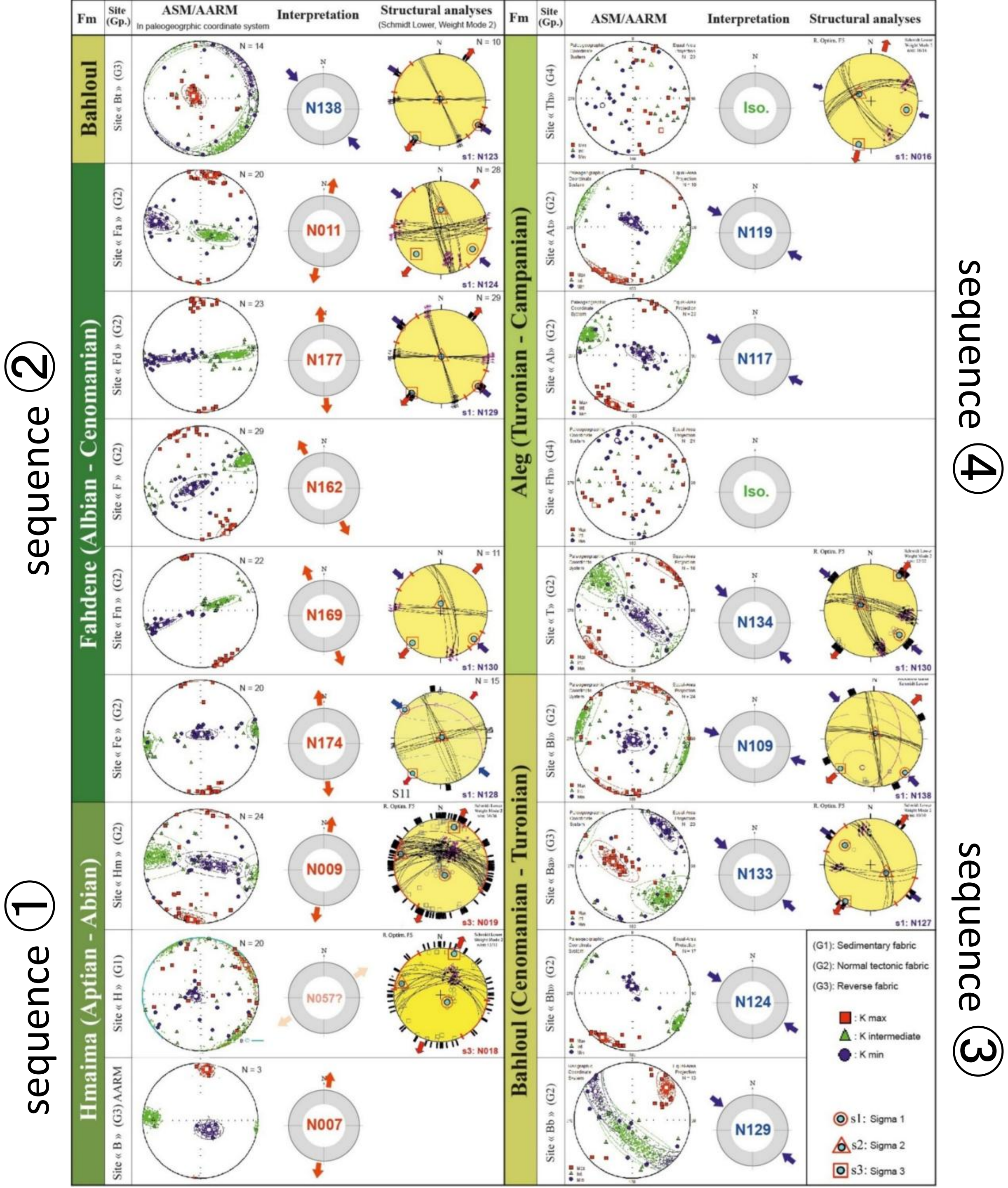
Kmax, Kint, Kmin

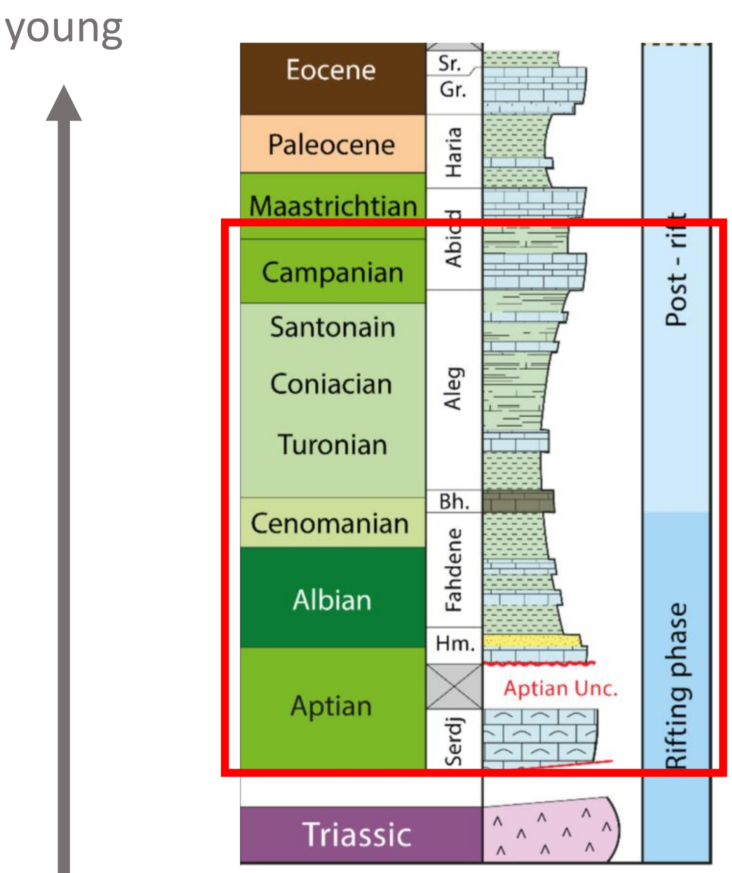


- AMS lineation aligns with tectonic σ3 in many sites (e.g., ①Hmaima), confirming extensional fabric.
- For the ③Bahloul, Kmax is perpendicular to the NW-SE trending "σ1" which is associated with the shortening direction.
- ②Fahdene shows exceptions: AMS fabric not always consistent with structural data.



Discussions



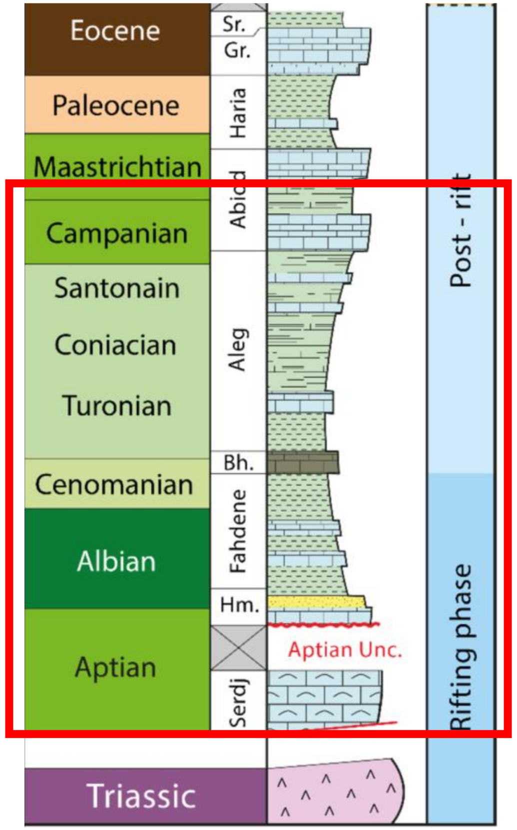


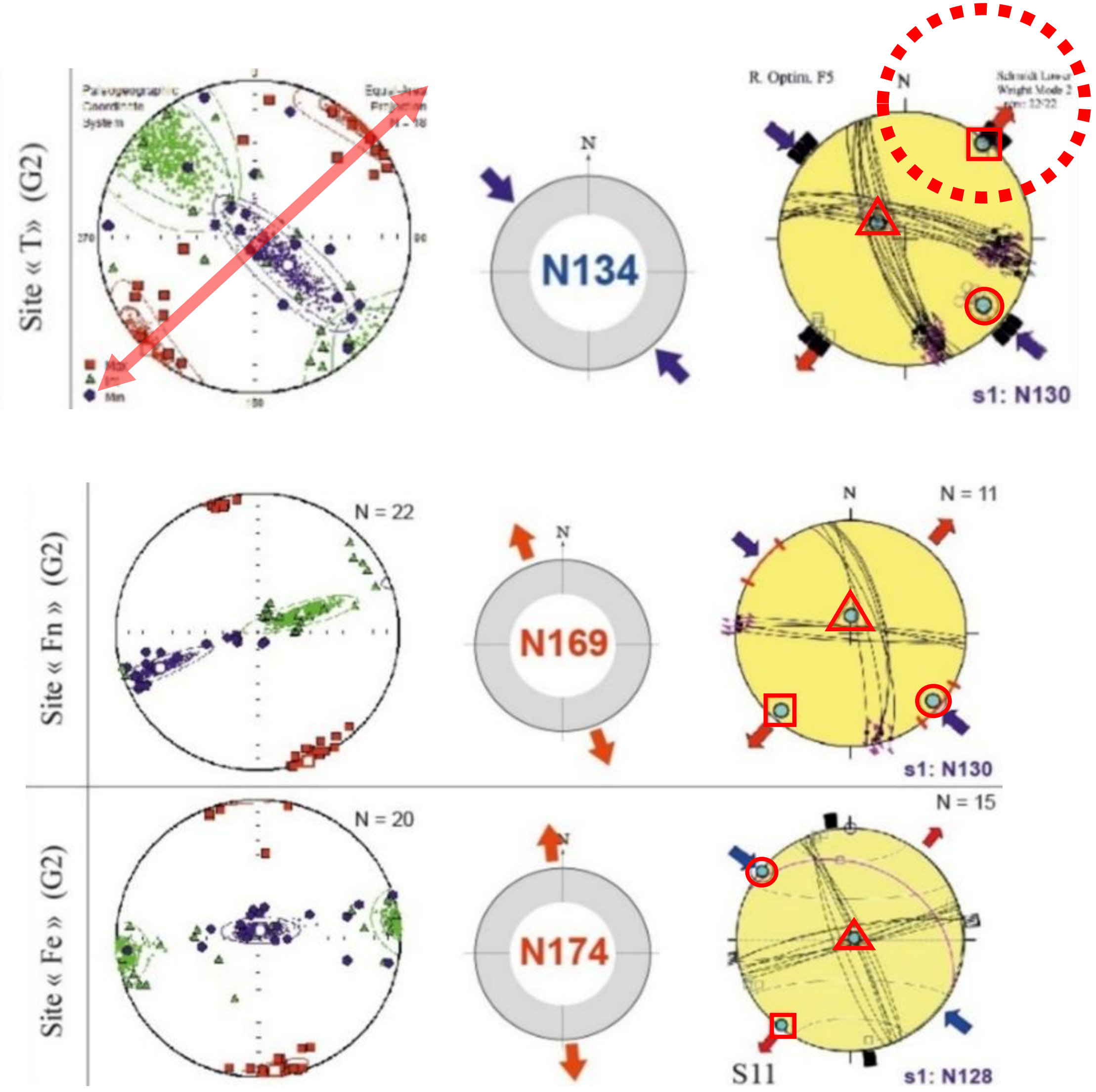
- AMS can retain tectonic memory beyond what brittle structures reveal, especially in low-strain formations.

Conclusion

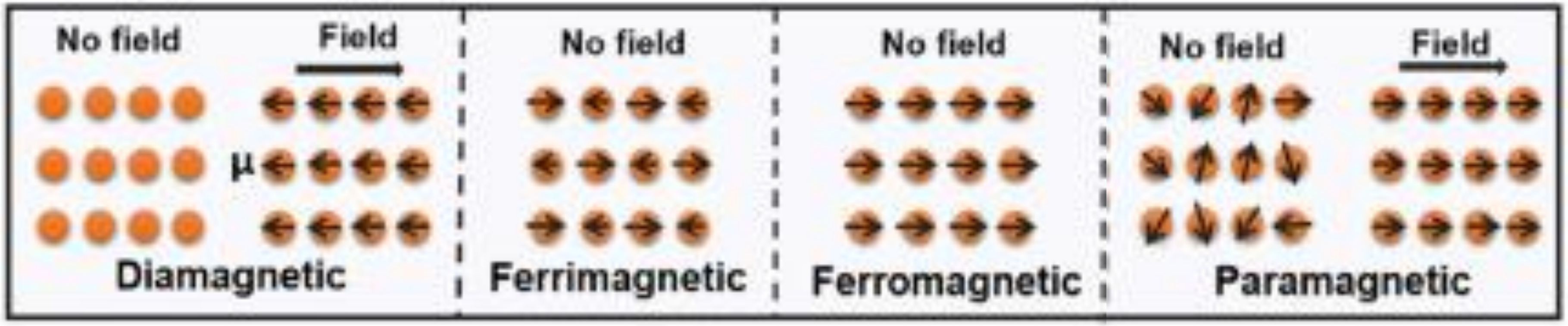
- The AMS fabric successfully captured deformation records formed during early burial or early tectonic processes at most sites.
- Even after later compressional events, AMS fabric remains well preserved in certain stratigraphic units.
- Normal magnetic fabric serves as an important tool for evaluating paleostress orientations in low-strain regions.

Thanks for your listening!


Eocene
Paleocene
Maastrichtian
Campanian
Santonain
Coniacian
Turonian
Cenomanian
Albian
Aptian
Triassic
Sr.
Gr.
Haria
Abiod
Aleg
Bh.
Fahdene
Hm.
Serdj
Aptian Unc.
Post - rift
Rifting phase

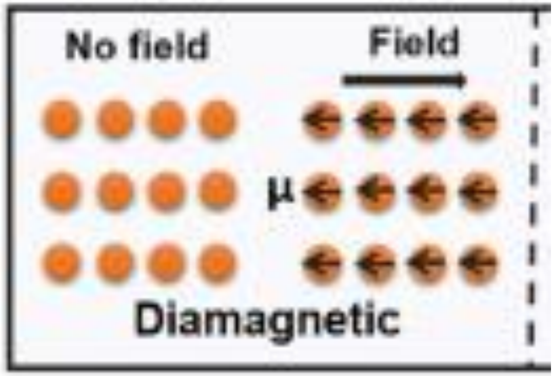

Site « T » (G2)
N134
R. Optim. F5
N
s1: N130
Site « Fn » (G2)
N = 22
N169
N = 11
s1: N130
Site « Fe » (G2)
N = 20
N174
N = 15
S11
s1: N128

dia-, para-, ferri-, ferromagnetic mineral



dia- magnetic mineral 抗磁性礦物

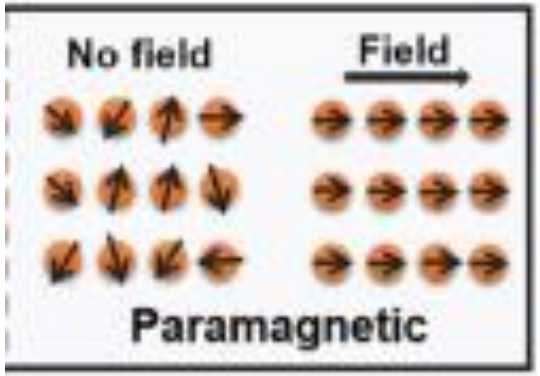
- Characteristics:
  - Exhibits very weak magnetism only in the presence of an external magnetic field, and the induced magnetization is in the opposite direction of the applied field. The magnetism disappears immediately once the field is removed.



- Examples:
  - Quartz, Calcite, Gold, Bismuth, and other non-magnetic minerals.
- Magnetic origin:
  - No unpaired electrons; the magnetic response arises from induced currents in electron orbitals that generate a magnetic moment opposing the external field.

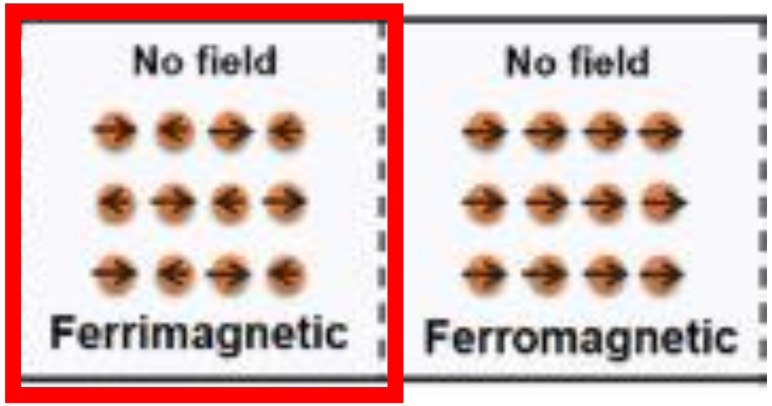
para- magnetic mineral 順磁性礦物

- Characteristics:
  - Slightly magnetized only in the presence of an external magnetic field; very weak magnetism and does not retain magnetization once the field is removed.
- Examples:
  - Illite, Kaolinite, Muscovite, and other clay minerals.
- Magnetic origin:
  - Weak magnetic moments due to unpaired electrons.



ferri- magnetic mineral 次鐵磁性礦物

- Characteristics:
  - Intermediate between paramagnetic and ferromagnetic; exhibit strong but weaker magnetism than ferromagnetic minerals.
- Examples:
  - Magnetite, Maghemite, Pyrrhotite
- Magnetic origin:
  - Magnetic moments in opposite directions are not fully canceled out, resulting in residual magnetism.

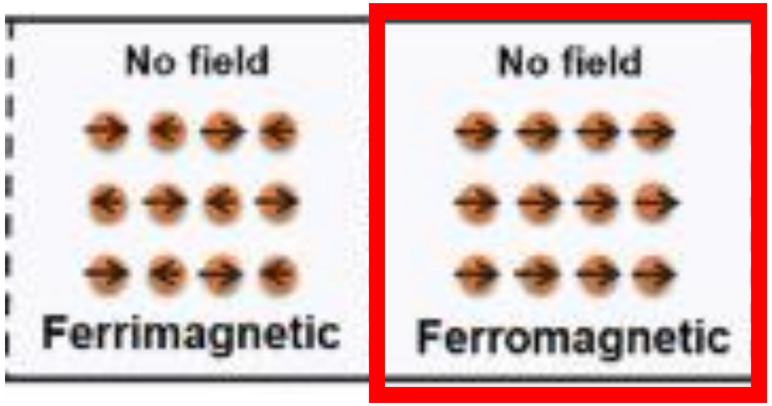


ferro- magnetic mineral 鐵磁性礦物

- Characteristics:
  - Can retain strong magnetization permanently, even without an external magnetic field.
- Examples:
  - Iron (Fe), Nickel (Ni), Cobalt (Co).
- Magnetic origin:
  - Spontaneous alignment of magnetic moments, producing strong magnetic fields.

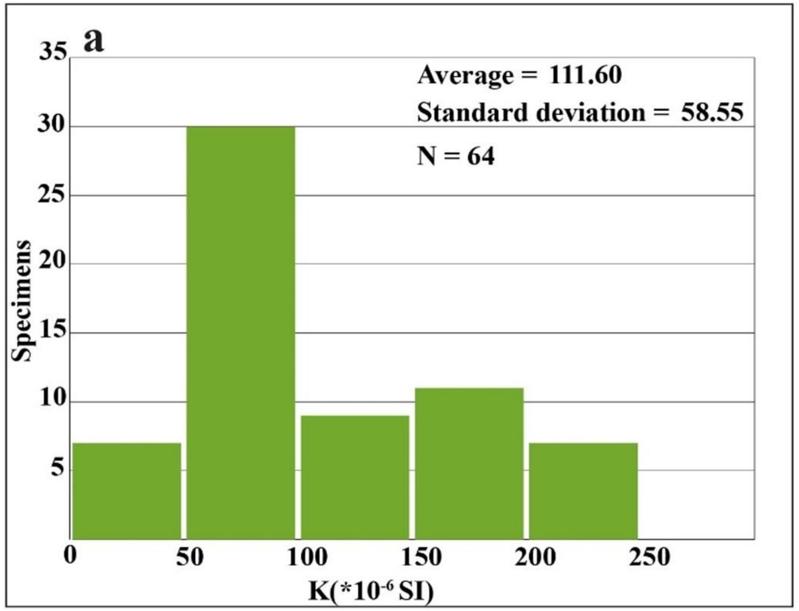
✓ NOTE**

These minerals may dominate AMS signals during analysis, but are relatively rare in sedimentary rocks.

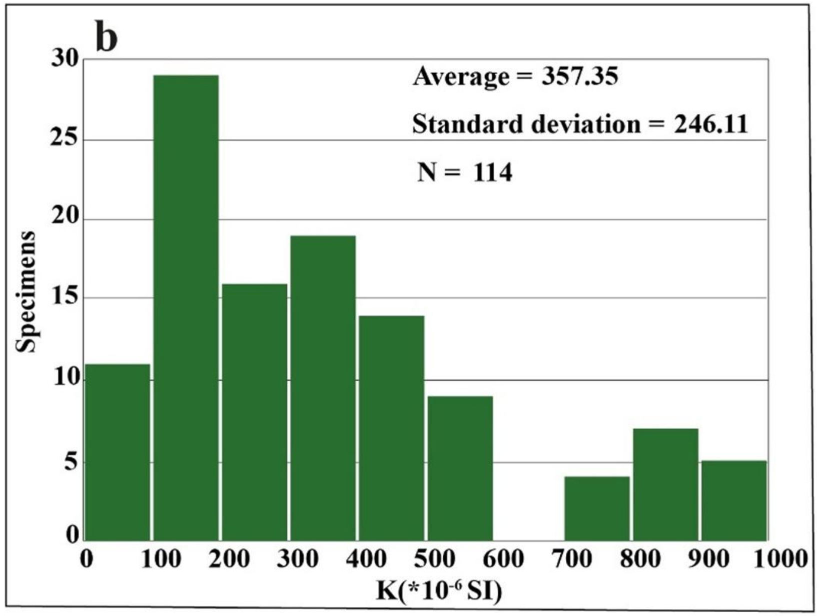


K: magnetic susceptibility $K = \frac{(K_{max}+K_{int}+K_{min})}{3}$

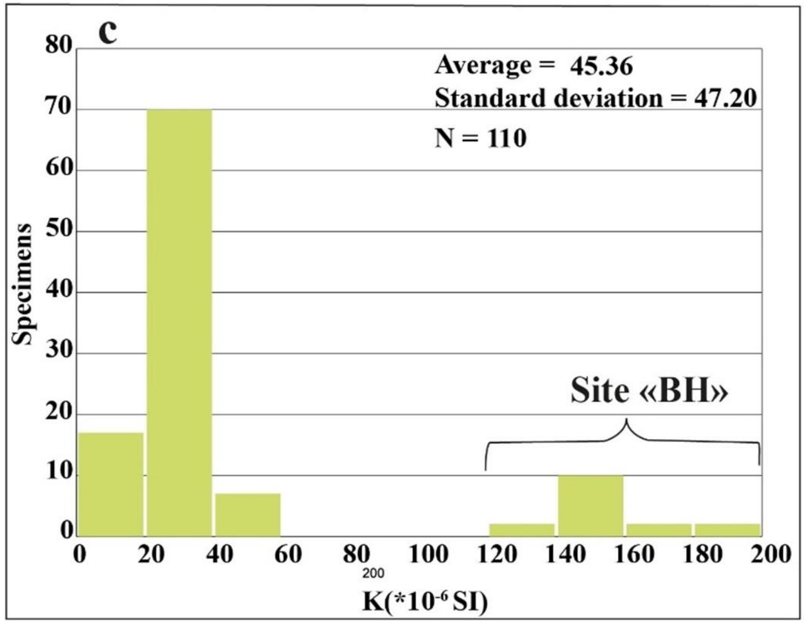
① Hmaima



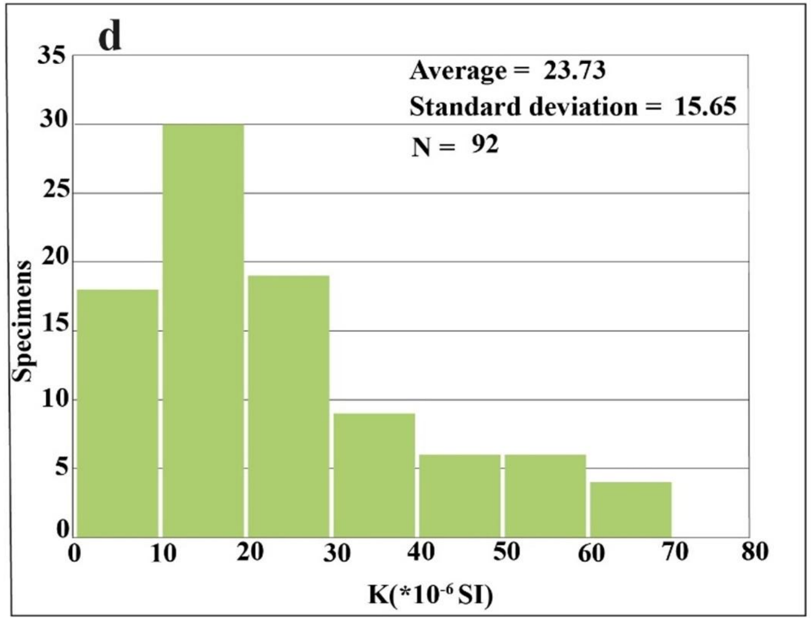
② Fahdene

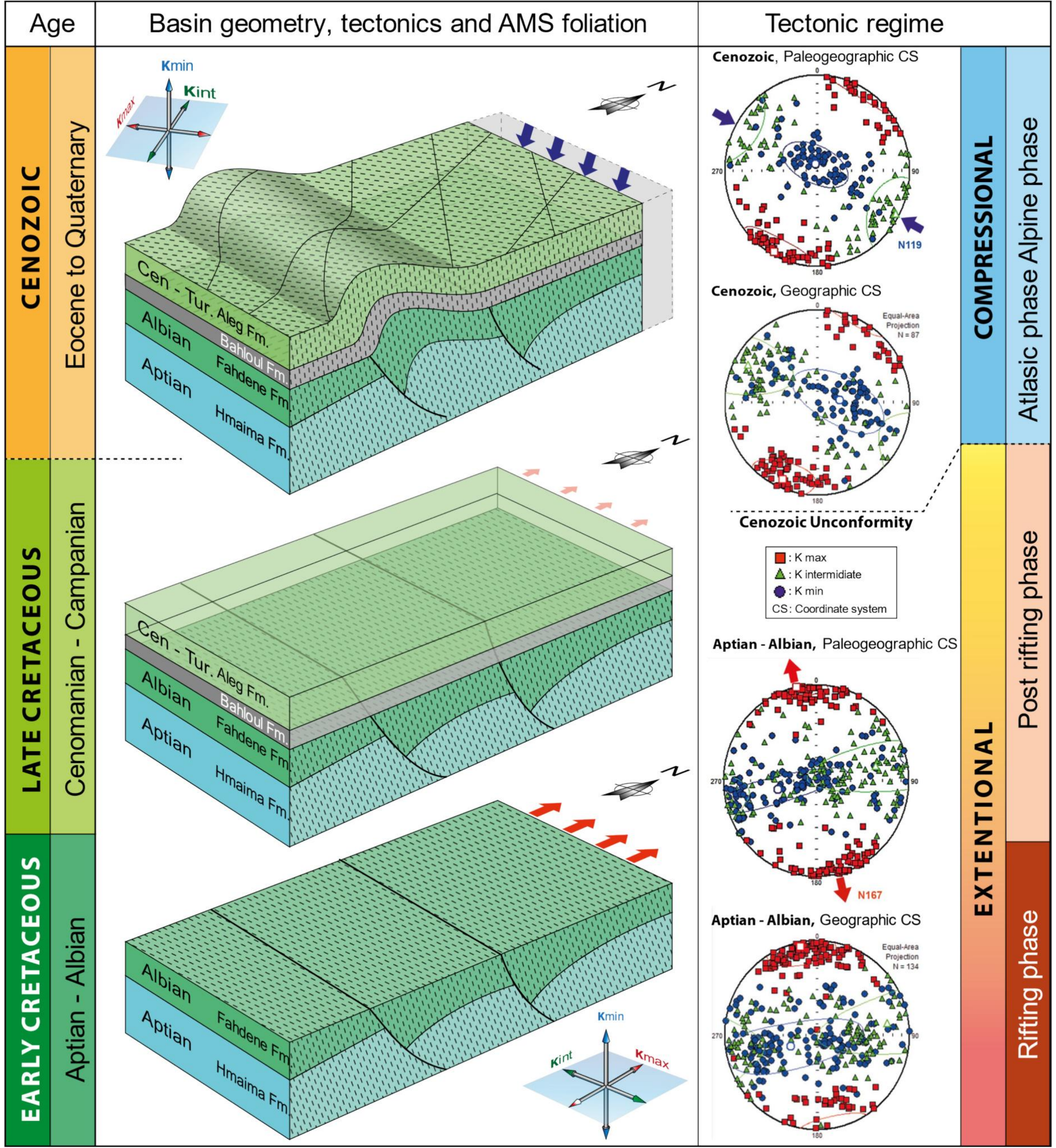


③ Bahloul



④ Aleg





Age
Basin geometry, tectonics and AMS foliation
Tectonic regime
CENOZOIC
Eocene to Quaternary
LATE CRETACEOUS
Cenomanian - Campanian
EARLY CRETACEOUS
Aptian - Albian
Kmin
Kint
Kmax
Cen - Tur. Aleg Fm.
Bahloul Fm.
Albian
Fahdene Fm.
Aptian
Hmaima Fm.
Cenozoic, Paleogeographic CS
N119
Cenozoic, Geographic CS
Equal-Area Projection N = 87
Cenozoic Unconformity
: K max
: K intermidiate
: K min
CS : Coordinate system
Aptian - Albian, Paleogeographic CS
N167
Aptian - Albian, Geographic CS
Equal-Area Projection N = 134
COMPRESSIONAL
Atlasic phase Alpine phase
EXTENTIONAL
Post rifting phase
Rifting phase