UNIVERSITÉ DE STRASBOURG

Institut de Physique du Globe de Strasbourg

Ecole et Observatoire des Sciences de la Terre

Laboratoire d'Hydrologie et de Géochimie de Strasbourg

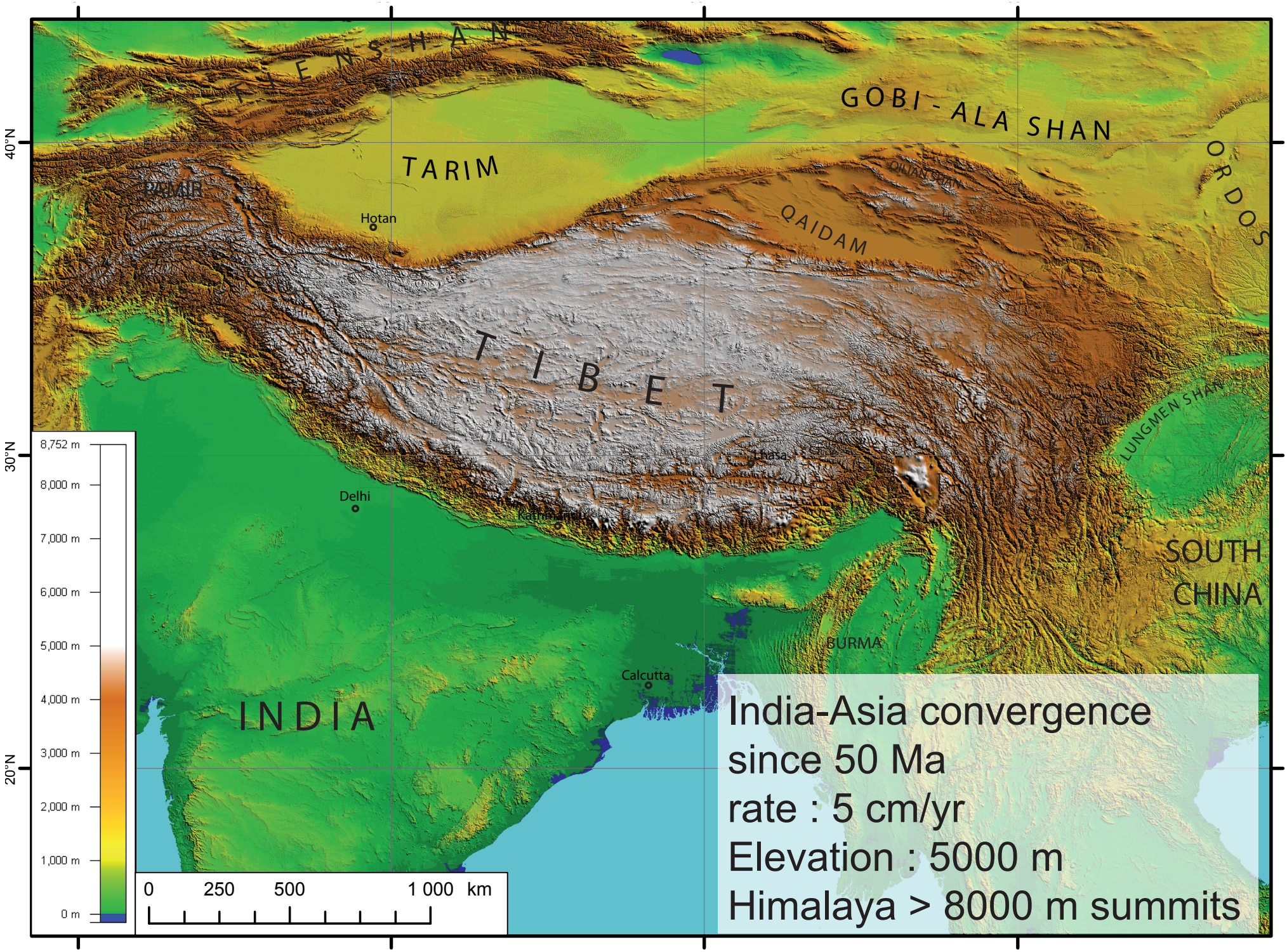
Ecole et Observatoire des Sciences de la Terre

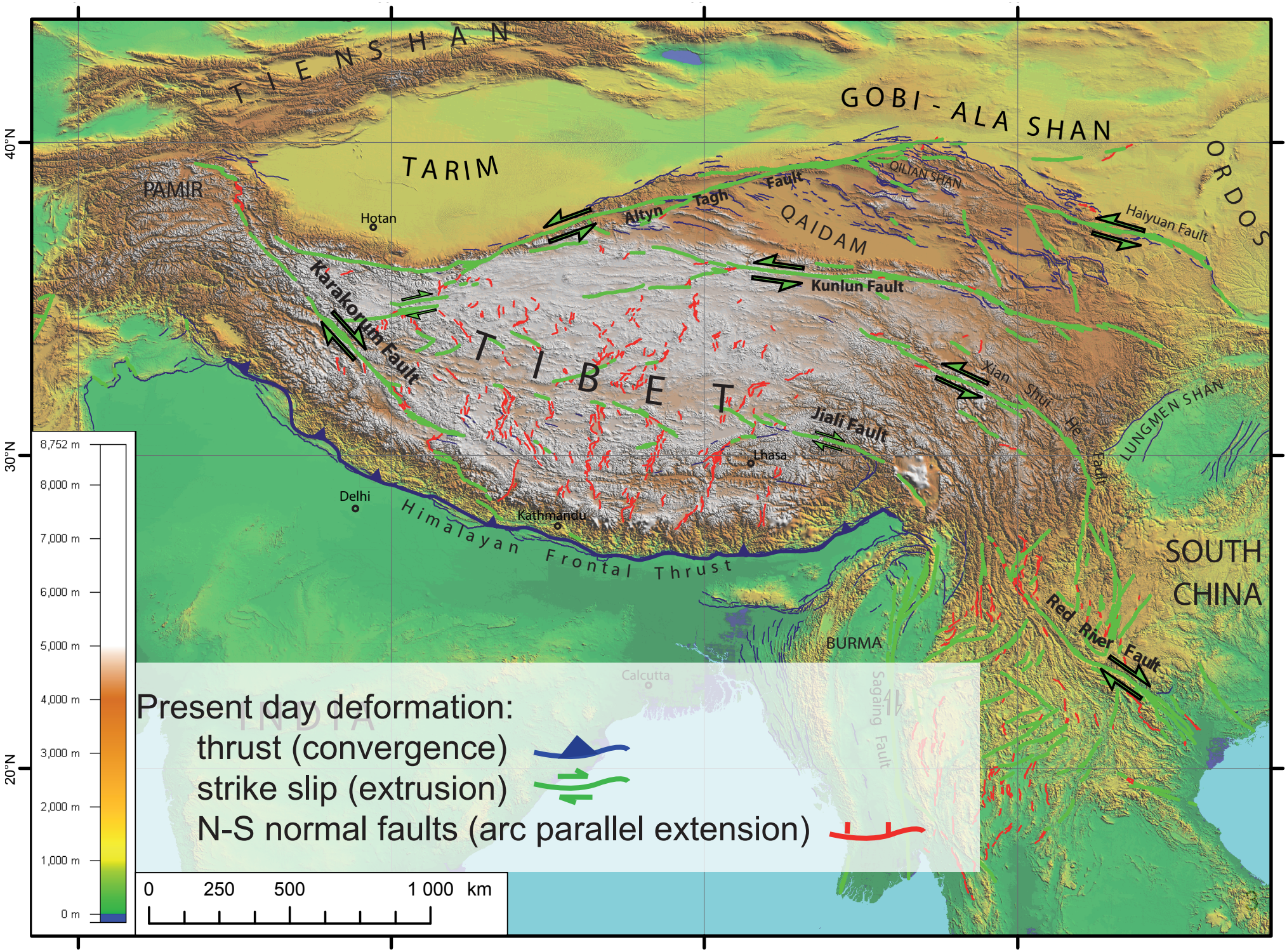
De la déformation long-terme à court-terme sur les failles normales du Sud-Tibet

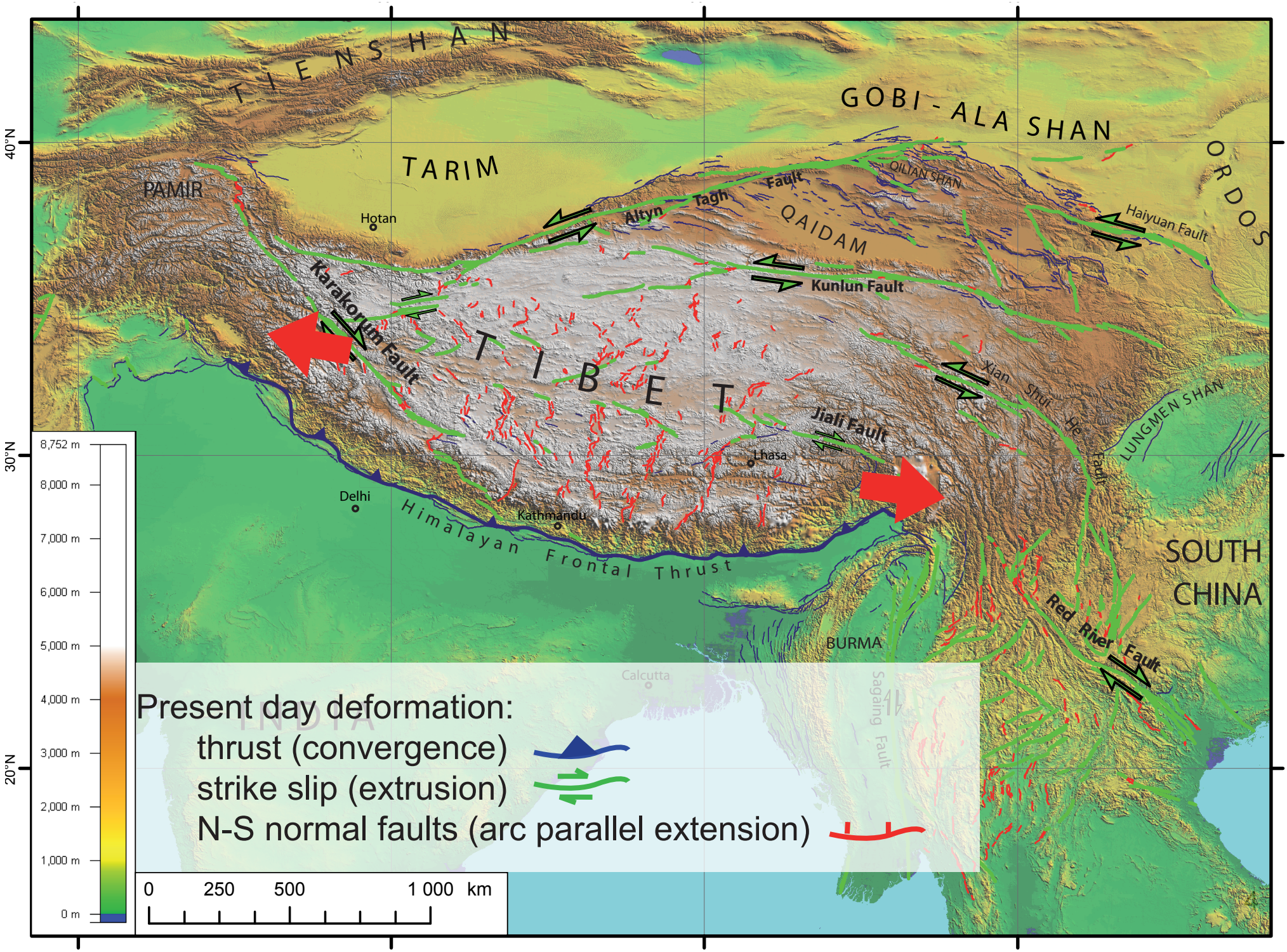
Approche géochronologique multi-méthode (^{10}Be, ^{26}Al, (U-Th)/He, ^{40}Ar/^{39}Ar, U/Pb)

Elise Kali

Soutenance de thèse
22 novembre 2010


TIENSHAN
GOBI - ALA SHAN
ORDOS
TARIM
PAMIR
Hotan
QILIAN SHAN
QAIDAM
TIBET
LUNGMEN SHAN
Lhasa
Delhi
Kathmandu
SOUTH CHINA
BURMA
Calcutta
INDIA
40°N
30°N
20°N
8,752 m
8,000 m
7,000 m
6,000 m
5,000 m
4,000 m
3,000 m
2,000 m
1,000 m
0 m
0 250 500 1 000 km
India-Asia convergence
since 50 Ma
rate : 5 cm/yr
Elevation : 5000 m
Himalaya > 8000 m summits


TIENSHAN
GOBI - ALA SHAN
ORDOS
TARIM
PAMIR
QILIAN SHAN
Altyn Tagh Fault
QAIDAM
Haiyuan Fault
Kunlun Fault
Karakorum Fault
TIBET
Xian Shuit He Fault
LUNGMEN SHAN
Jiali Fault
Hotan
Lhasa
Delhi
Kathmandu
Himalayan Frontal Thrust
SOUTH CHINA
Red River Fault
BURMA
Calcutta
INDIA
Sagaing Fault
40°N
30°N
20°N
8,752 m
8,000 m
7,000 m
6,000 m
5,000 m
4,000 m
3,000 m
2,000 m
1,000 m
0 m
Present day deformation:
thrust (convergence)
strike slip (extrusion)
N-S normal faults (arc parallel extension)
0 250 500 1 000 km


TIENSHAN
GOBI-ALASHAN
ORDOS
TARIM
PAMIR
QILIAN SHAN
QAIDAM
Altyn Tagh Fault
Haiyuan Fault
Kunlun Fault
Karakorum Fault
TIBET
Xian Shuit He Fault
LUNGMEN SHAN
Jiali Fault
Hotan
Lhasa
Delhi
Kathmandu
Himalayan Frontal Thrust
SOUTH CHINA
Red River Fault
BURMA
Calcutta
Sagaing Fault
INDIA
40°N
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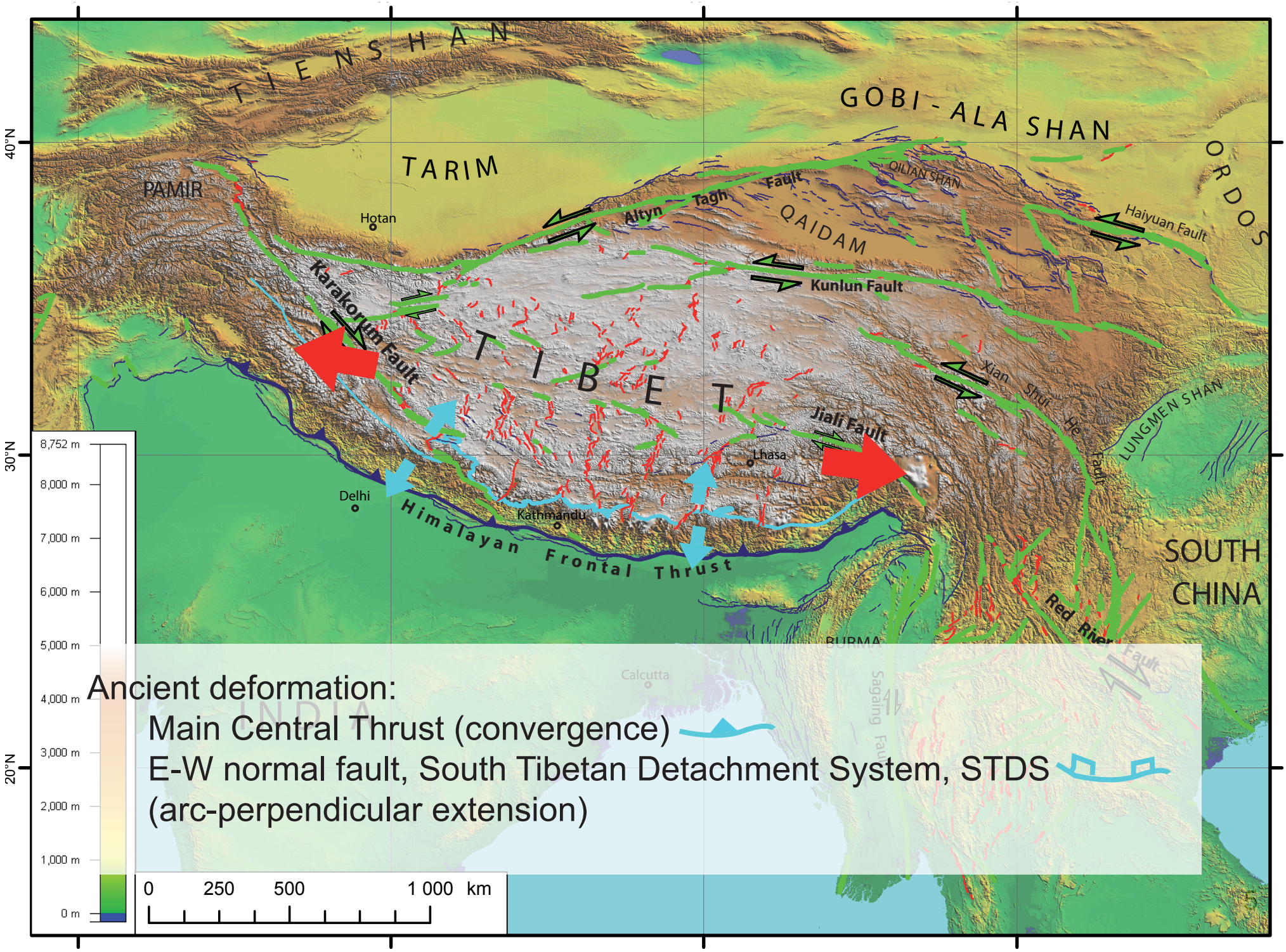
8,752 m
8,000 m
7,000 m
6,000 m
5,000 m
4,000 m
3,000 m
2,000 m
1,000 m
0 m
Present day deformation:
thrust (convergence)
strike slip (extrusion)
N-S normal faults (arc parallel extension)
0 250 500 1 000 km


TIENSHAN
GOBI - ALA SHAN
ORDOS
TARIM
PAMIR
QILIAN SHAN
QAIDAM
Altyn Tagh Fault
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Kunlun Fault
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Himalayan Frontal Thrust
SOUTH CHINA
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INDIA
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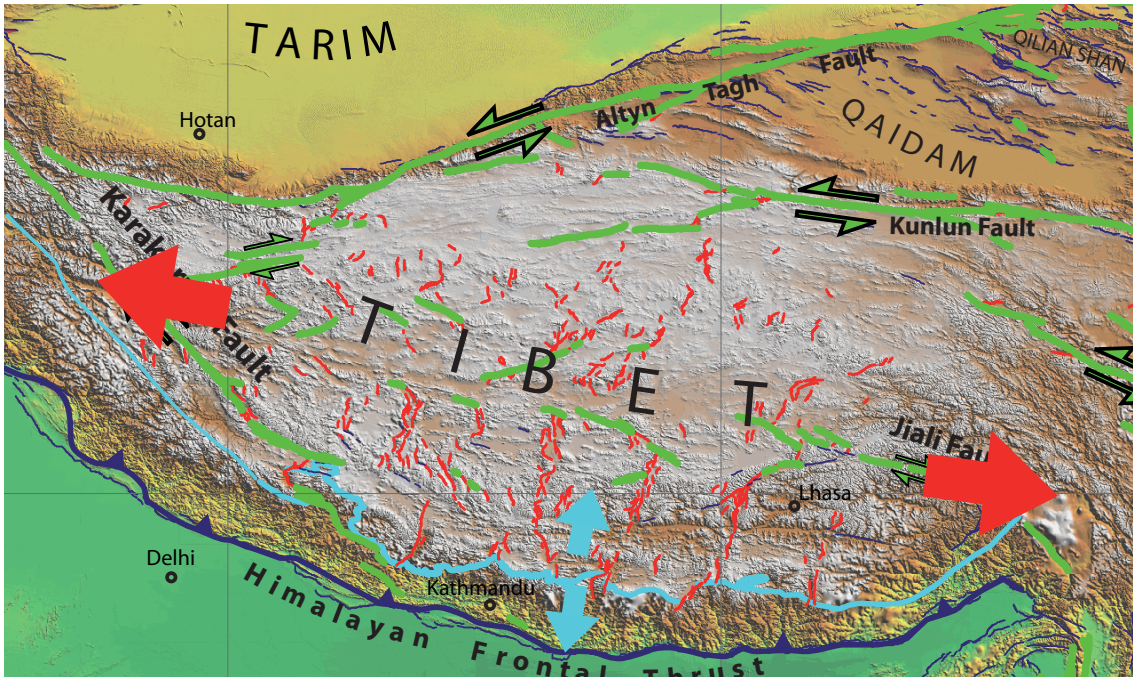
40°N
30°N
20°N
8,752 m
8,000 m
7,000 m
6,000 m
5,000 m
4,000 m
3,000 m
2,000 m
1,000 m
0 m
0 250 500 1 000 km
Ancient deformation:
Main Central Thrust (convergence)
E-W normal fault, South Tibetan Detachment System, STDS
(arc-perpendicular extension)

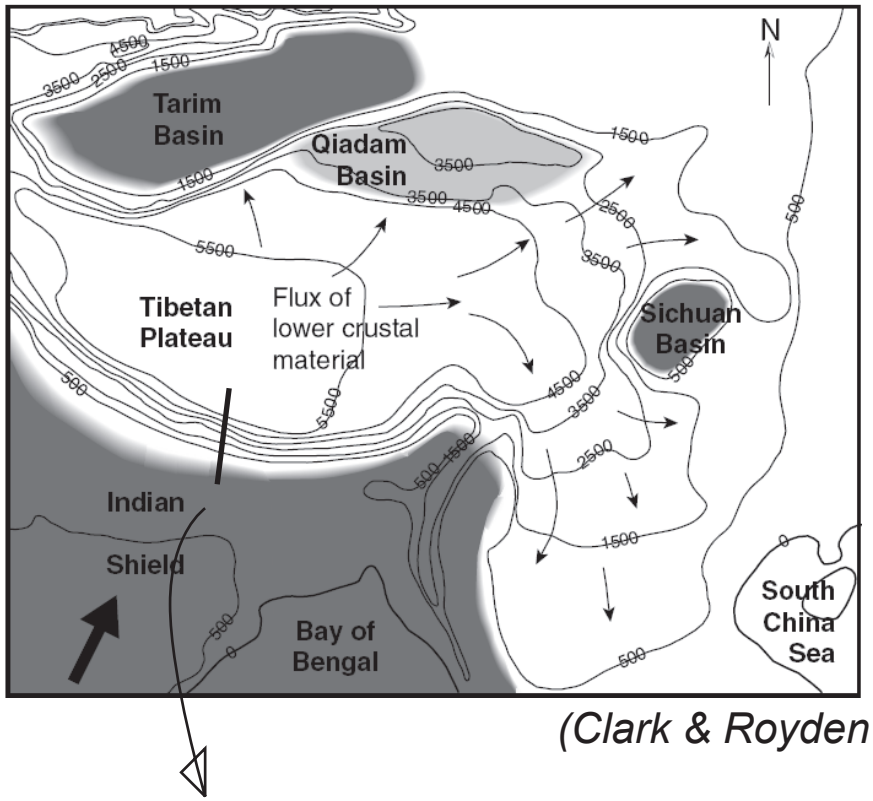
- Ancient perpendicular extension: South Tibetan Detachment System or «Faille Nord Himalayenne»

- Present day parallel extension : N-S Normal Faults

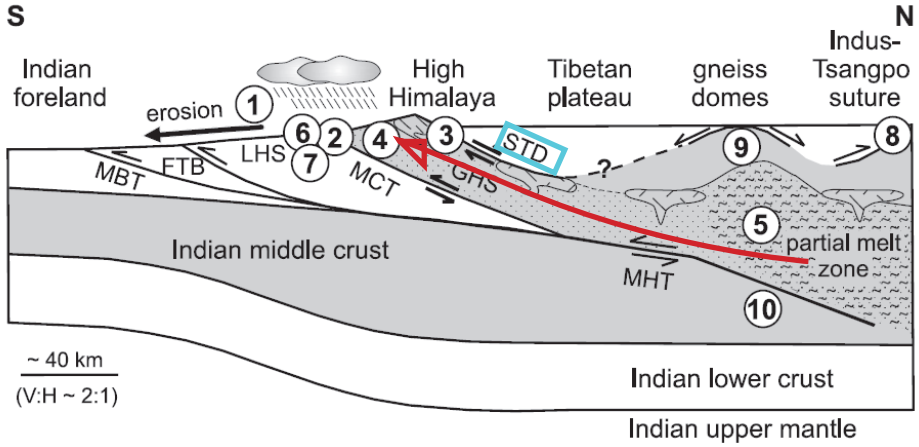
Various models have been proposed to explain extension across the Tibetan plateau:
- «Gravitary» models
- «Block» models



Gravitary models



(Clark & Royden 2000)



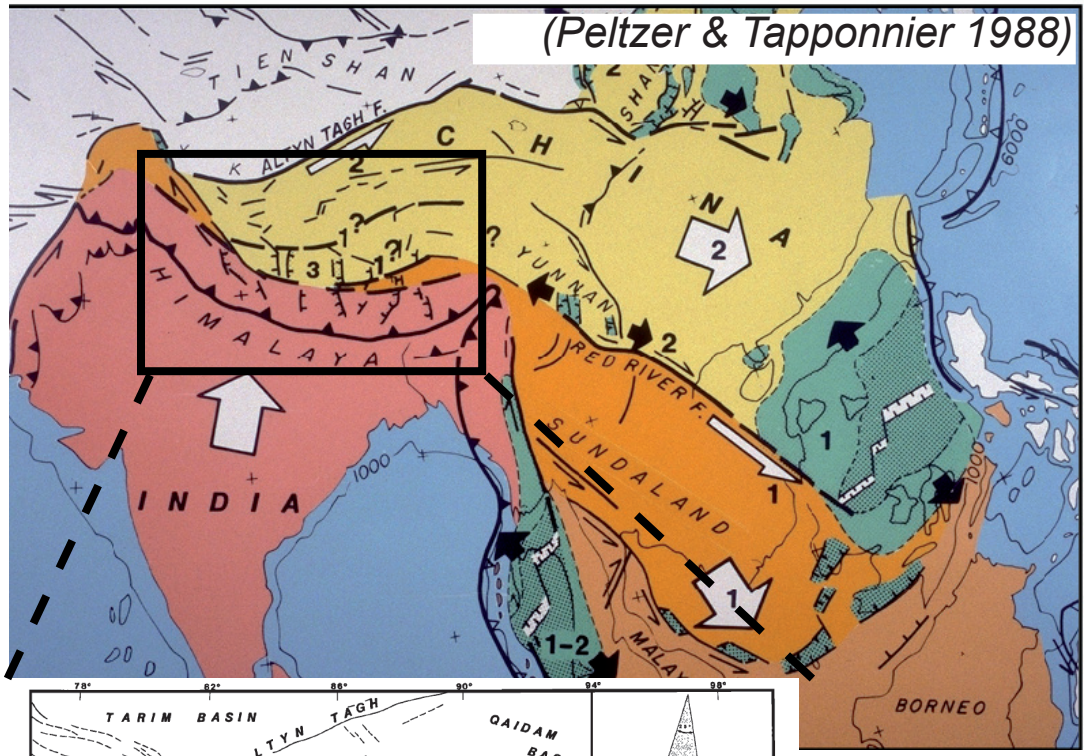
(Beaumont et al., 2004)

-Diffuse deformation across the plateau

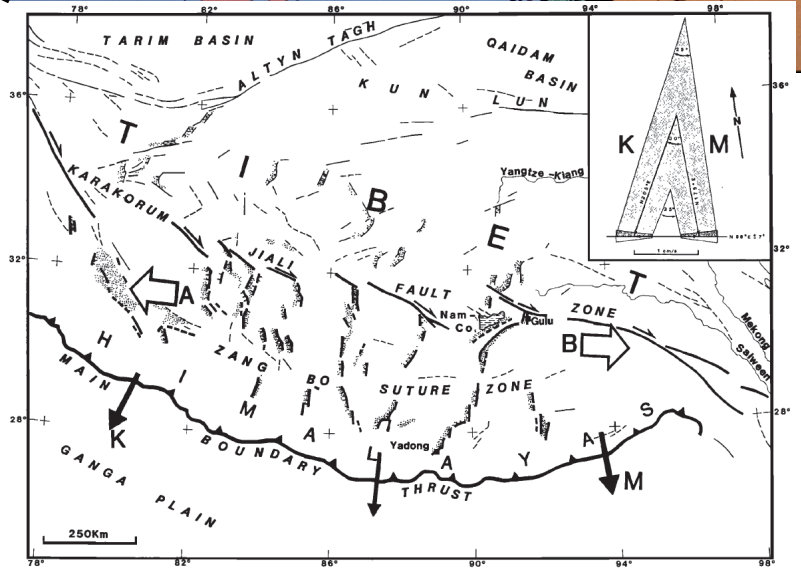
-Large strike slip faults are minor players

-Arc parallel extension explained by orogenic collapse

-Arc perpendicular extension explained by exhumation of «Channel Flow»



(Peltzer & Tapponnier 1988)

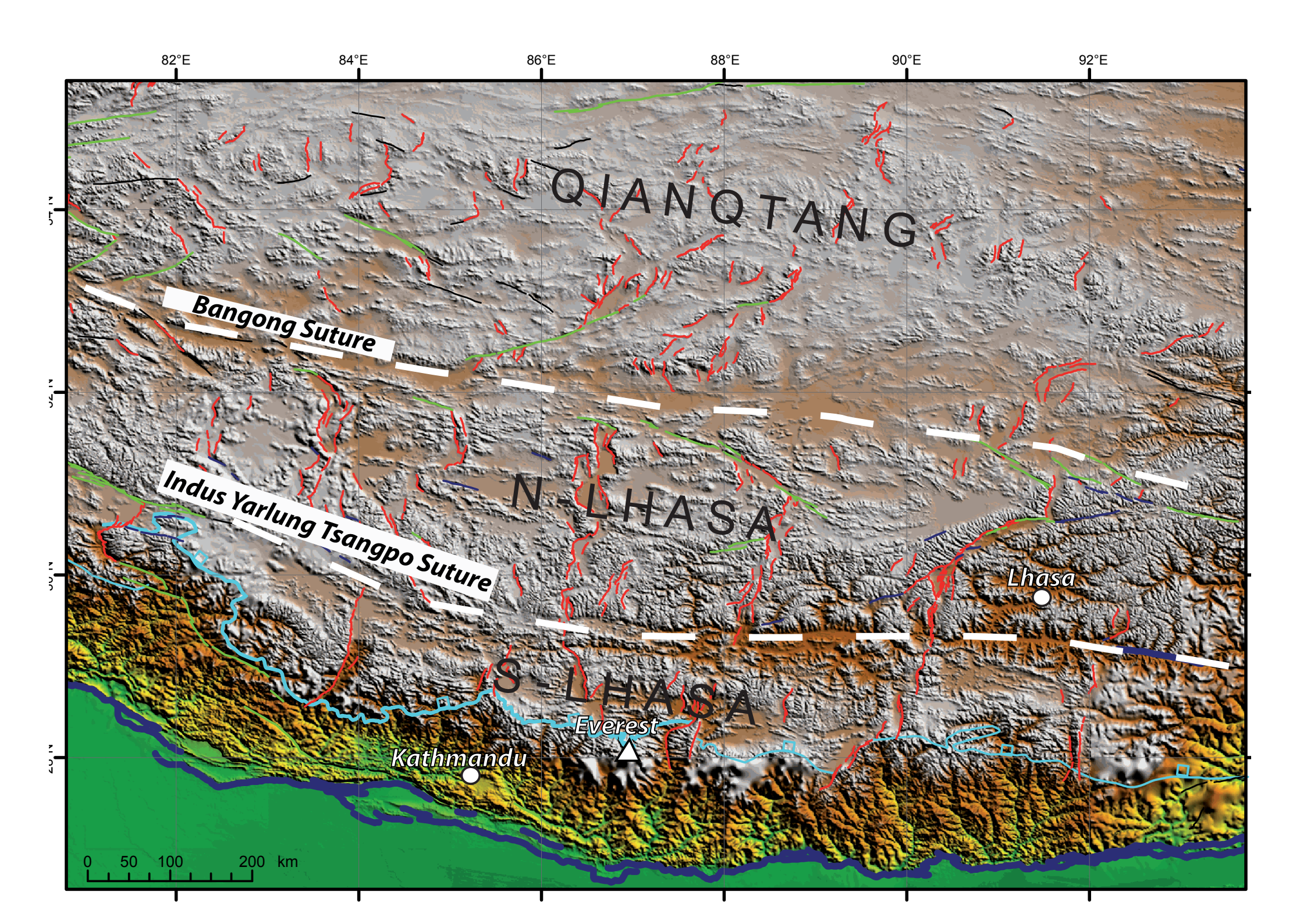


(Armijo et al., 1986)

-Main deformation is localized at block boundaries

-Internal deformation of blocks is minor

-N-S normal faulting in South-Tibet linked to extrusion (right lateral faulting along Karakorum-Jiali Fault Zone)


82°E
84°E
86°E
88°E
90°E
92°E
QIANGTANG
Bangong Suture
N-LHASA
Indus Yarlung Tsangpo Suture
S-LHASA
Lhasa
Everest
Kathmandu
0 50 100 200 km

Extension in Tibet?

How are normal fault distributed?

-crustal thickness
-plateau elevation
-geology

Initiation when and where ?

- Age of early deformation

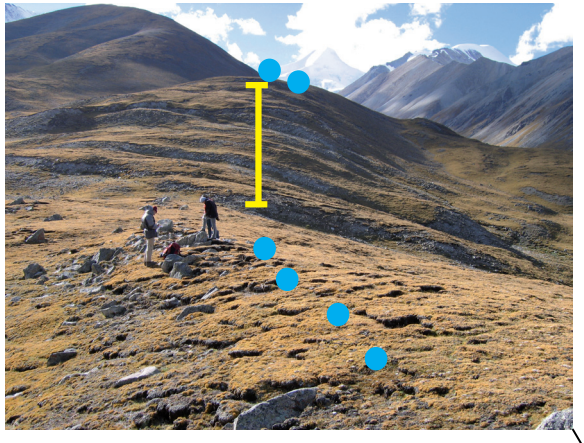
Continuous since initiation?

- Slip rate variation
- Phased extension

Mechanisms?

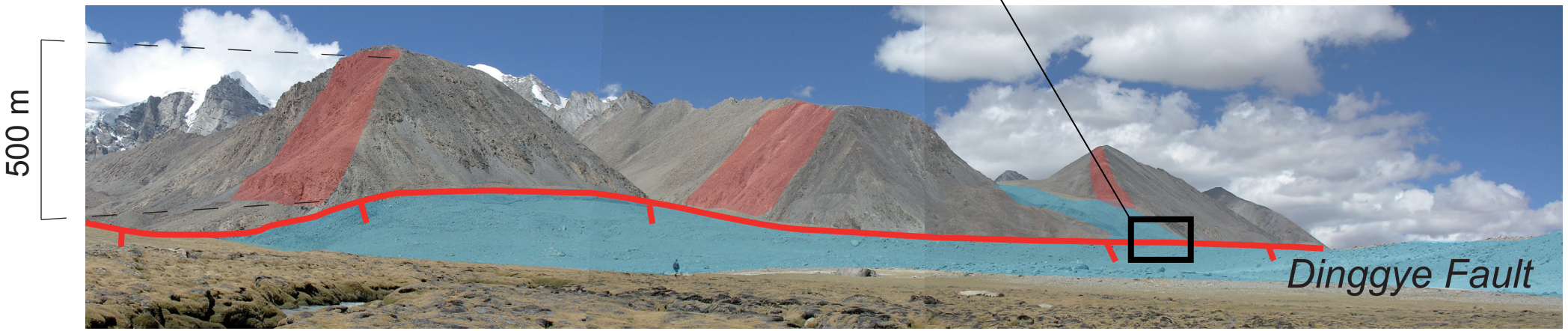

500 m
Dinggye Fault

Short-term Deformation Quantification

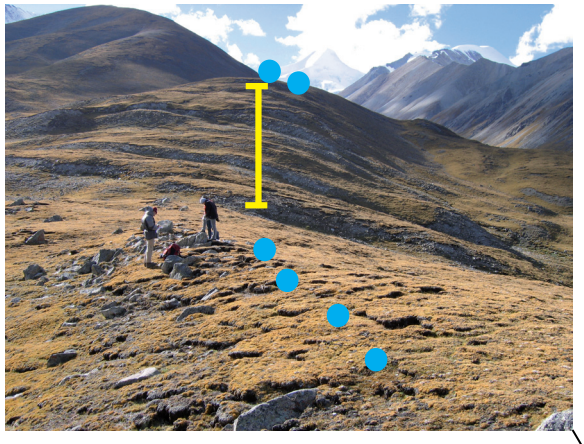


Morpho-tectonic analysis
+
isotope cosmogenic datations
(^{10}Be - ^{26} Al)

Vertical Slip-Rates

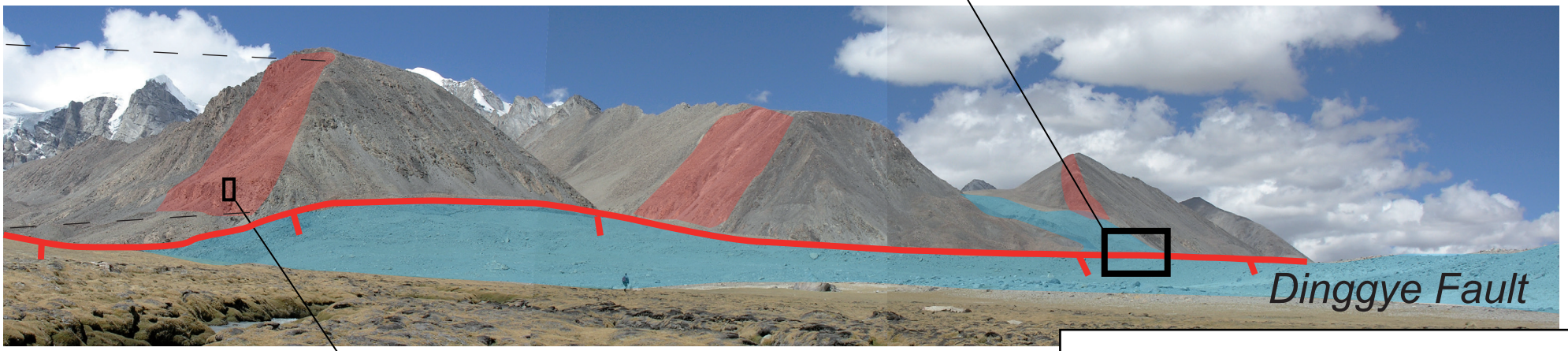


Short-term Deformation Quantification



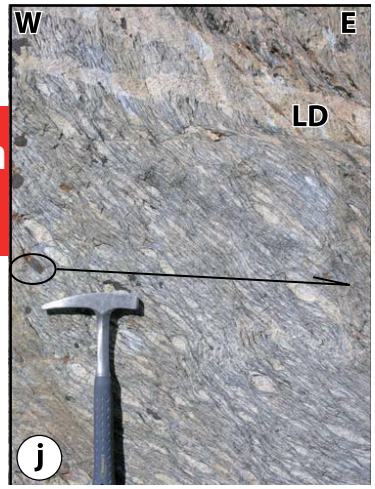
Morpho-tectonic analysis
+
isotope cosmogenic datations
(^{10}Be - ^{26} Al)

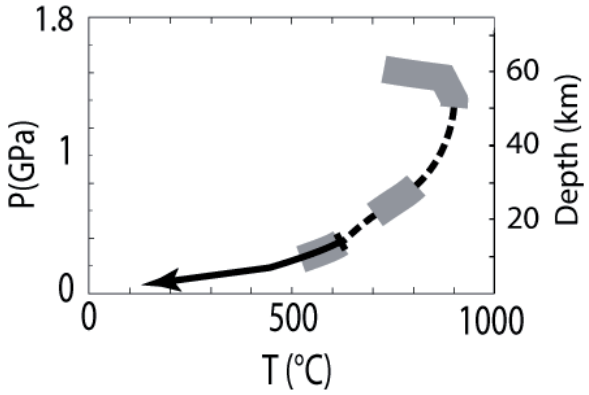
Vertical Slip-Rates



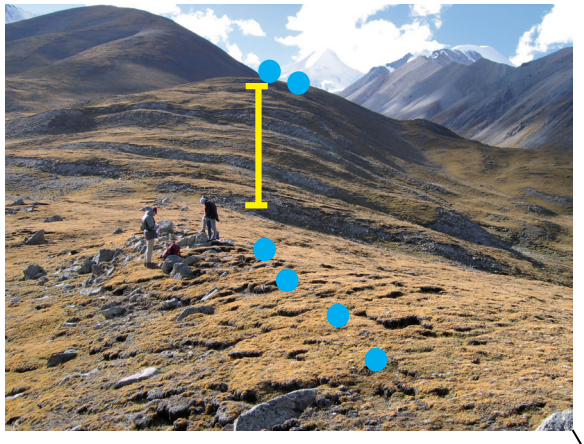
Structural geology & Petrology
+
(U-Th)/He, ^{40}Ar/^{39}Ar, U/Pb datations
--> (P-T-t-D paths)

Long-term Deformation Quantification



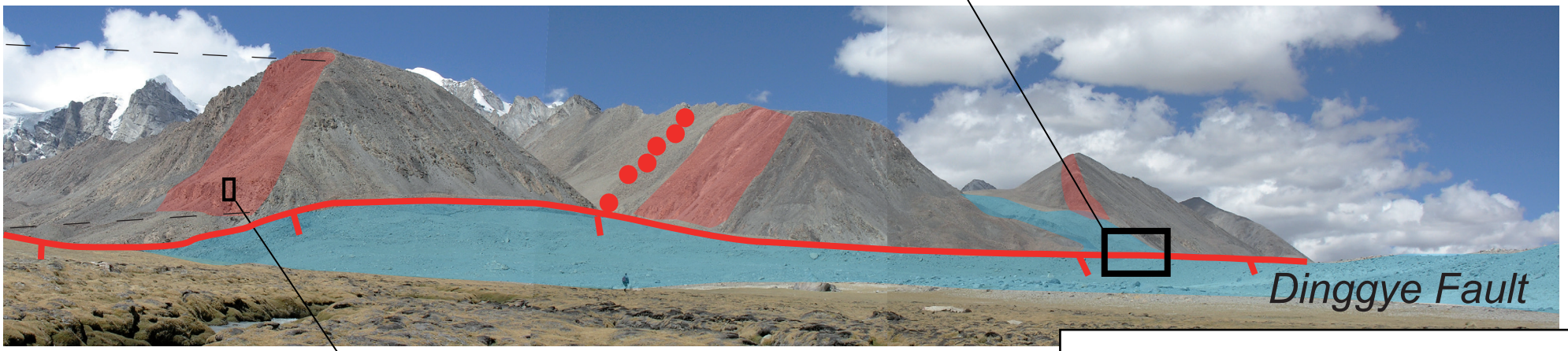


Short-term Deformation Quantification

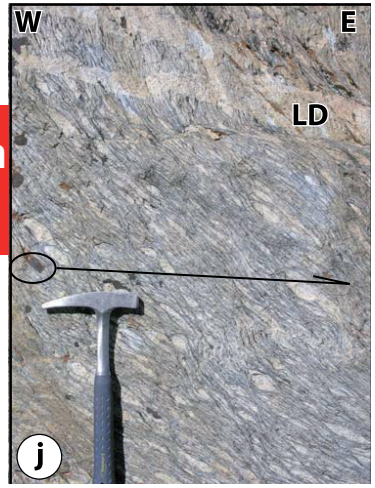


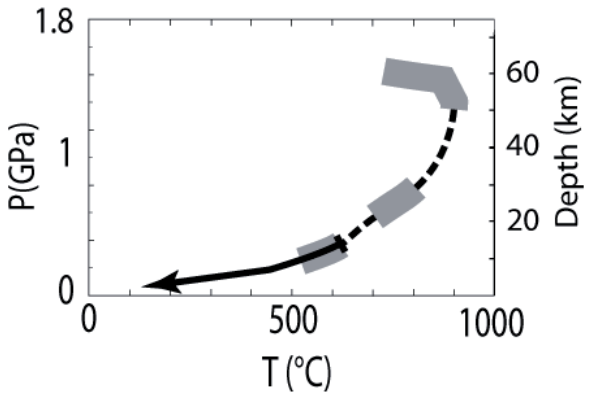
Morpho-tectonic analysis
+
isotope cosmogenic datations
(^{10}Be - ^{26} Al)

Vertical Slip-Rates



Long-term Deformation Quantification

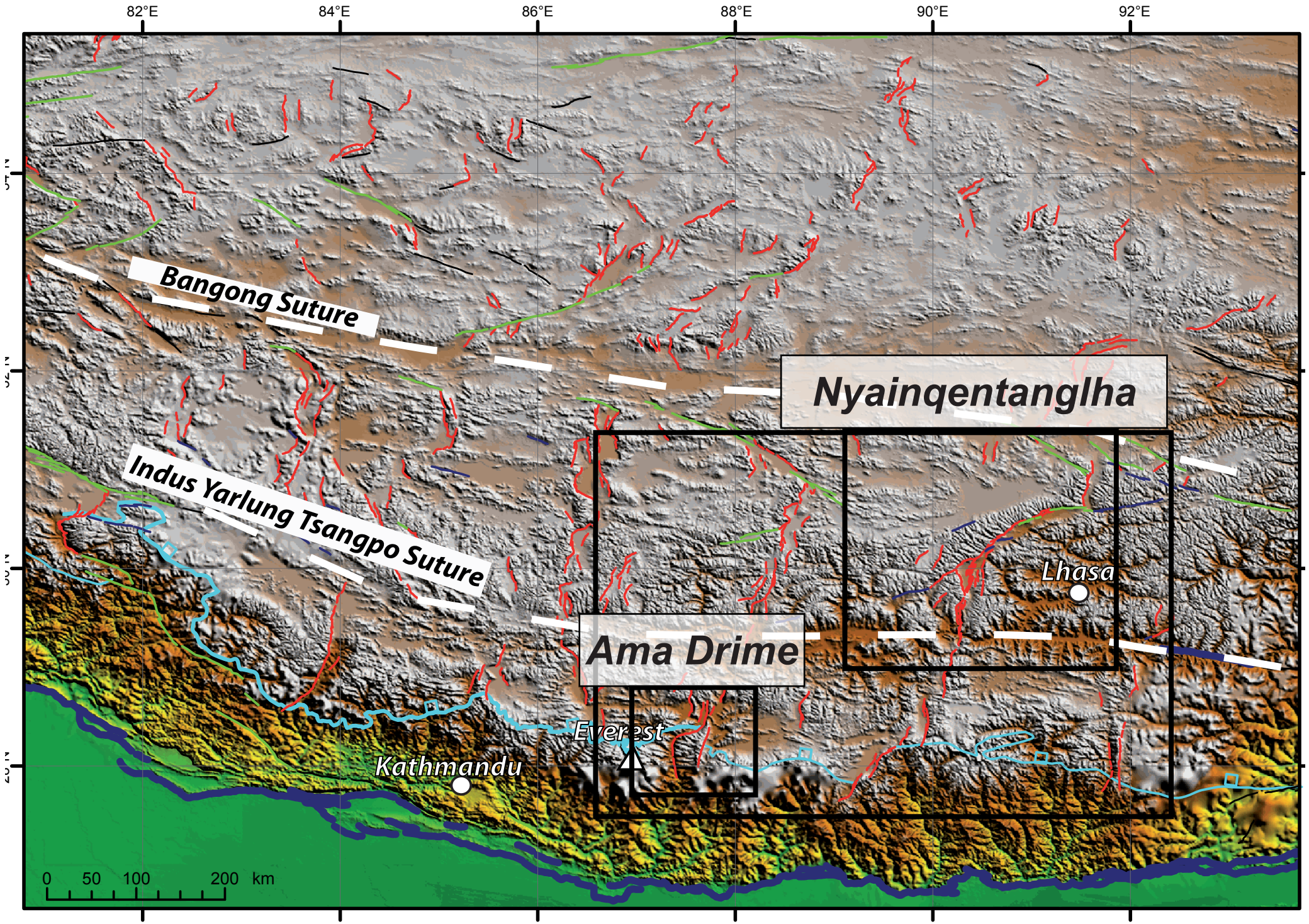




Structural geology & Petrology
+
(U-Th)/He, ^{40}Ar/^{39}Ar, U/Pb datations
--> (P-T-t-D paths)

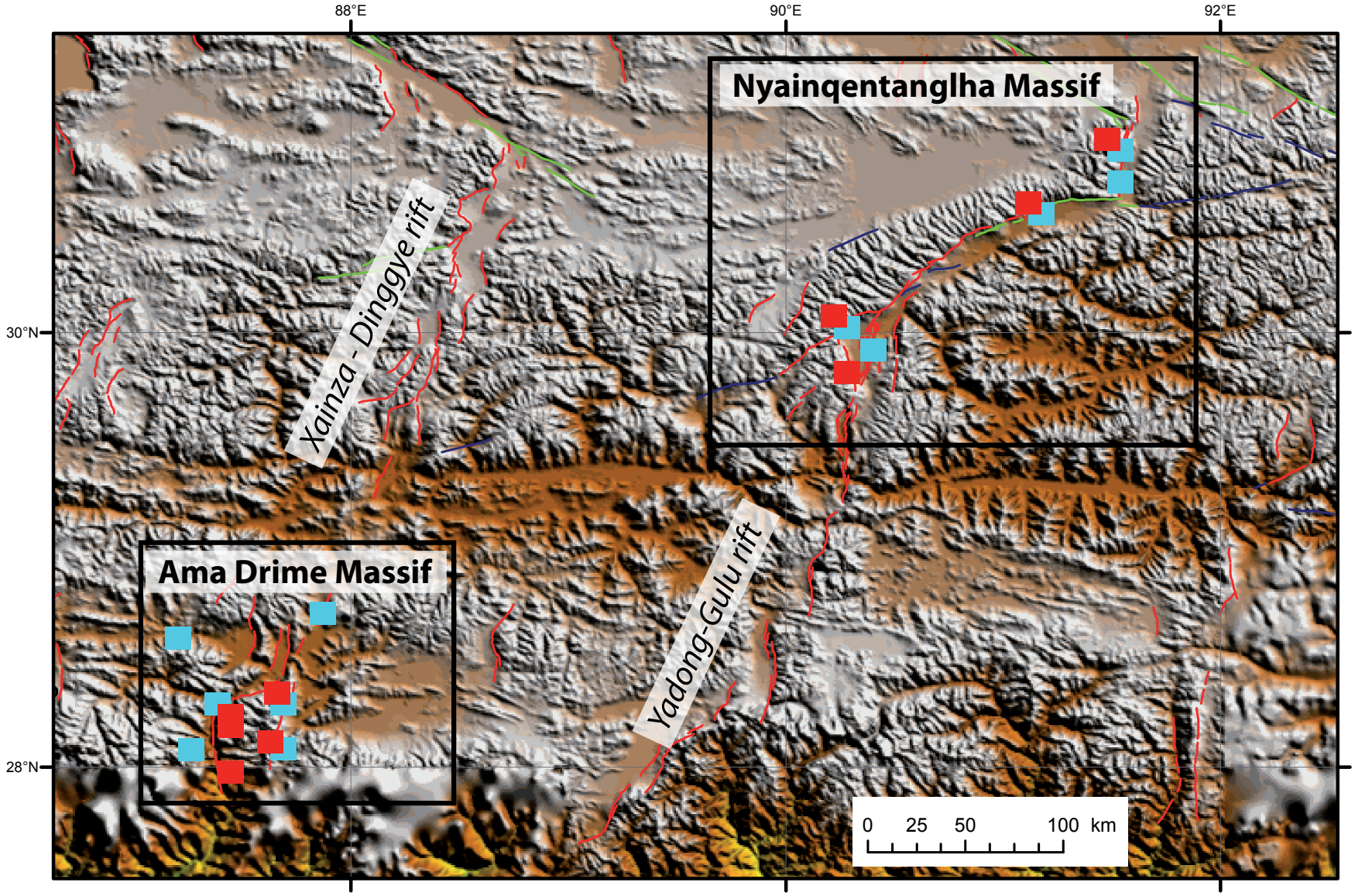
Vertical profile
+
(U-Th)/He, ^{40}Ar/^{39}Ar,
--> thermochronology/T-t paths

Exhumation Rate

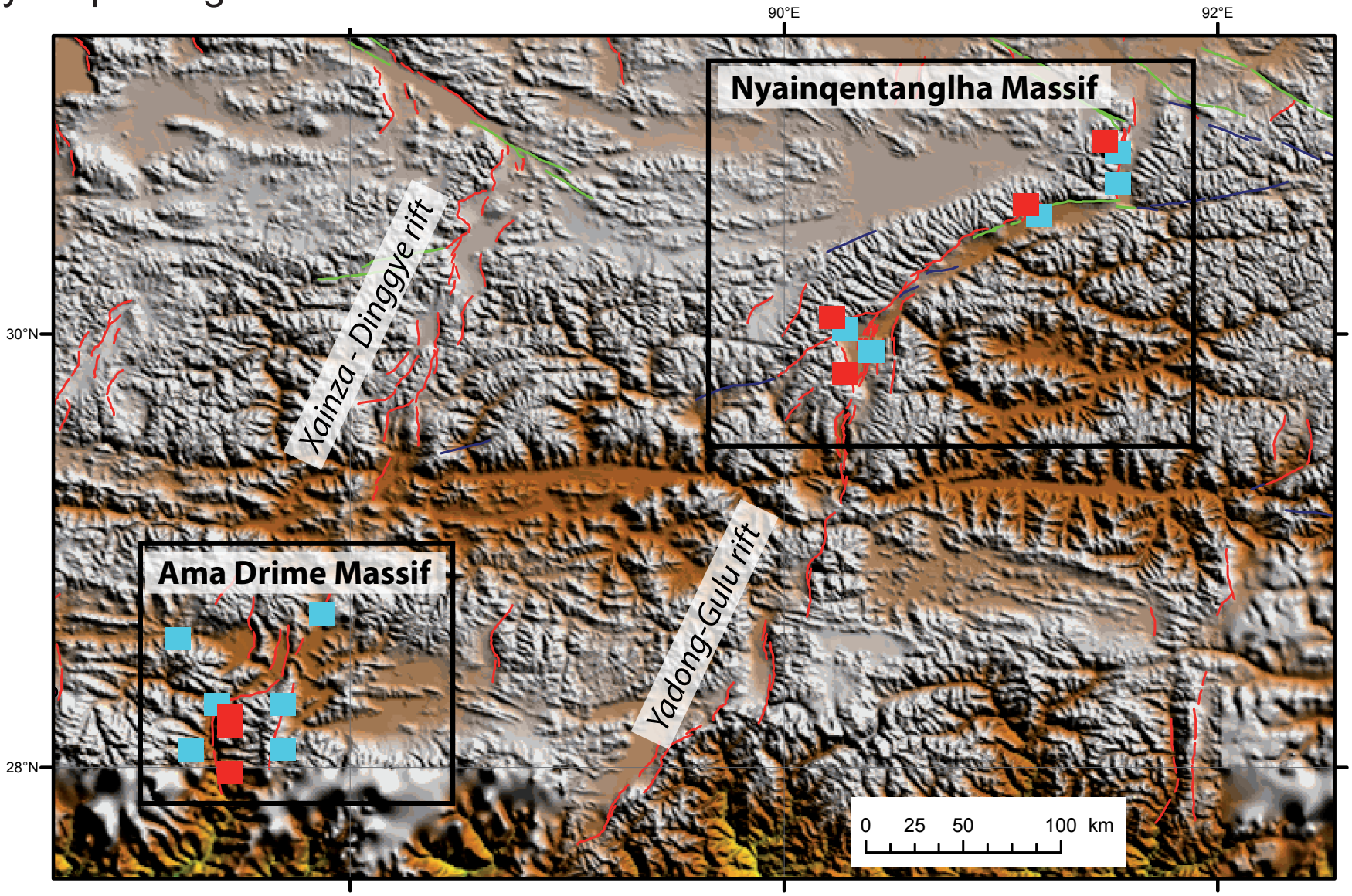

82°E
84°E
86°E
88°E
90°E
92°E
Bangong Suture
Nyainqentanglha
Indus Yarlung Tsangpo Suture
Ama Drime
Lhasa
Everest
Kathmandu
0 50 100 200 km

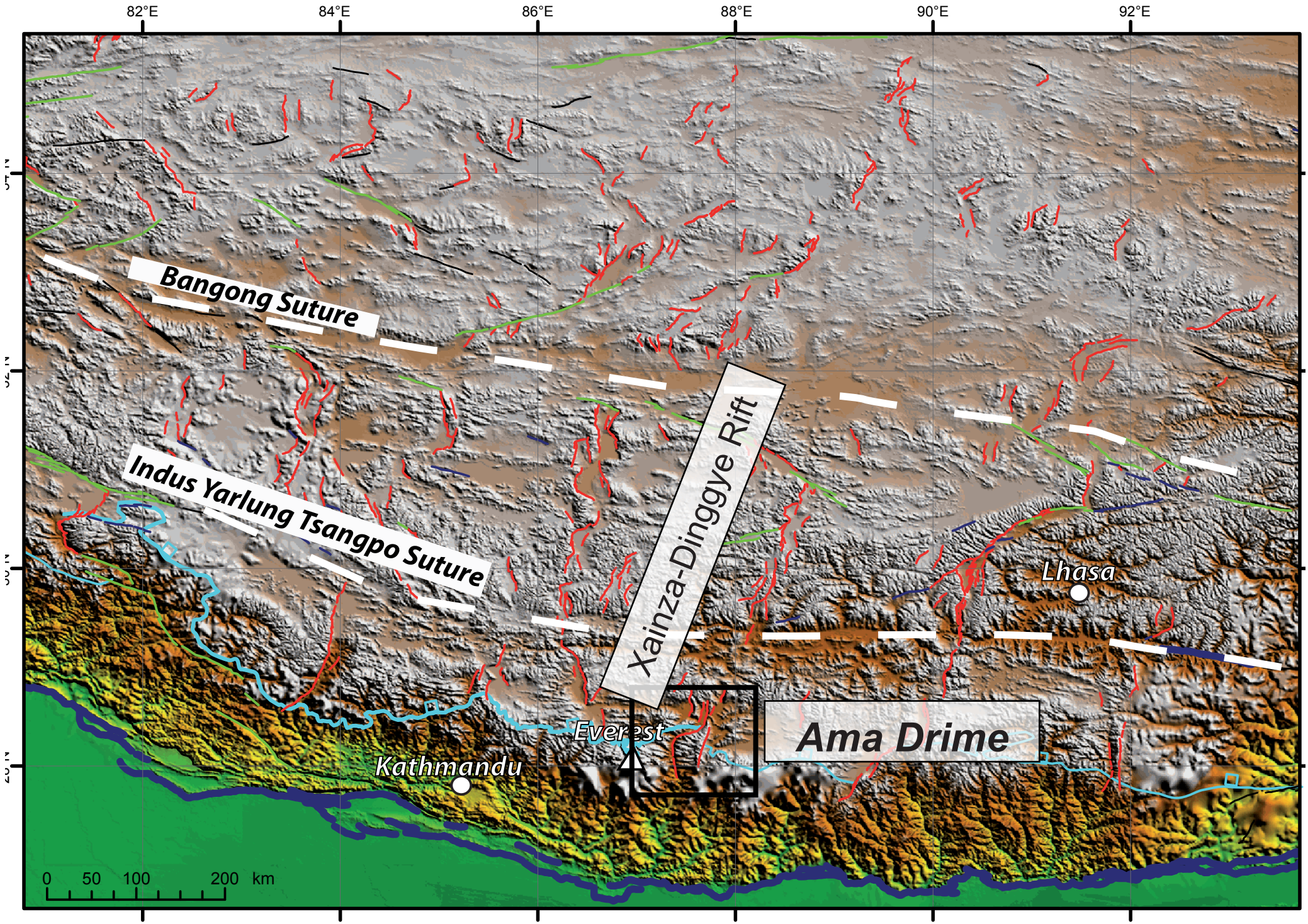
14 sites studied
Two missions: 2005-2007

Long-Term Ages and Structural data
Cosmo Ages and Morphological data

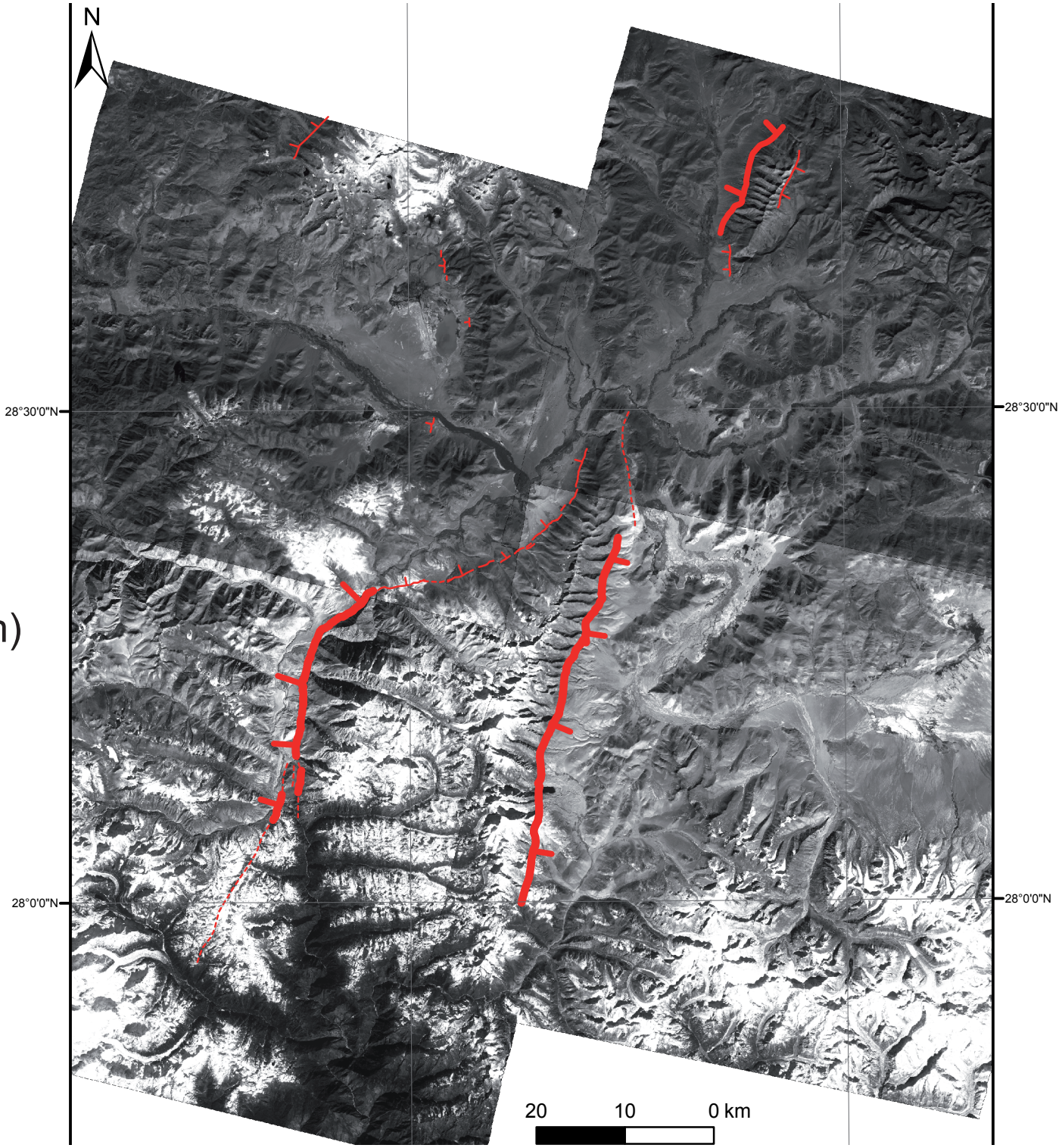


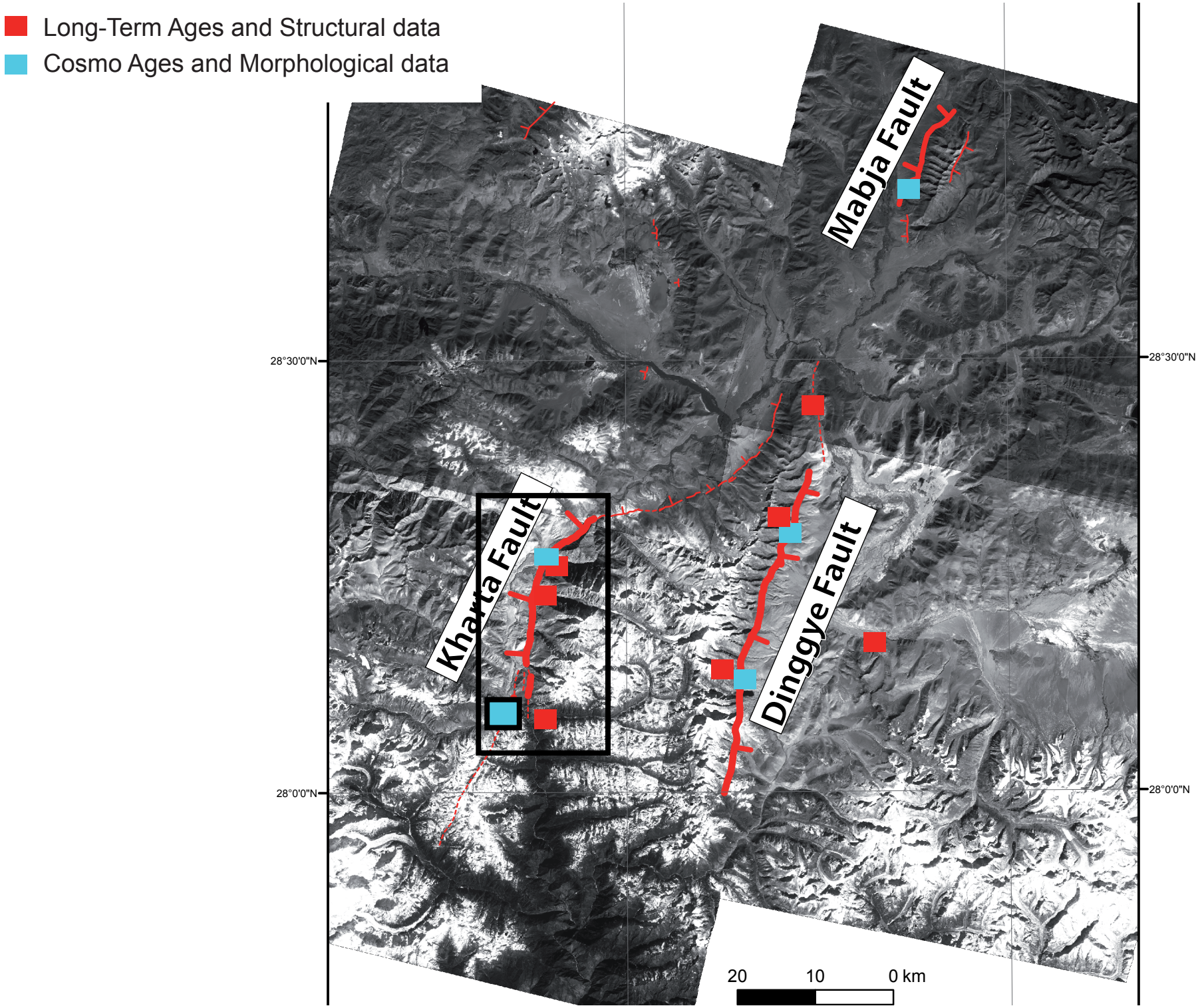
1. Ama Drime, Short-term deformation
2. Ama Drime, Long-term deformation
3. Nyainqentanglha Massif




82°E
84°E
86°E
88°E
90°E
92°E
Bangong Suture
Indus Yarlung Tsangpo Suture
Xainza-Dinggye Rift
Lhasa
Everest
Ama Drime
Kathmandu
0 50 100 200 km

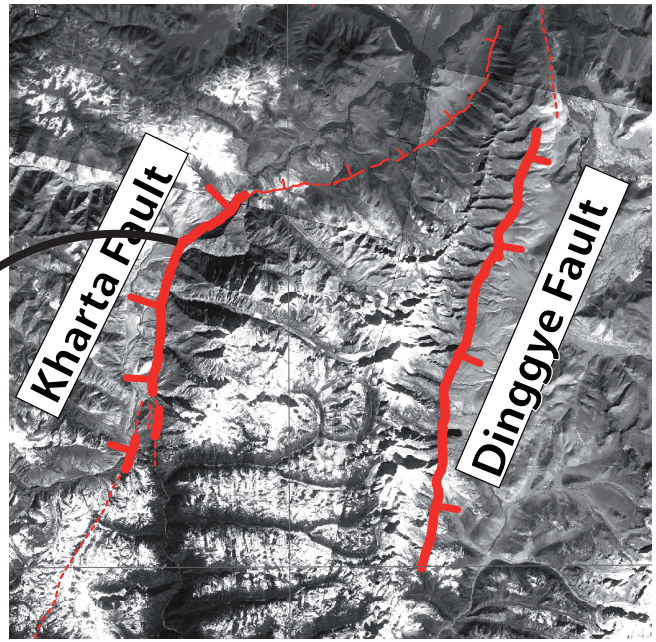
SPOT-satellite image (resolution 2 m)

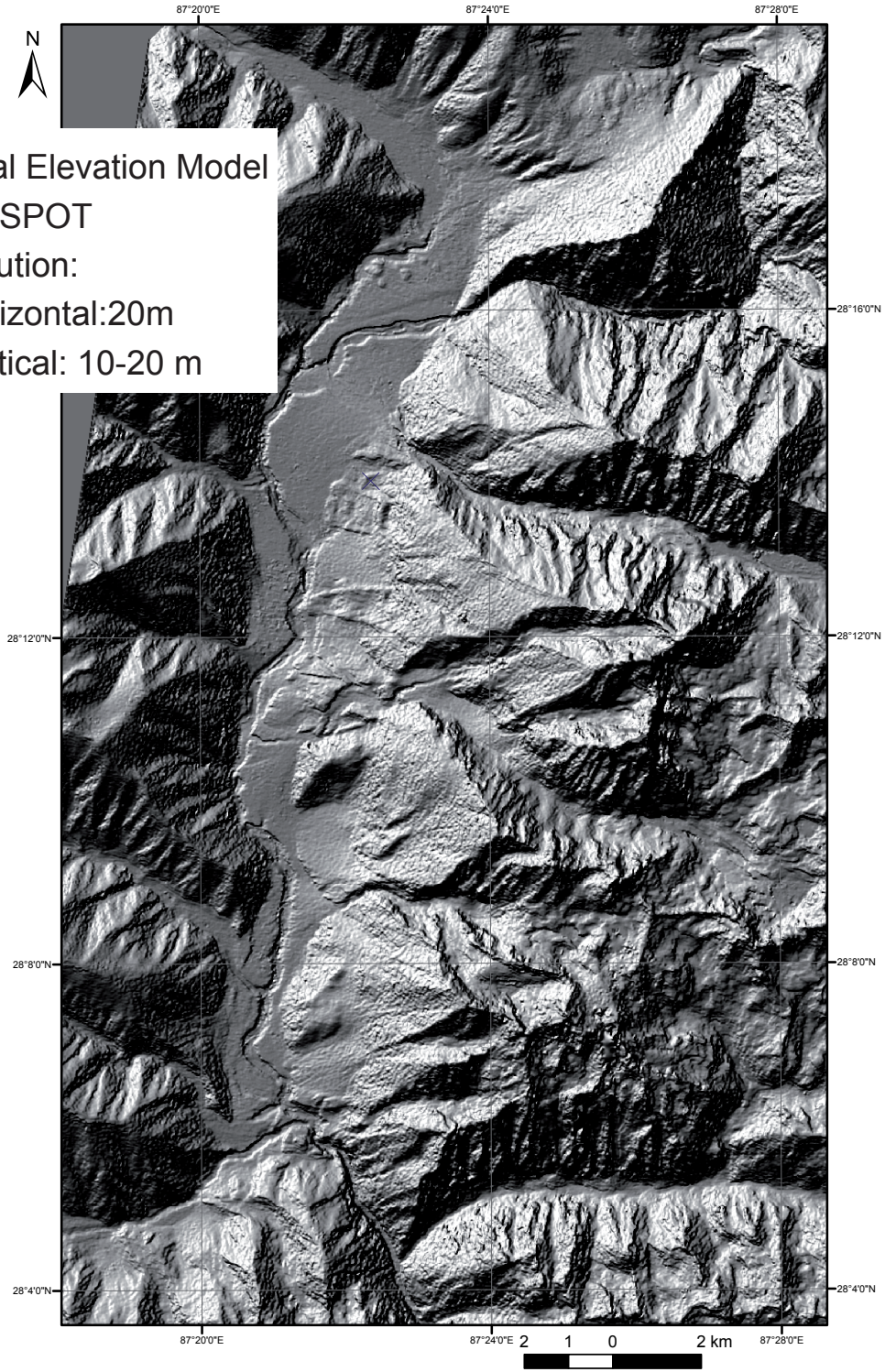



Long-Term Ages and Structural data
Cosmo Ages and Morphological data
Mabja Fault
Khayta Fault
Dinggye Fault
28°30'0"N
28°0'0"N
20
10
0 km

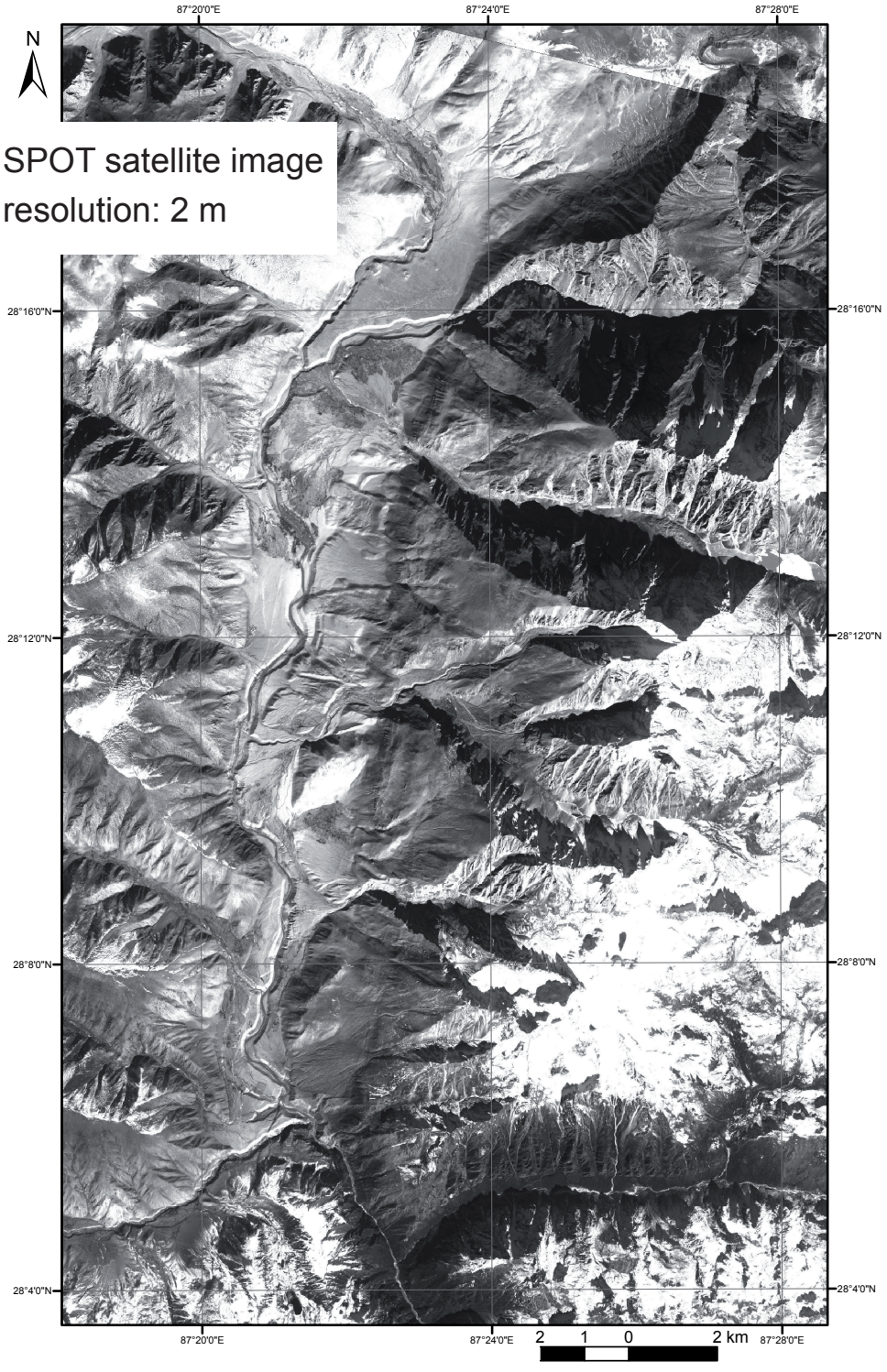
2. The Ama Drime Massif

Short term deformation





Digital Elevation Model
from SPOT
resolution:
horizontal:20m
vertical: 10-20 m



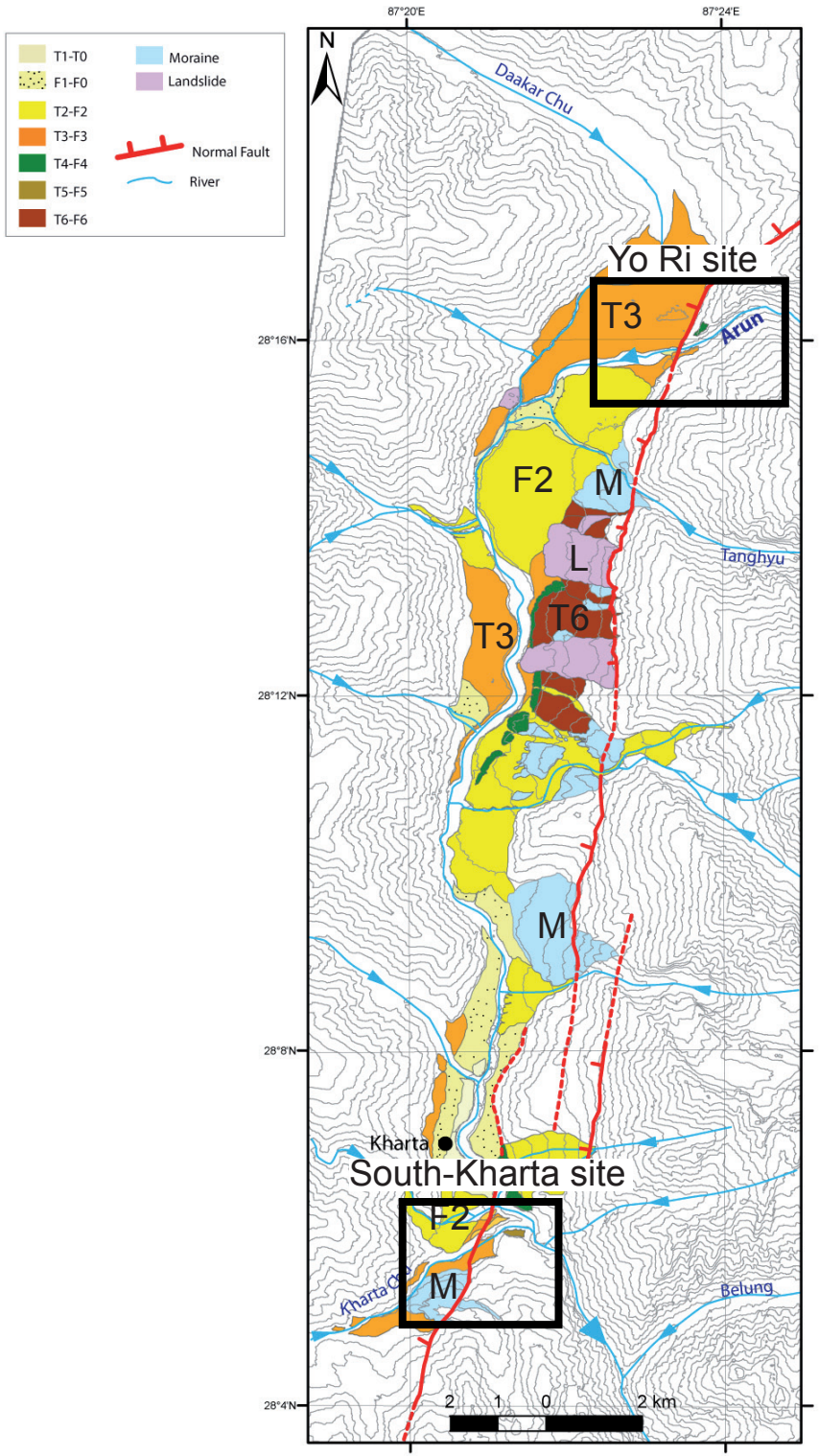
SPOT satellite image
resolution: 2 m

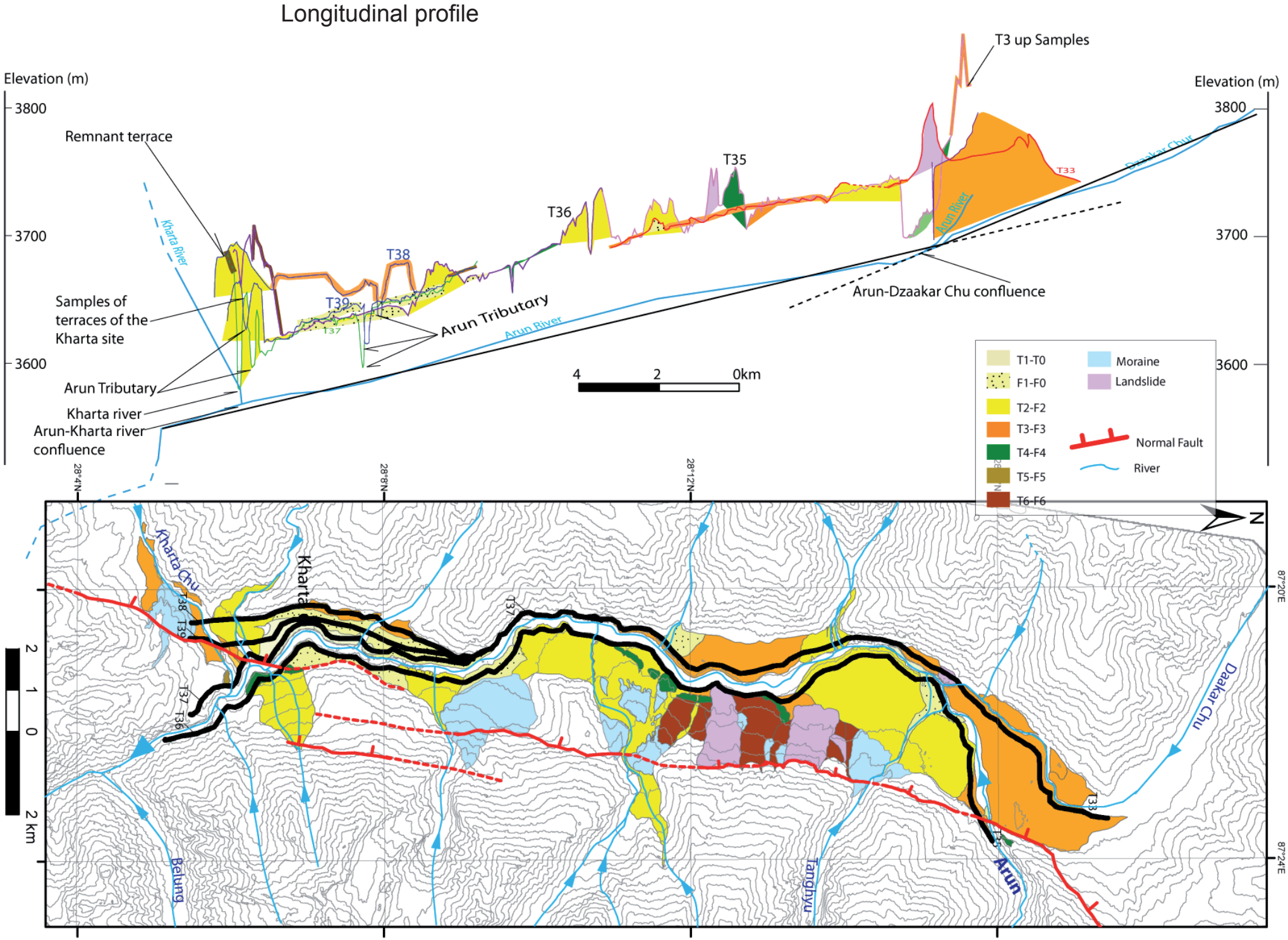
Mapping: - field work
- SPOT images and DEM analysis

ArcGis and Global Mapper Softwares

Two sampling sites separated by ~20 km along the fault

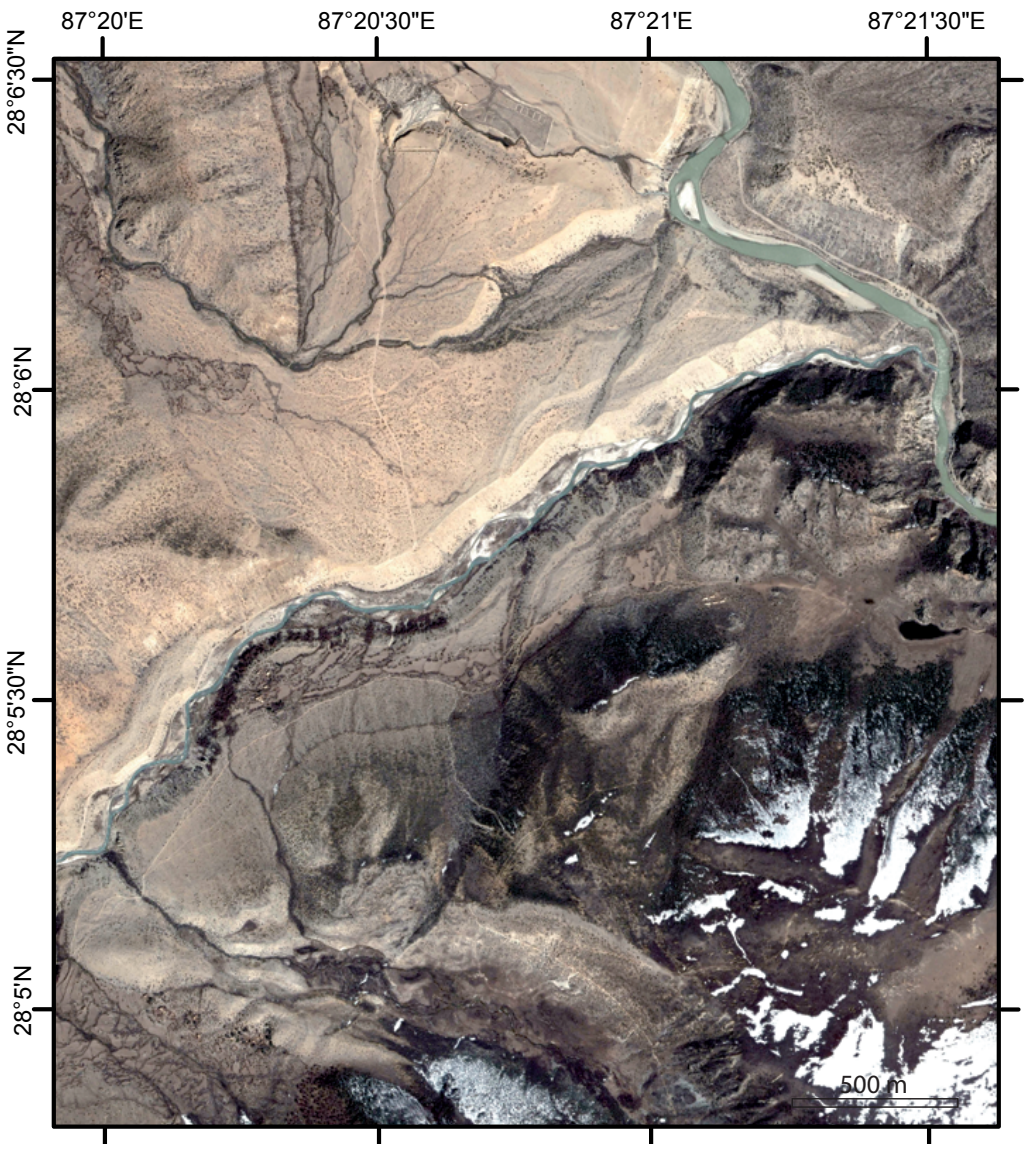
Need to rely the two site by global mapping of the quaternary formation along the fault and the Arun river

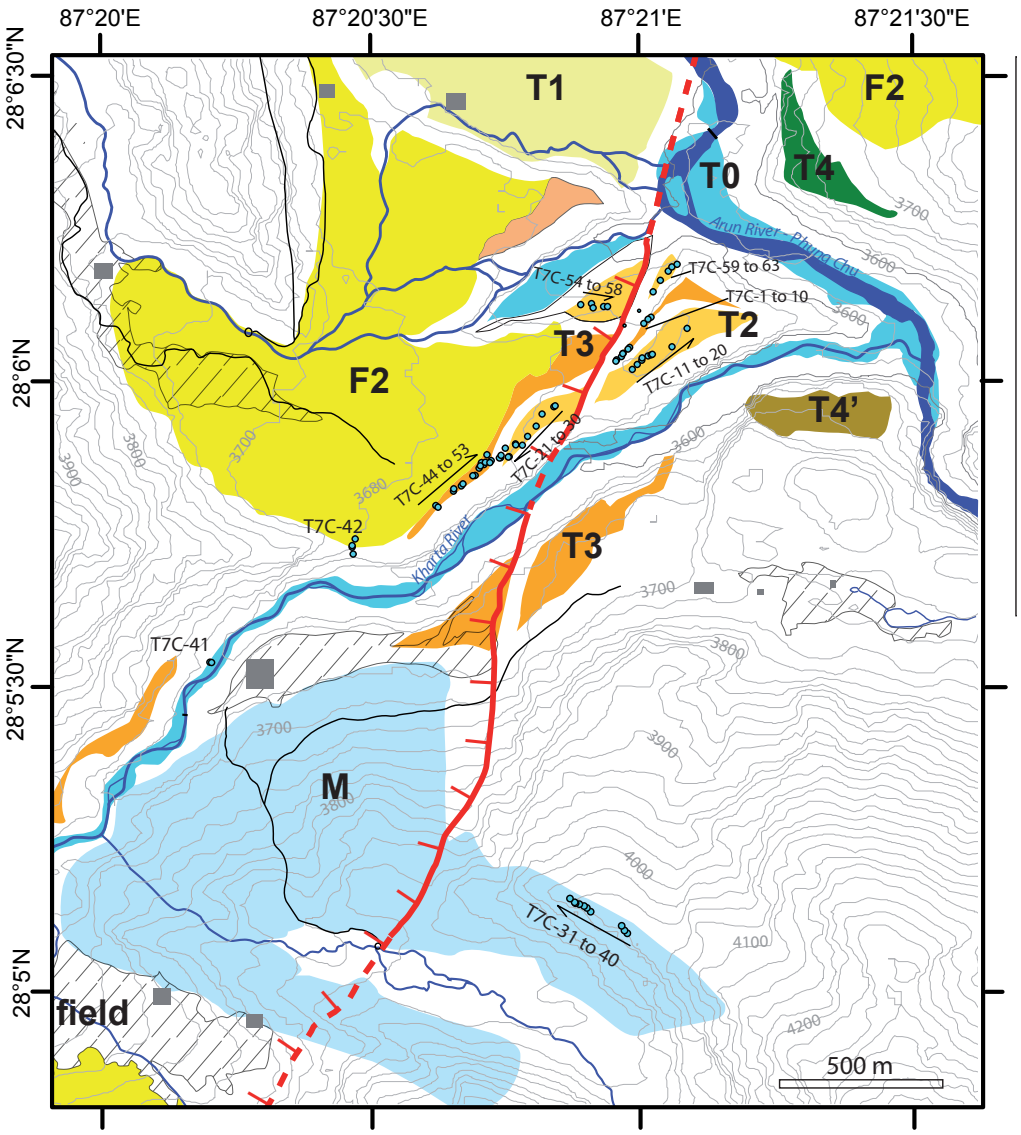



Longitudinal profile
Elevation (m)
3800
3700
3600
Remnant terrace
Samples of terraces of the Kharta site
Arun Tributary
Kharta river
Arun-Kharta river confluence
Kharta River
T38
T39
T37
T36
T35
T33
T3 up Samples
Arun Tributary
Arun River
Arun-Dzaakar Chu confluence
Dzaakar Chuu
4
2
0km
T1-T0
F1-F0
T2-F2
T3-F3
T4-F4
T5-F5
T6-F6
Moraine
Landslide
Normal Fault
River
28°4'N
28°8'N
28°12'N
87°20'E
87°24'E
N
Kharta Chu
Kharta
Dzakar Chu
Arun
Tangkyu
Belung
2 km

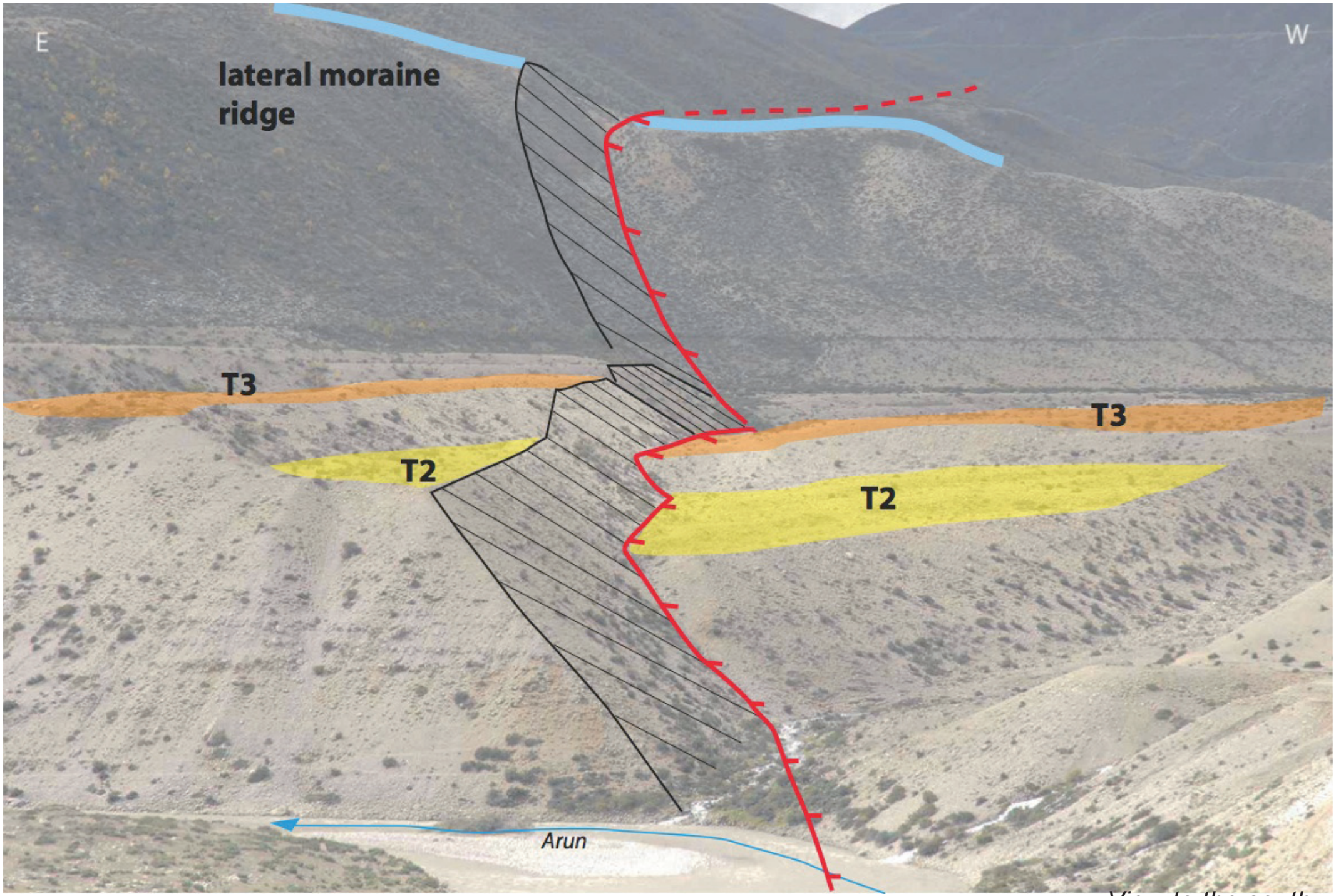
2. The Ama Drime Massif

Short term deformation, The Kharta Fault - Southern site





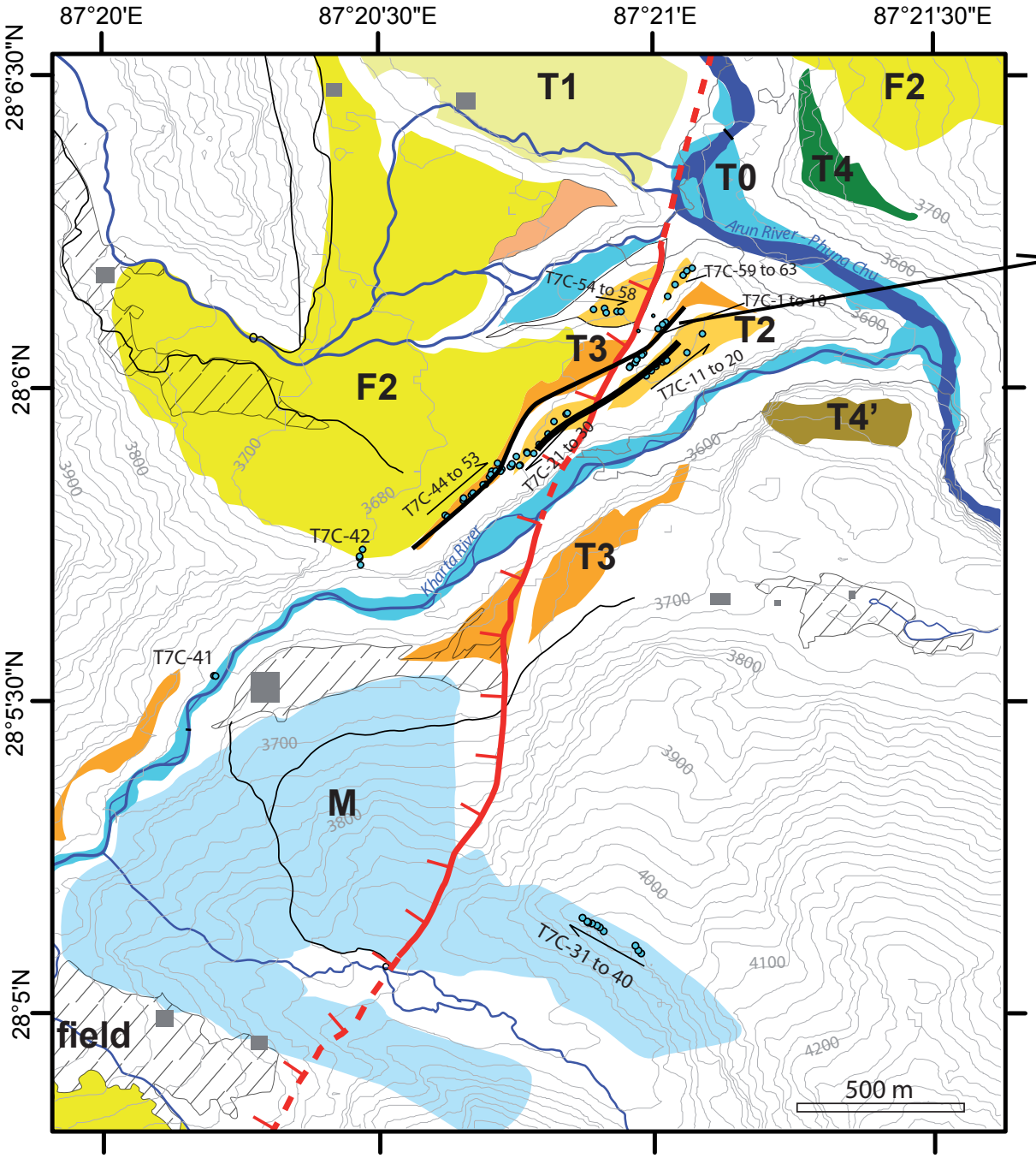
View to the south

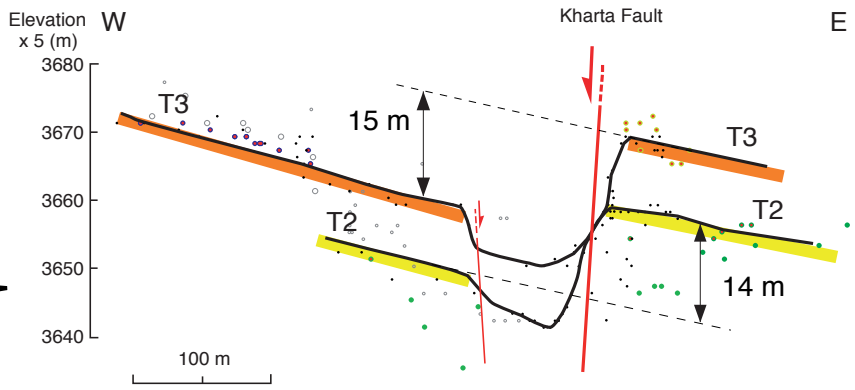


View to the south

2. The Ama Drime Massif

Short term deformation, The Kharta Fault - Southern site





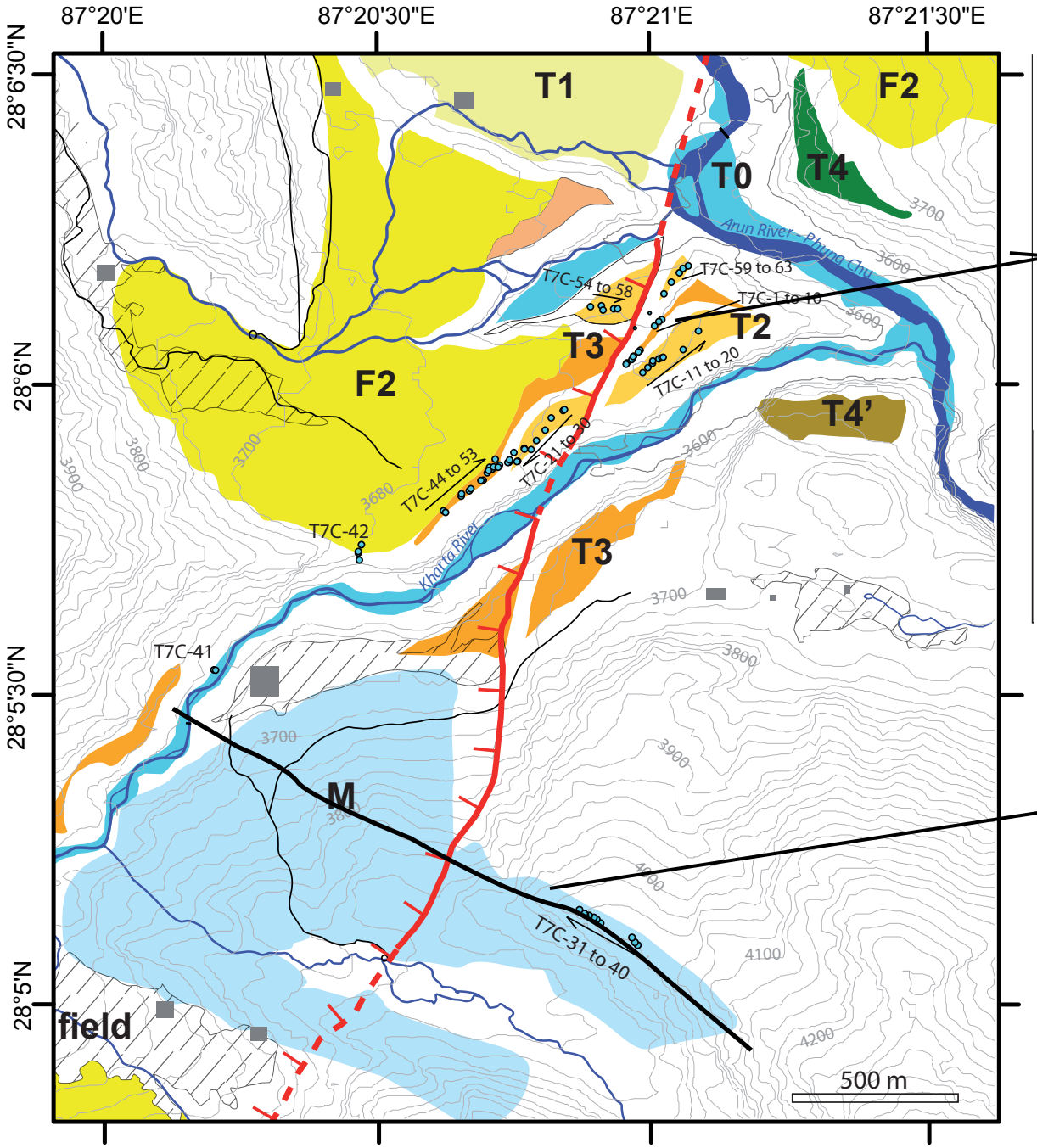
Profiles with GPS points in the field compared with profiles with the DEM, elevation correction.

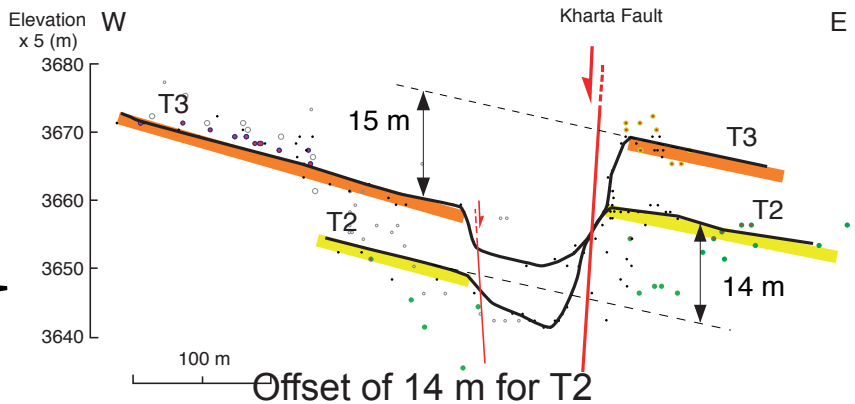
Offset of 14 m for T2

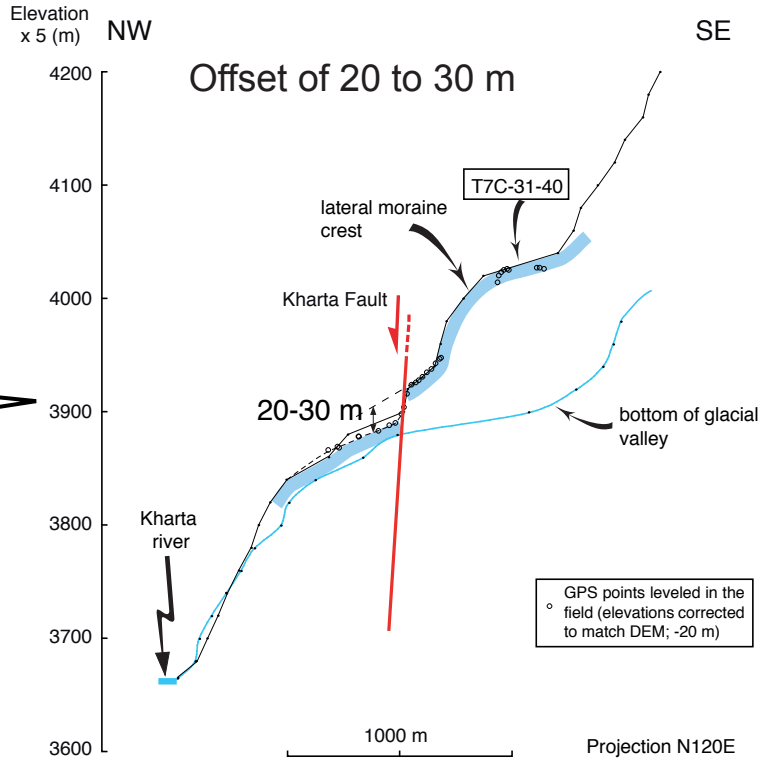
15 m for T3

2. The Ama Drime Massif

Short term deformation, The Kharta Fault - Southern site







Surface exposure dating, ^{10}Be ^{26}Al

Accumulation of the cosmo-genic radionuclides in quartz, interaction with cosmic rays.

Production rate *Depth depence* *Radioactive constant*

$$N(z,t) = N(z,0)e^{-\lambda t} + \frac{P0}{\epsilon\mu + \lambda} e^{-\mu z}(1 - e^{-(\lambda+\mu\epsilon)t})$$

Inheritance *Erosion rate*

Exposure age = age of abandonment of the terrace

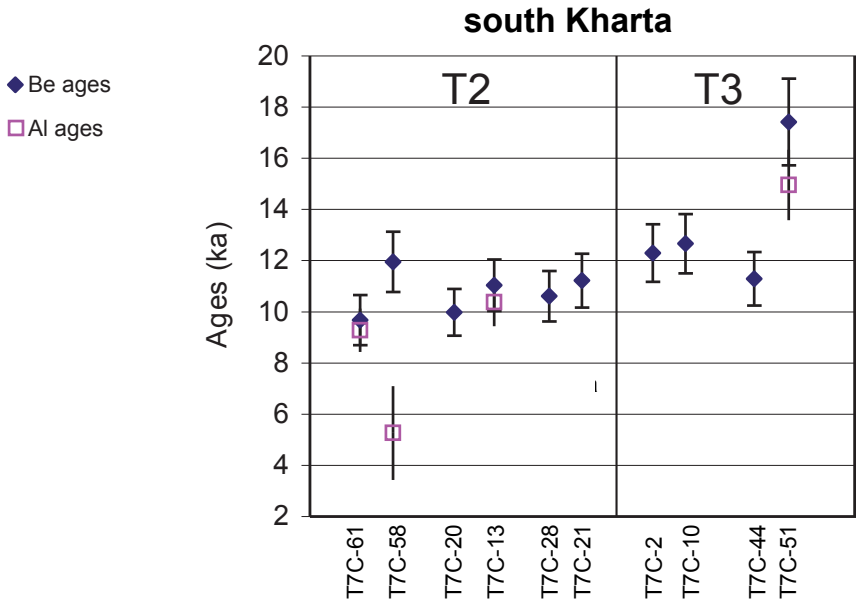
- Surface sampling
- Negligeable erosion and inhe-ritance

$$t = \frac{1}{\lambda} ln \frac{1 - N\lambda}{P}$$

Paved surface
Sampling of varied size rocks
Sampling on the surface center
Embeded cobbles

2. The Ama Drime Massif

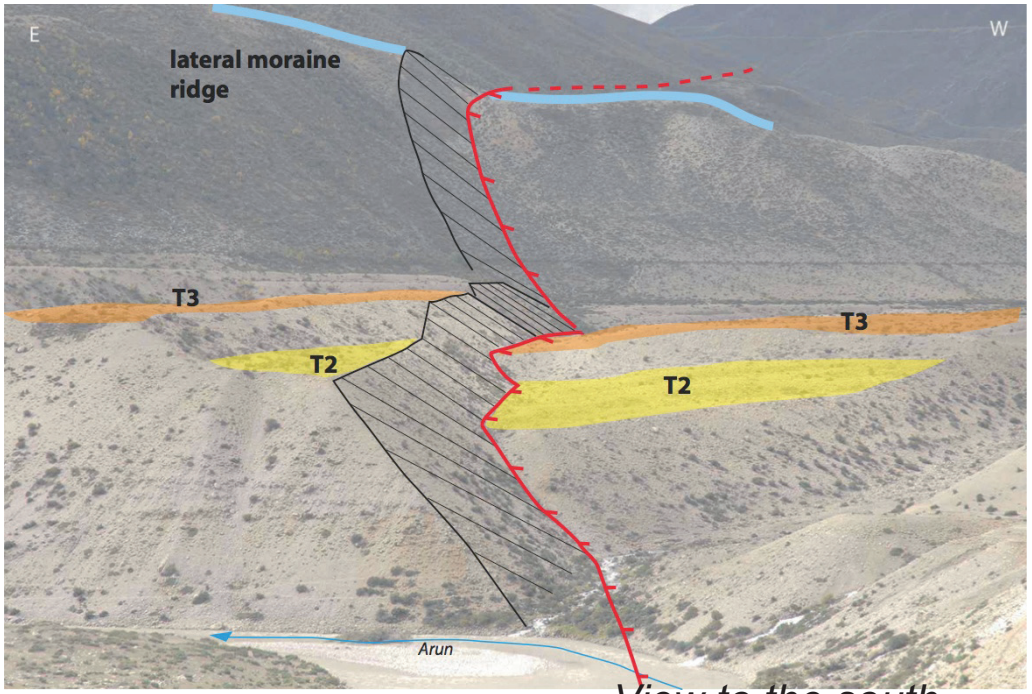
Short term deformation, The Kharta Fault - Southern site



-^{10}Be and ^{26}Al ages

-Sample preparation EOST, Strasbourg
-AMS, CEREGE, Aix en Provence

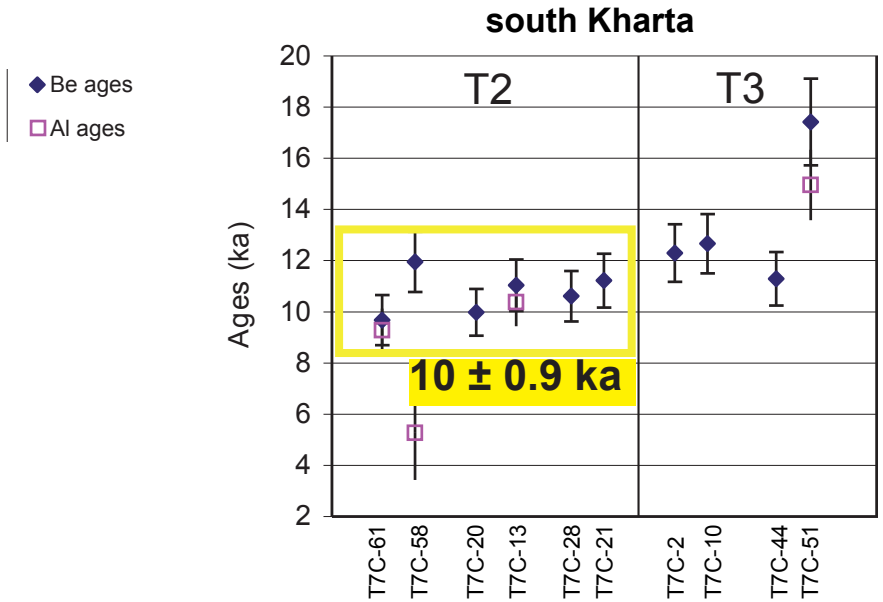
-^{10}Be and ^{26}Al ages agree except for samples with chemistry problems



View to the south

2. The Ama Drime Massif

Short term deformation, The Kharta Fault - Southern site

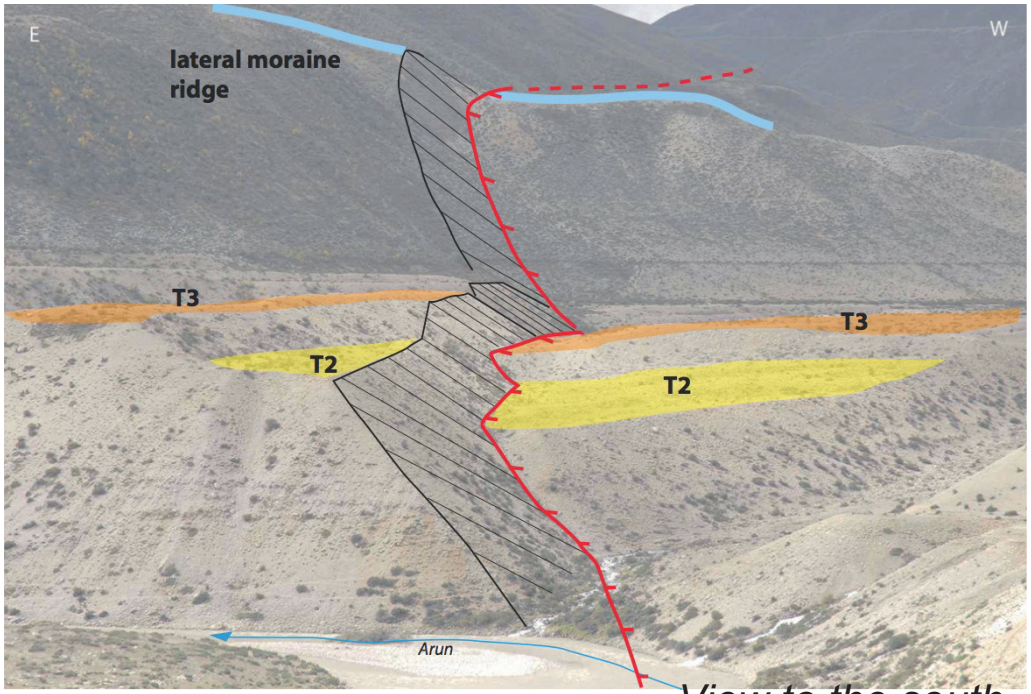


-^{10}Be and ^{26}Al ages

-Sample preparation LHyGeS, Strasbourg
-AMS, CEREGE, Aix en Provence

-^{10}Be and ^{26}Al ages agree except for samples with chemistry problems

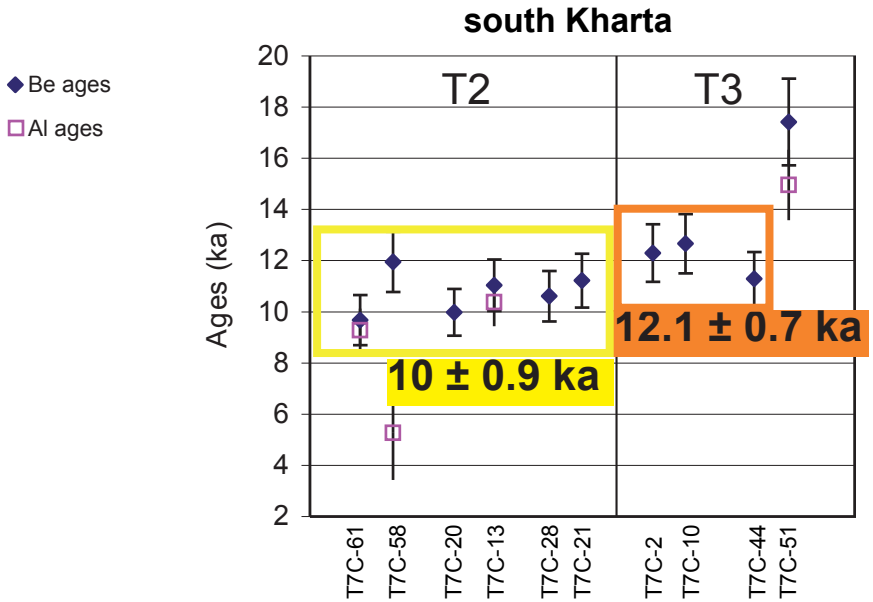
-T2 : 9.3 ± 0.9 ka < age < 11.9 ± 1.2 ka
average = **age of abandonment of the terrace** : 10 ± 0.9 ka (± standard deviation)



View to the south

2. The Ama Drime Massif

Short term deformation, The Kharta Fault - Southern site



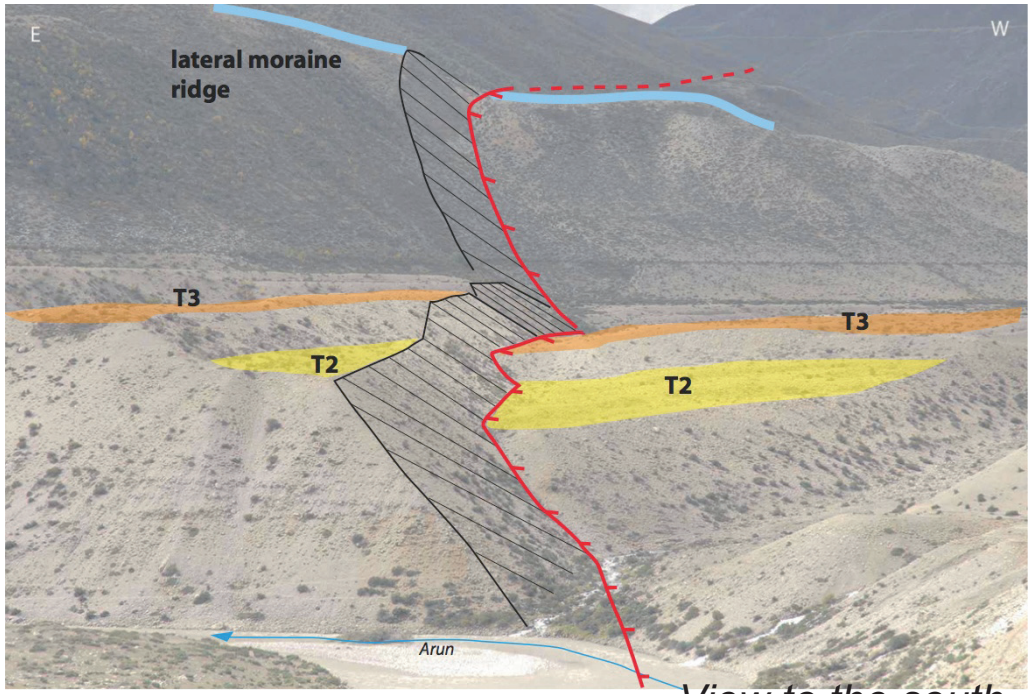
-^{10}Be and ^{26}Al ages

-Sample preparation LHyGeS, Strasbourg
-AMS, CEREGE, Aix en Provence

-^{10}Be and ^{26}Al ages agree except for samples with chemistry problems

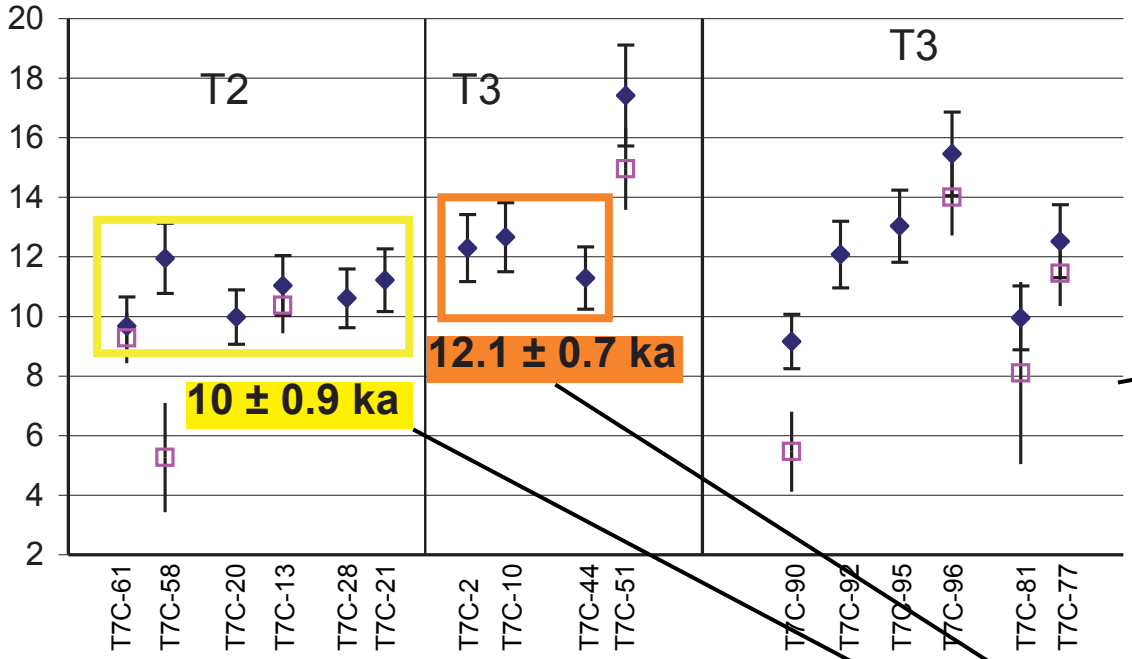
-T2 : 9.3 ± 0.9 ka < age < 11.9 ± 1.2 ka
average : 10 ± 0.9 ka (± standard deviation)

-T3 : 11.3 ± 1.0 ka < age < 17.4 ± 1.7 ka
17.4 ± 1.7 ka age excluded
age of abandonment of the terrace :
12.1 ± 0.7 ka



View to the south

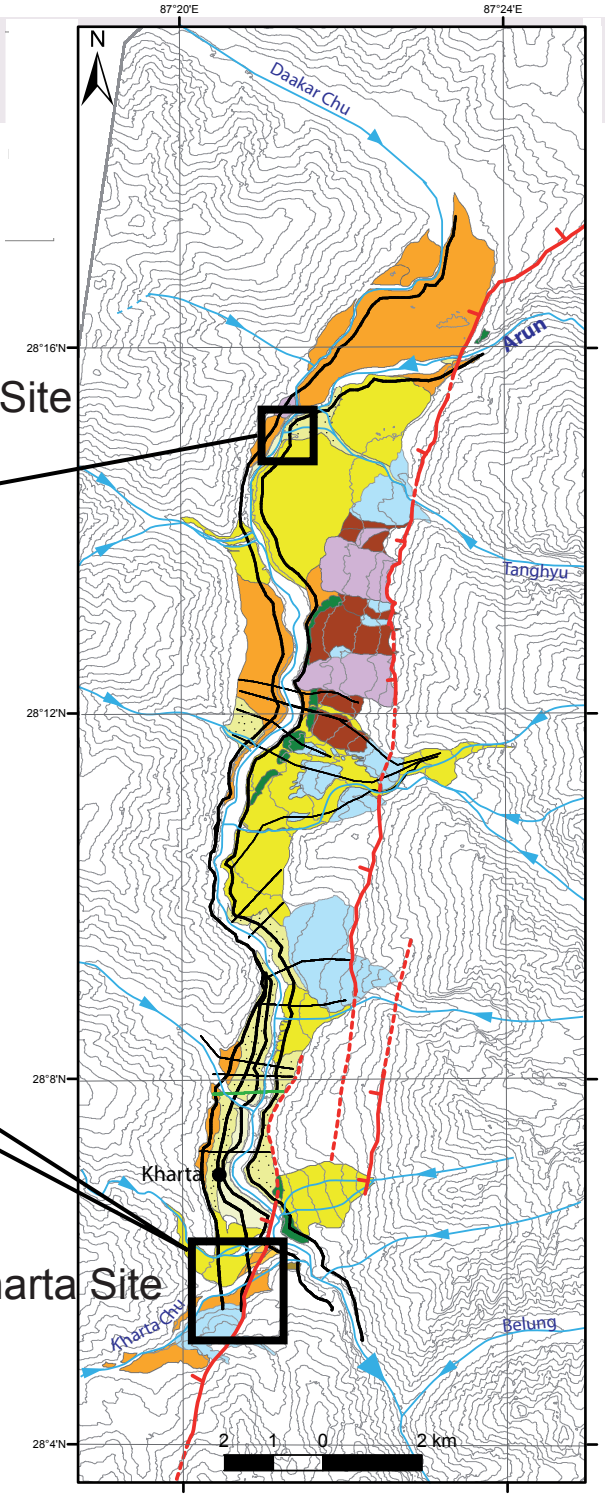
2. The Ama Drime Massif
Short term deformation



u : up
d : down
◆ Be ages
□ Al ages

Yo Ri Site

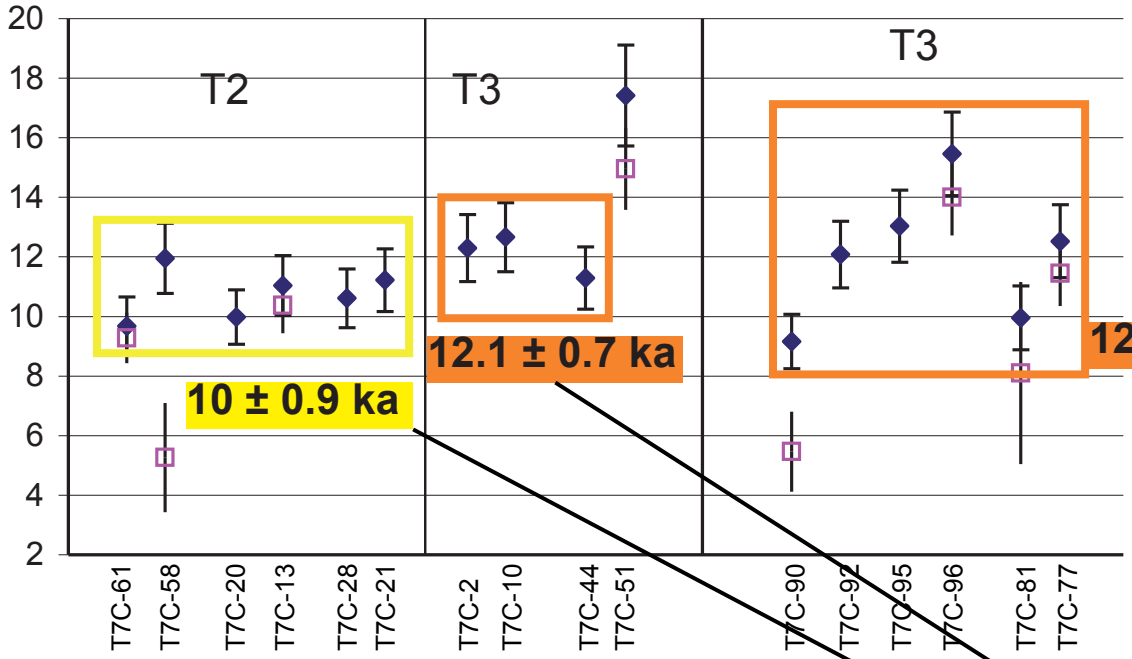
South-Kharta Site



-^{10}Be and ^{26}Al ages agree except for samples with chemistry problems

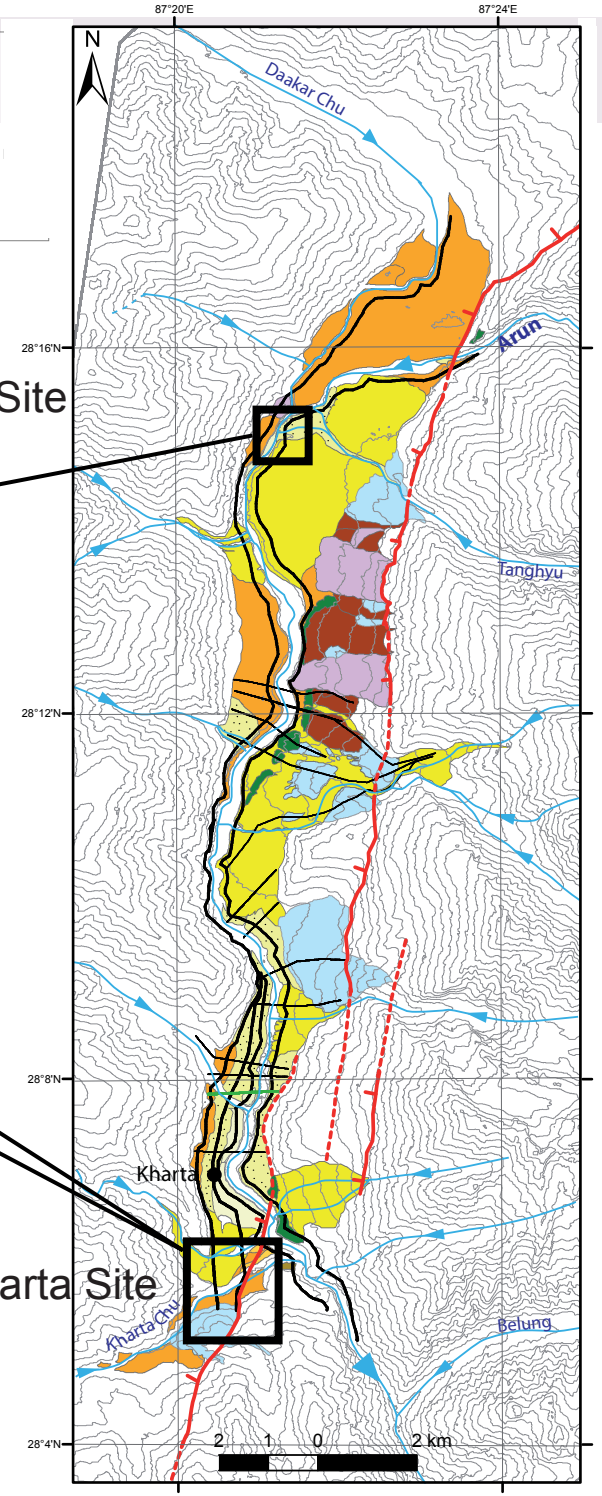
-T3 : 9.2 ± 0.9 ka < age < 15.5 ± 1.4 ka

2. The Ama Drime Massif
Short term deformation



Yo Ri Site

South-Kharta Site

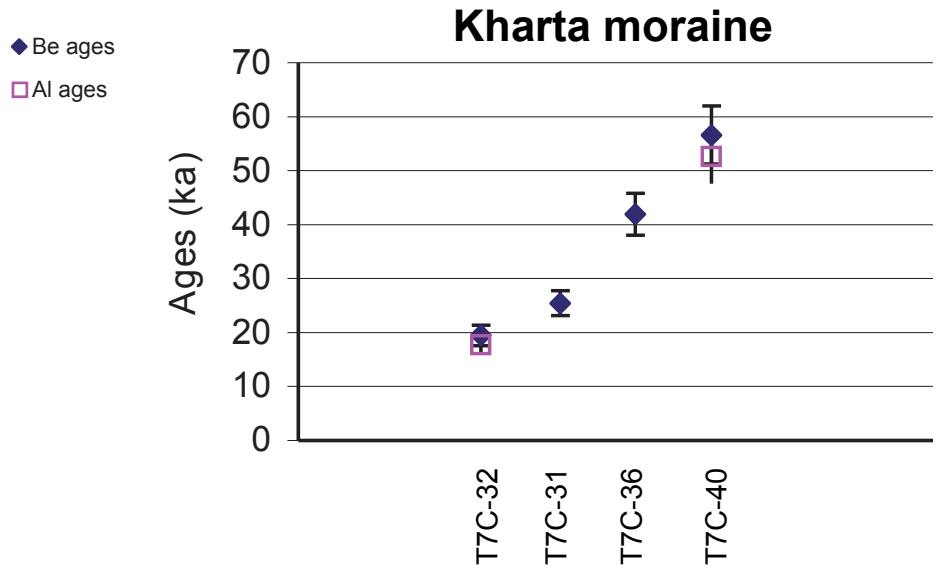


- ^{10}Be and ^{26}Al ages agree except for samples with chemistry problems

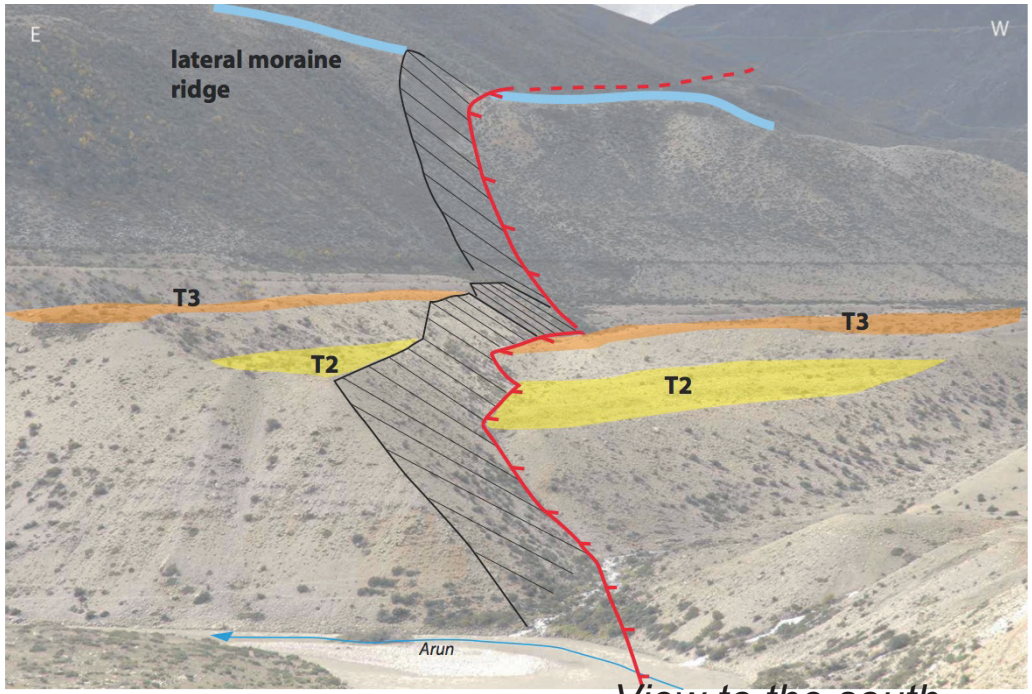
- T3 : 9.2 ± 0.9 ka < age < 15.5 ± 1.4 ka
  average : 12.1 ± 2.3 ka (± standard deviation)

2. The Ama Drime Massif

Short term deformation, The Kharta Fault - Southern site



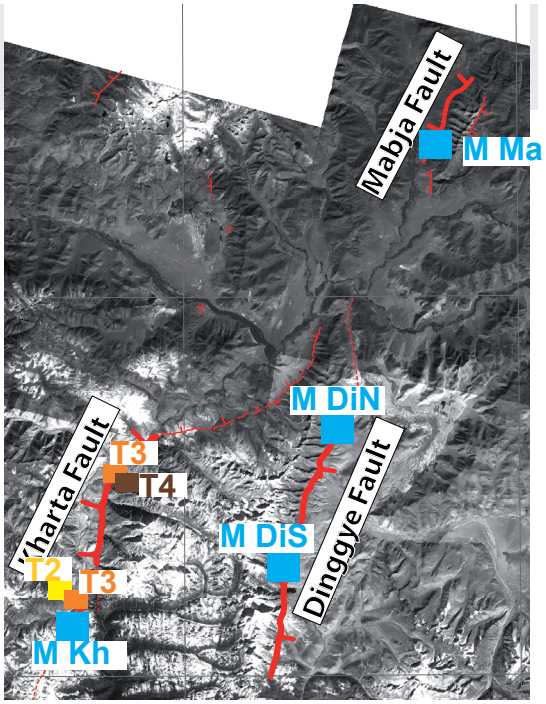
Last glacial period (Würm), 80-10 ka
Last Glacial Maximum (LGM) : 25-20 ka

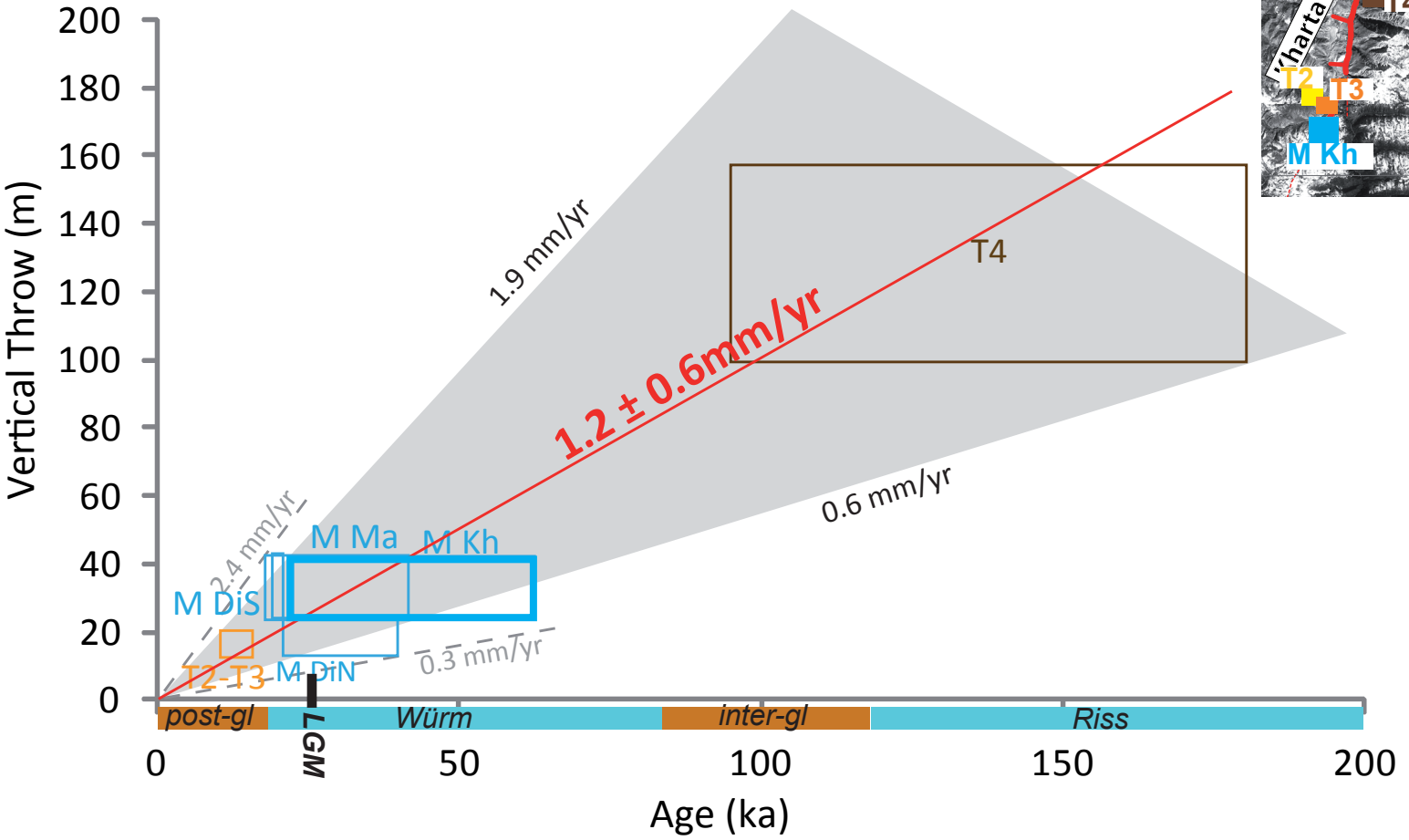


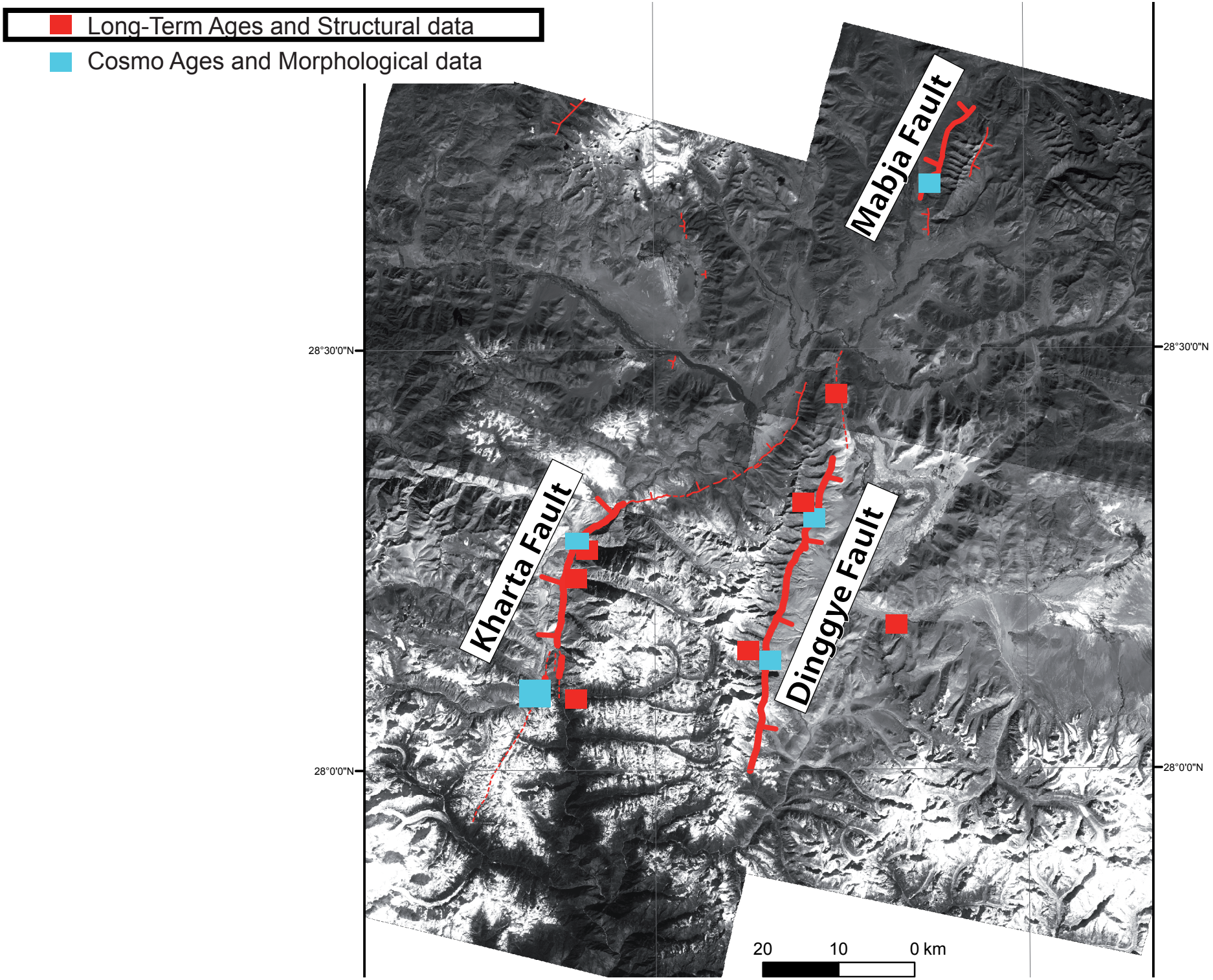
View to the south

1. The Ama Drime Massif
Short-Term deformation

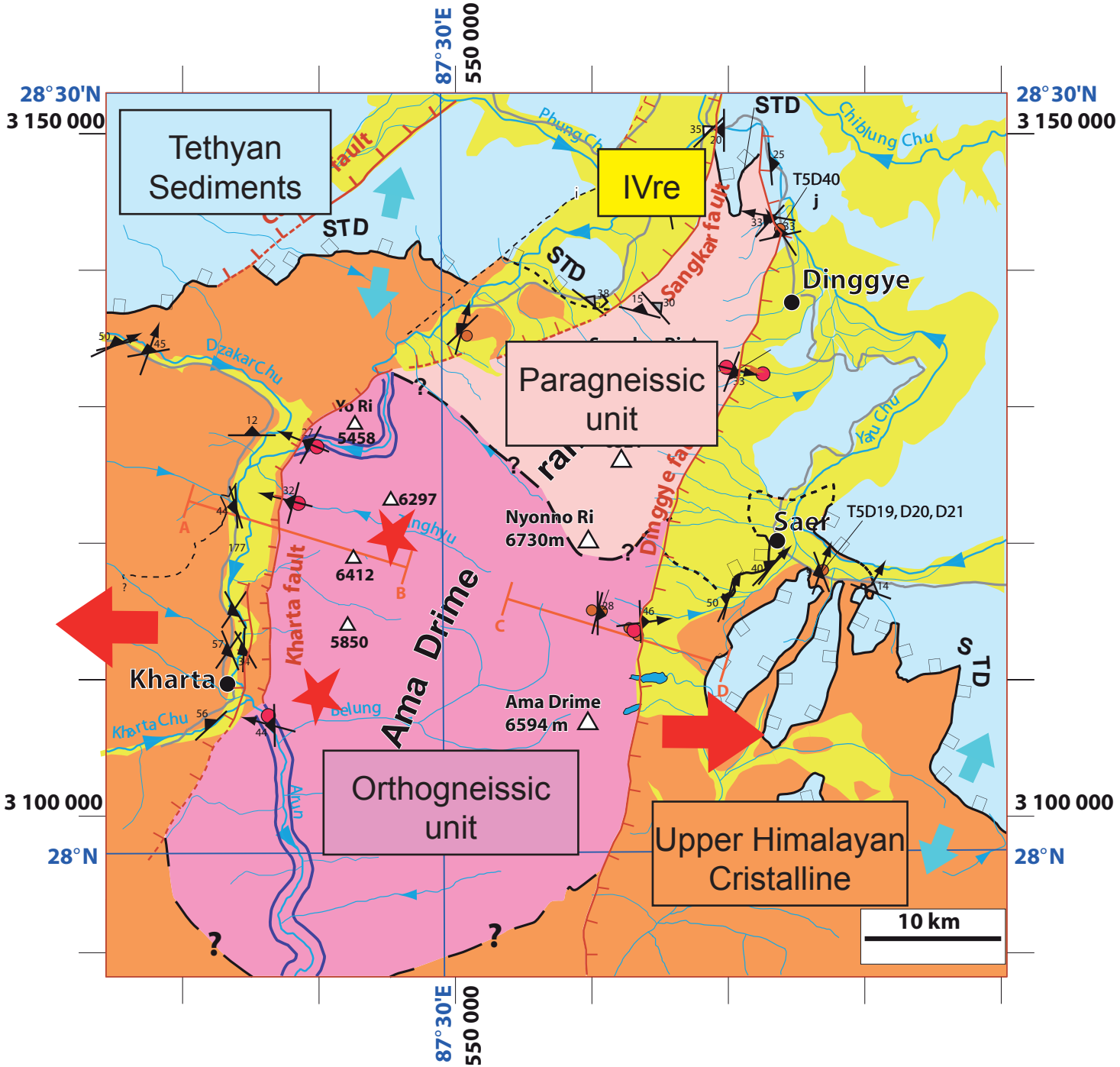
1.2 ± 0.6 mm/yr






Long-Term Ages and Structural data
Cosmo Ages and Morphological data
Mabja Fault
Kharta Fault
Dinggye Fault
28°30'0"N
28°0'0"N
20
10
0 km

2. The Ama Drime Massif
Long-Term Deformation



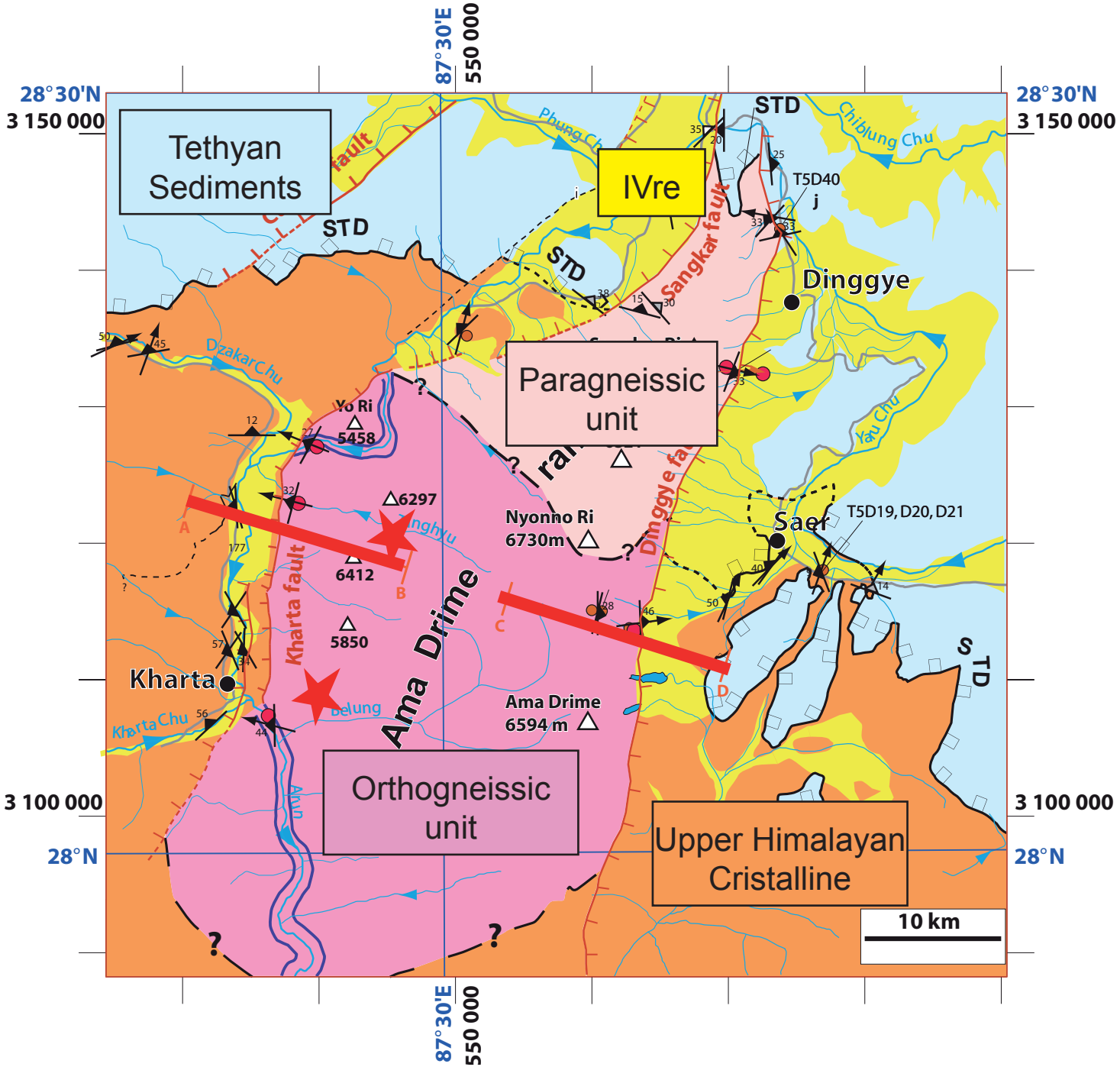
- 5 main units

- STD (South Tibetan Detachment)

- Kharta and Dinggye Shear Zone

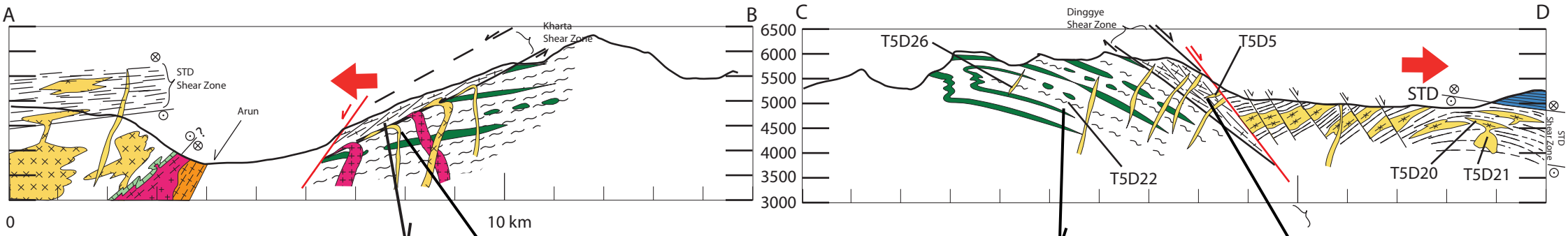
-Eclogites ★ *(Lombardo & Rolfo 2000)*

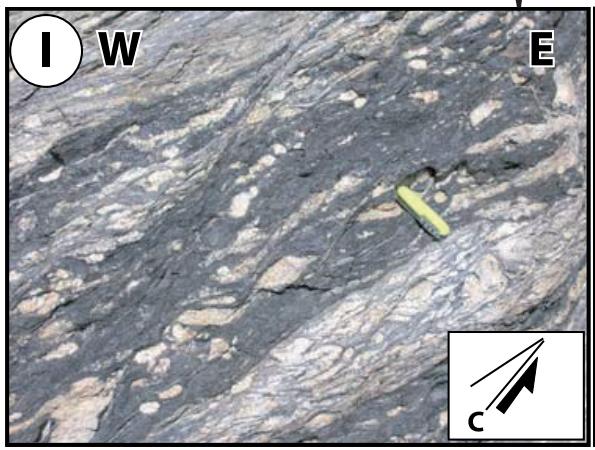
2. The Ama Drime Massif
Long-Term Deformation



- 5 main units
- STD (South Tibetan Detachment)
- Kharta and Dinggye Shear Zone
- Eclogites ★ *(Lombardo & Rolfo 2000)*

2. The Ama Drime Massif
Long-Term Deformation



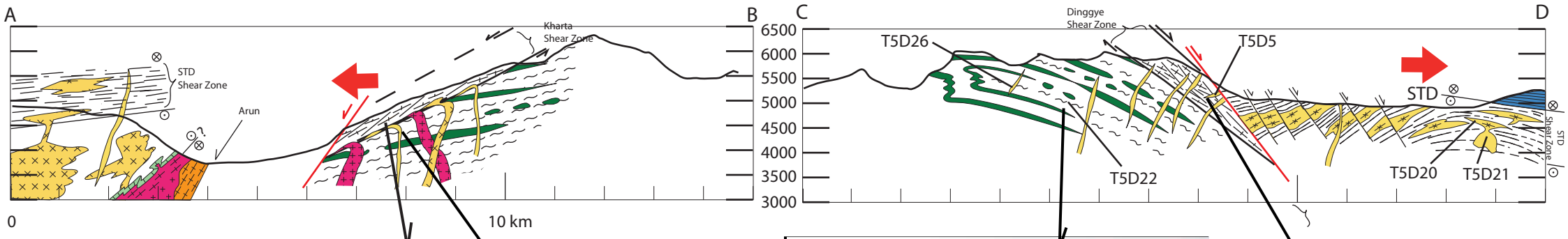


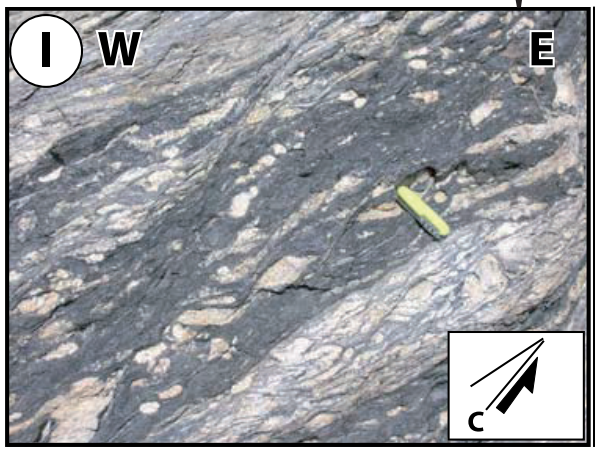
Ductile deformation (mylonites-orthogneiss to cataclasites) cut by brittle normal fault

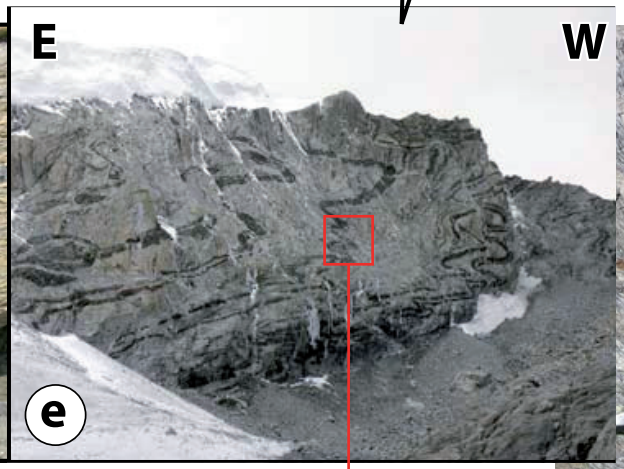
Deformed and undeformed leucogranits

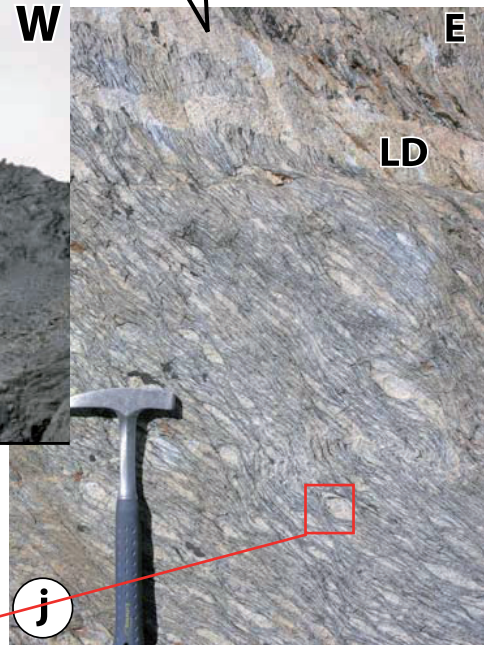
Metabasite boudins
--> Eclogites

2. The Ama Drime Massif
Long-Term Deformation









Ductile deformation (mylonites-orthogneiss to cataclasites) cut by brittle normal fault

P-T condition
--> vertical movement

Deformed and undeformed leucogranits

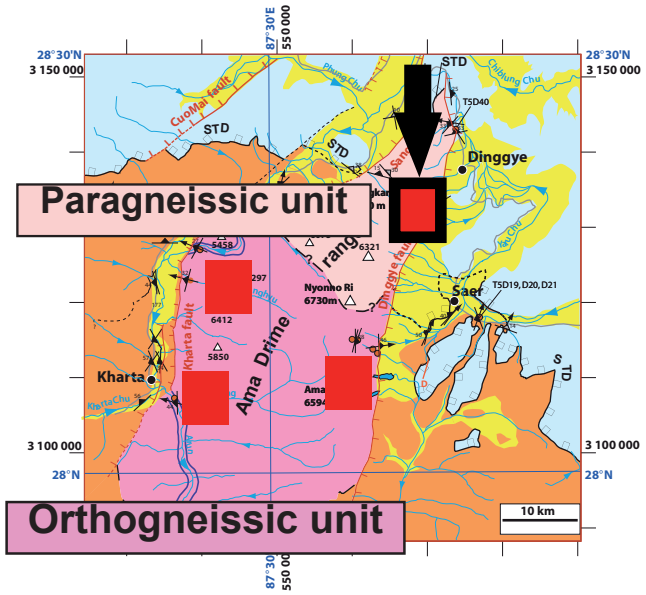
Metabasite boudins
--> Eclogites

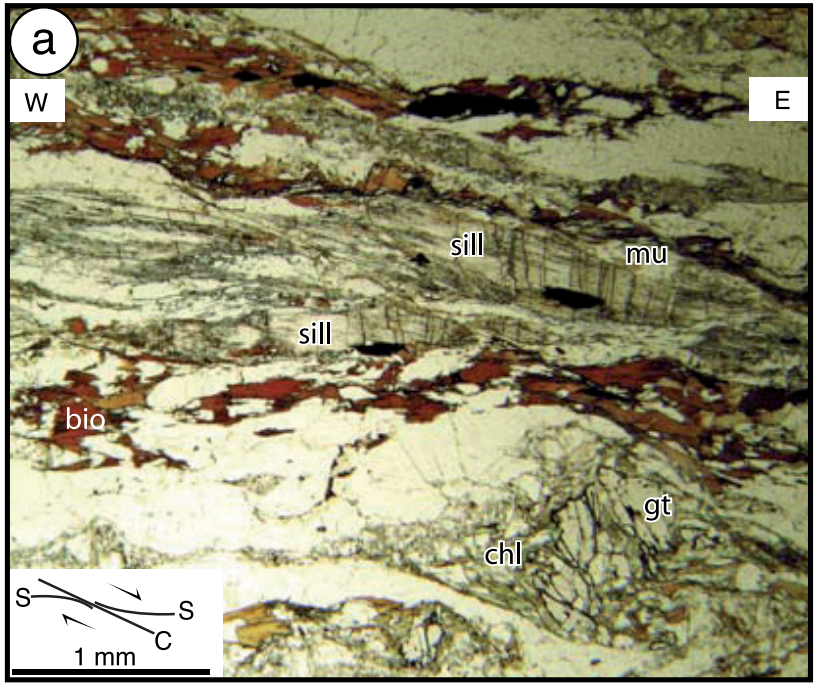
datation:
--> shear age

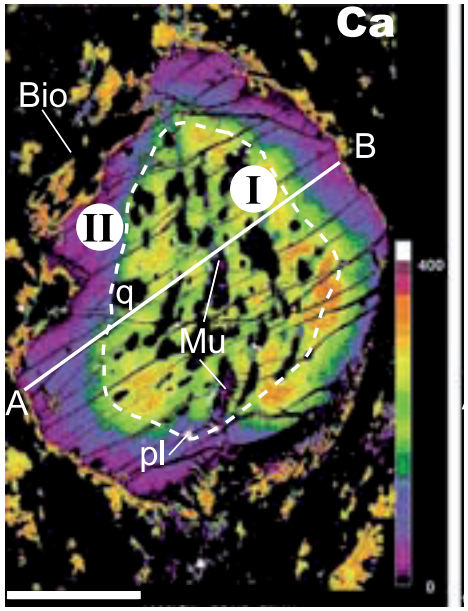
+

Exhumation Rates

P-T paths reconstitution





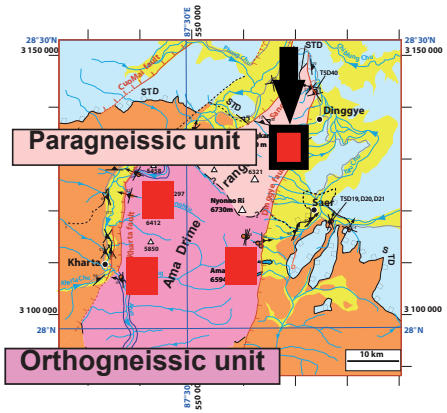


-Microscope observations

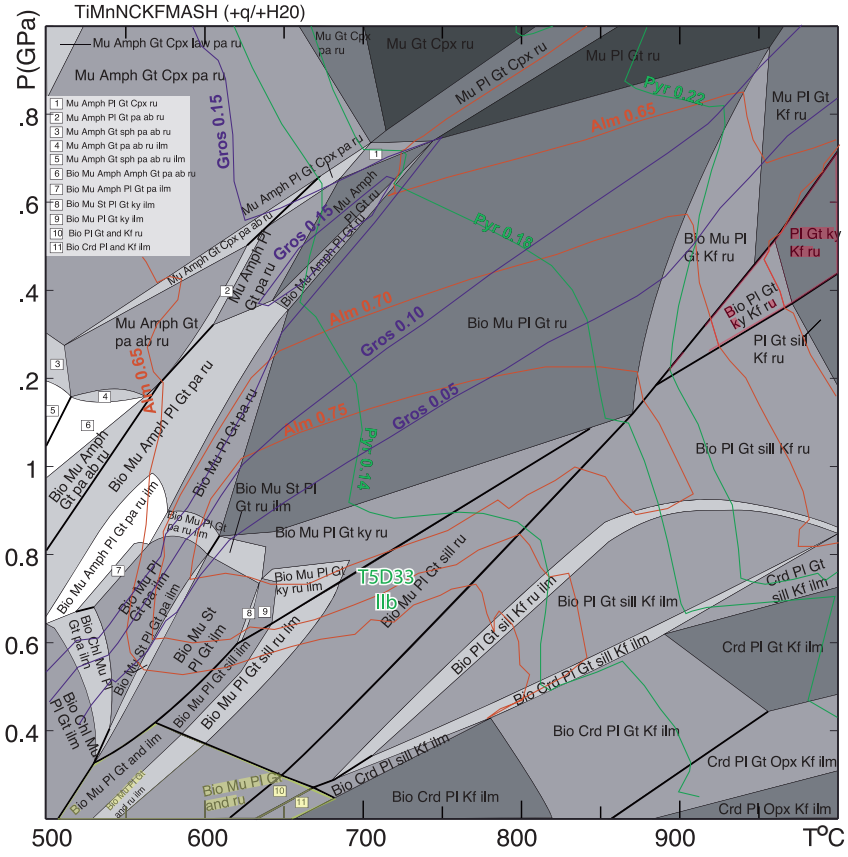
-Microprobe mineral analysis
-X-ray map and microproble traverse of garnet
(SX100 Cameca CAMEBAX Microprobe, University of Montpellier)

-Rocks total analysis

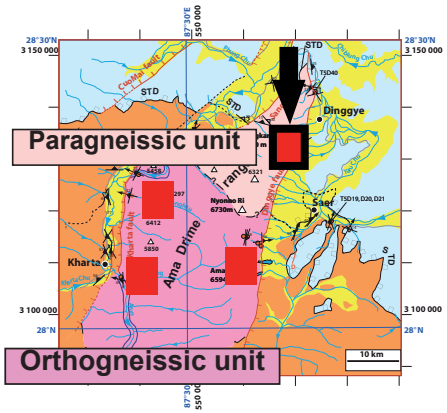
2. The Ama Drime Massif
Long-Term Deformation



Pseudosection calculations (Perple_X software, 2007) based on thermodynamics laws
= modelisation of mineralogical assemblages stable at given P-T and predict chemistry of minerals

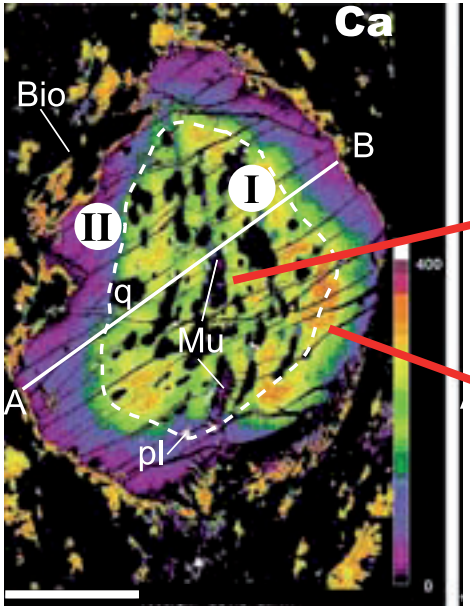


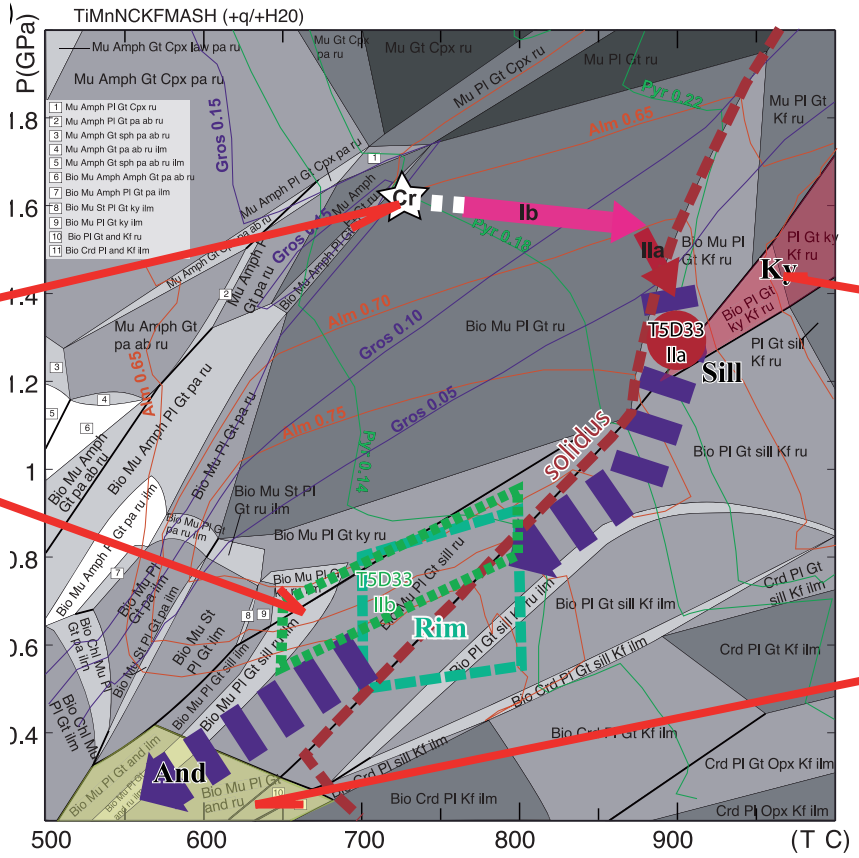
2. The Ama Drime Massif
Long-Term Deformation

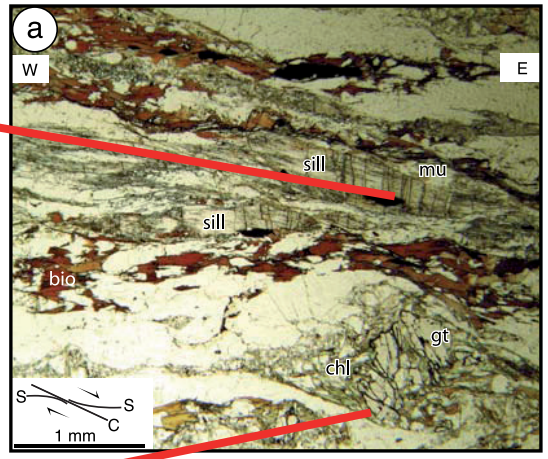


Pseudosection calculations (Perple_X software, 2007) based on thermodynamics laws
= modelisation of mineralogical assemblages stable at given P-T and predict chemistry of minerals

Modelised chemistry compared with analysis of minerals:
--> PT path







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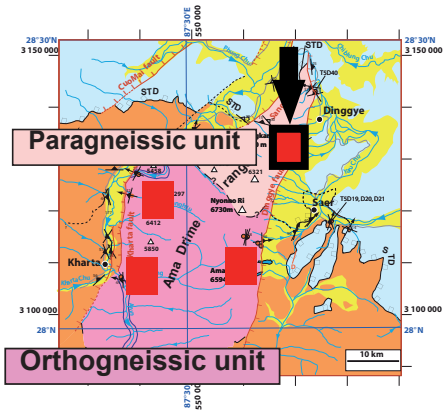
Long-Term Deformation

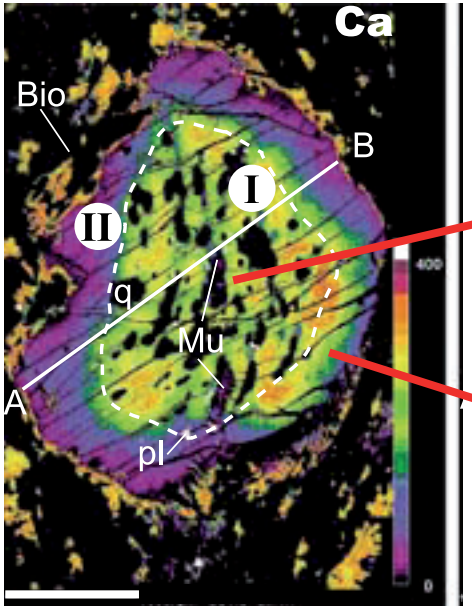


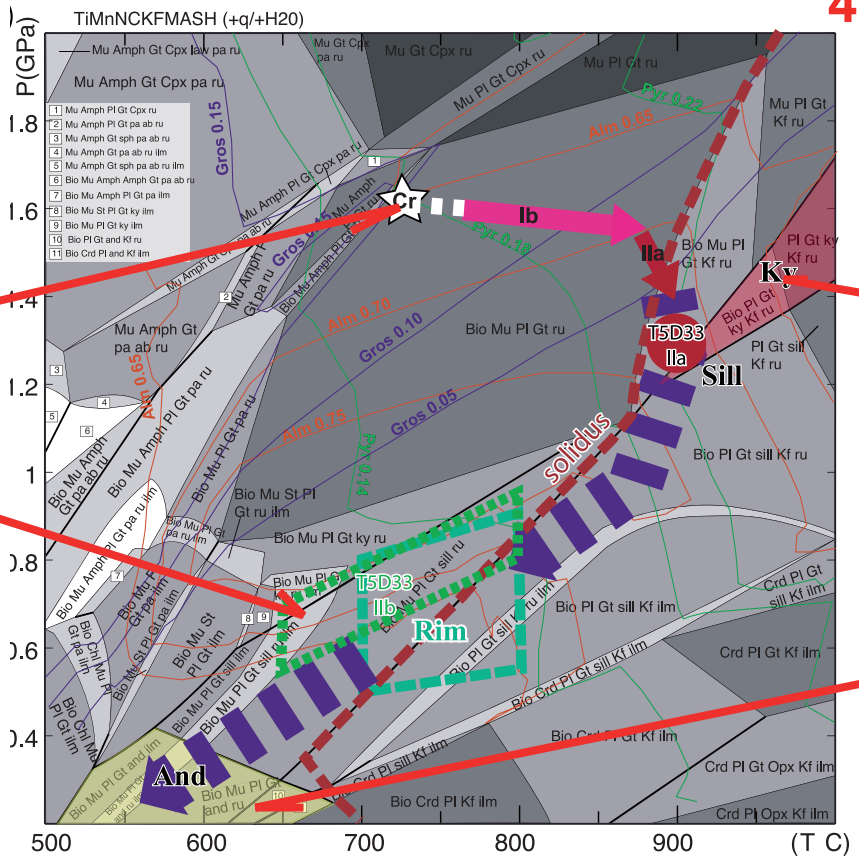
Pseudosection calculations (Perple_X software, 2007) based on thermodynamics laws
= modelisation of mineralogical assemblages stable at given P-T and predict chemistry of minerals

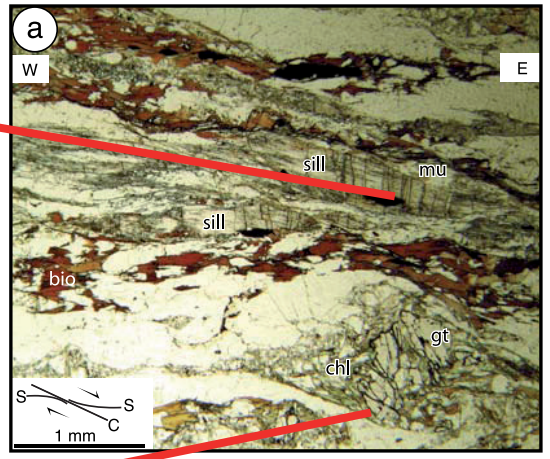
Modelised chemistry compared with analysis of minerals:
--> PT path

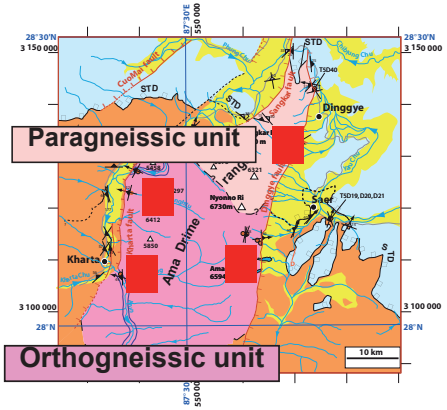
60 km depth

45 km of decompression, 900-600°C







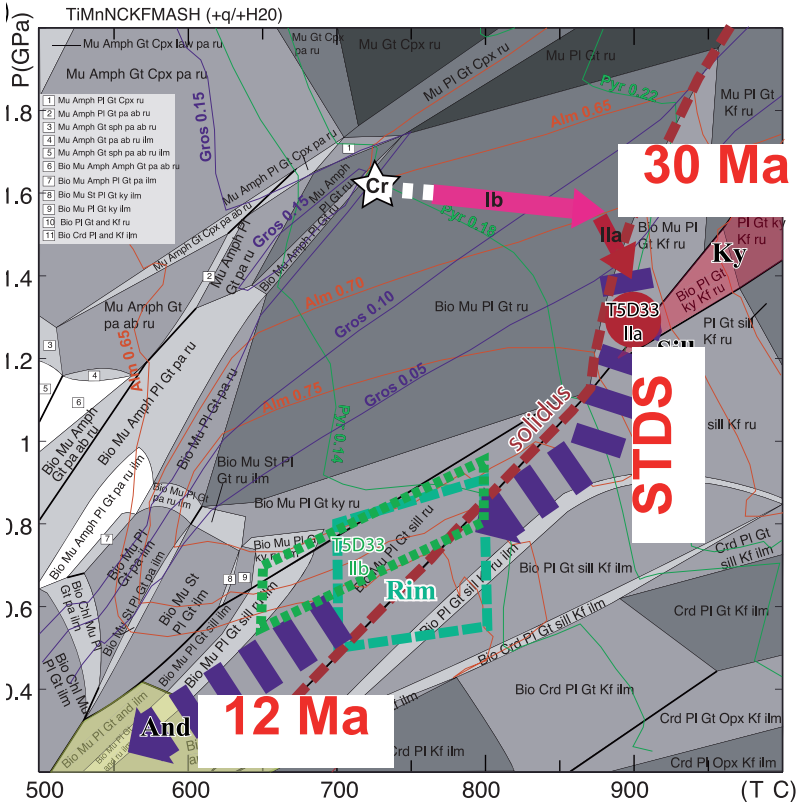


P-T--> P-T-t-D path

U/Pb datations, (this study and literature)
Associated with closure temperature and deformation event

1. Early exhumation stage of the Ama Drime Massif rocks

Paragneissic unit

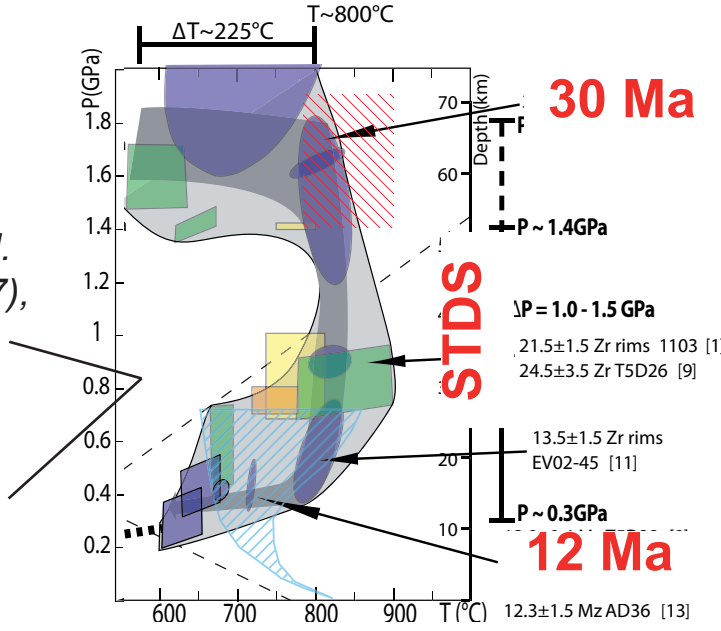


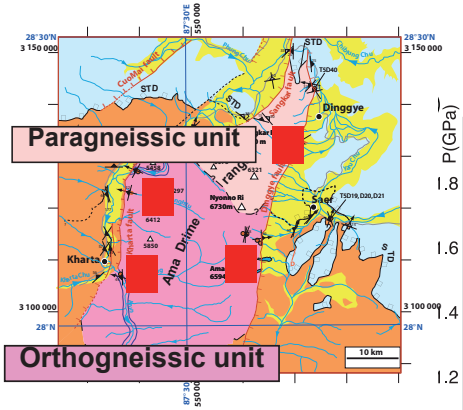
2 to 3 mm/yr

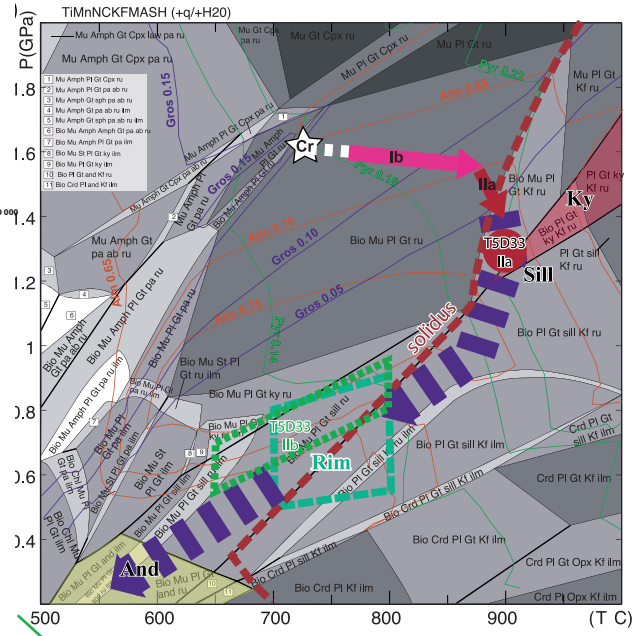
P-T data from Liu et al. (2005), Liu et al. (2007), Groppo et al. (2007), Cottle et al. (2009)

Ages from Liu et al. (2007), Rolfo et al. 2007), Cottle et al. (2009), this study

Orthogneissic unit

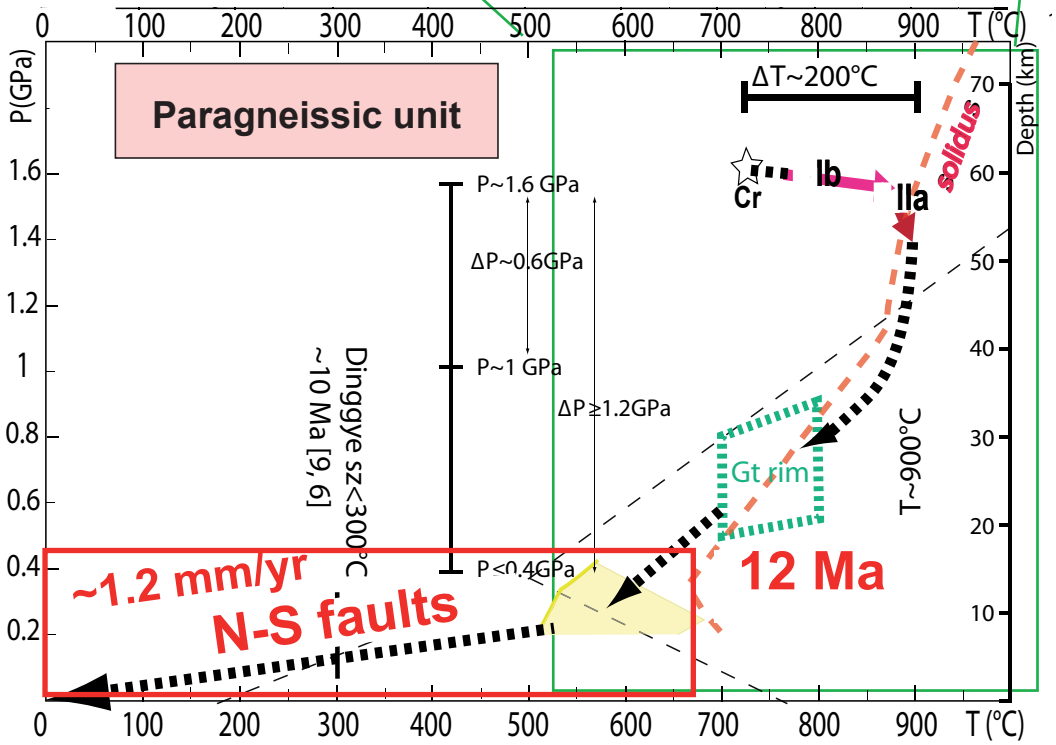


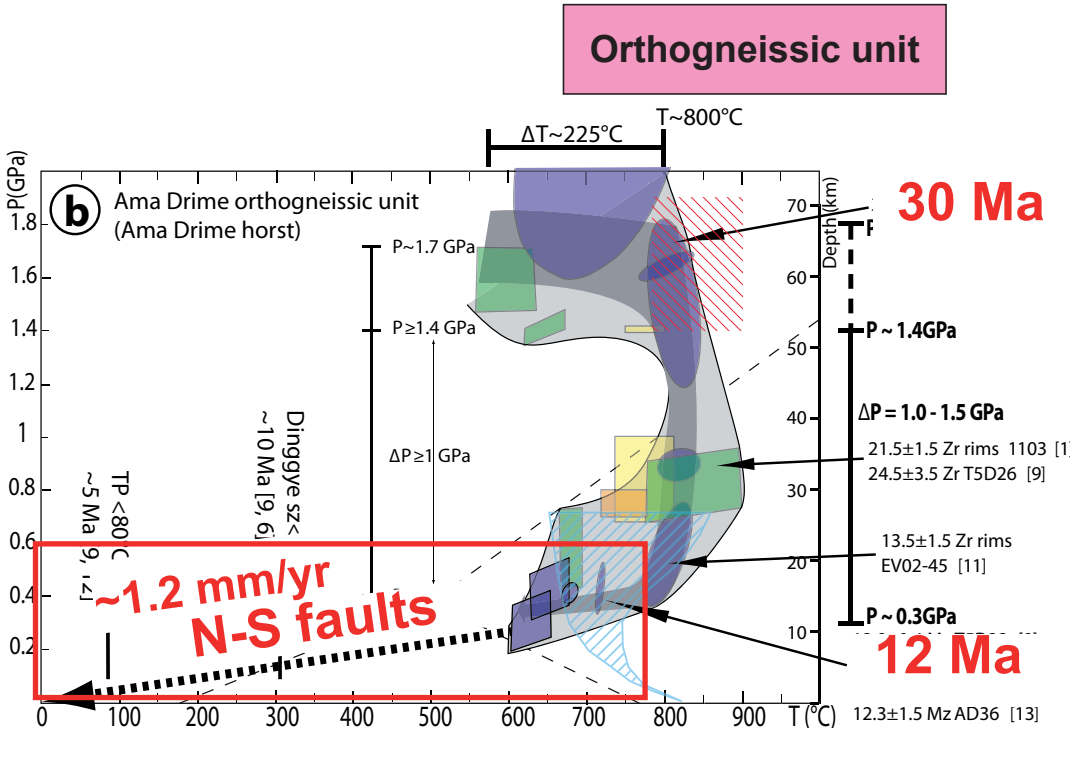




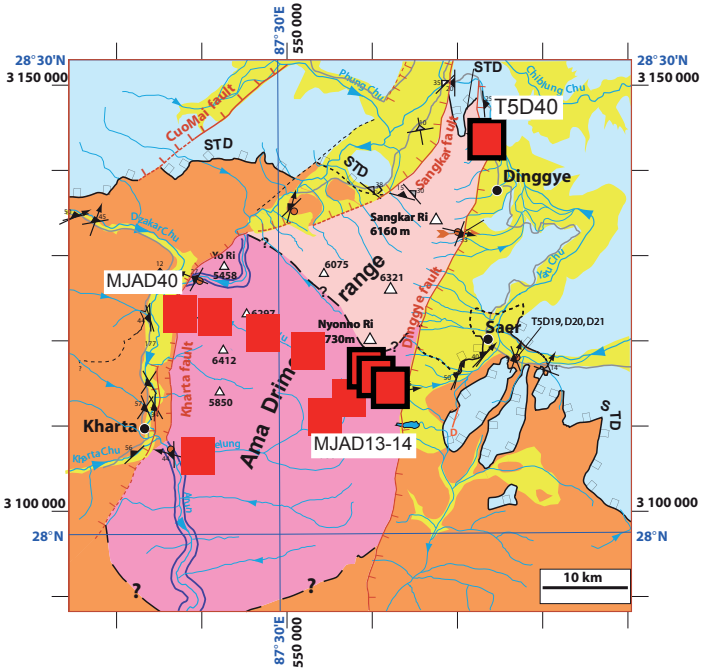
2. Late exhumation stage

15 km
12-0 Ma :
~1.2 mm/yr





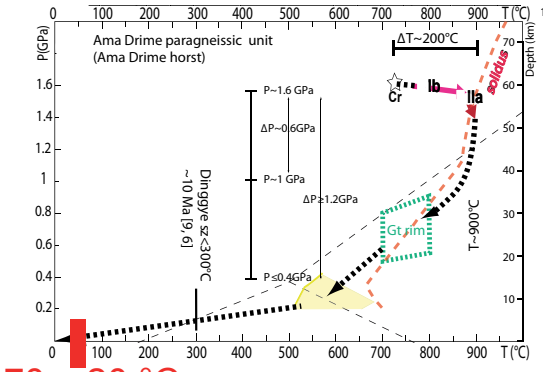
2. The Ama Drime Massif
Long-Term Deformation



This study

Jessup et al. (2008)

(U-Th)/He, apatite, Tc : 70 ± 20 °C
(Farley, 2000)

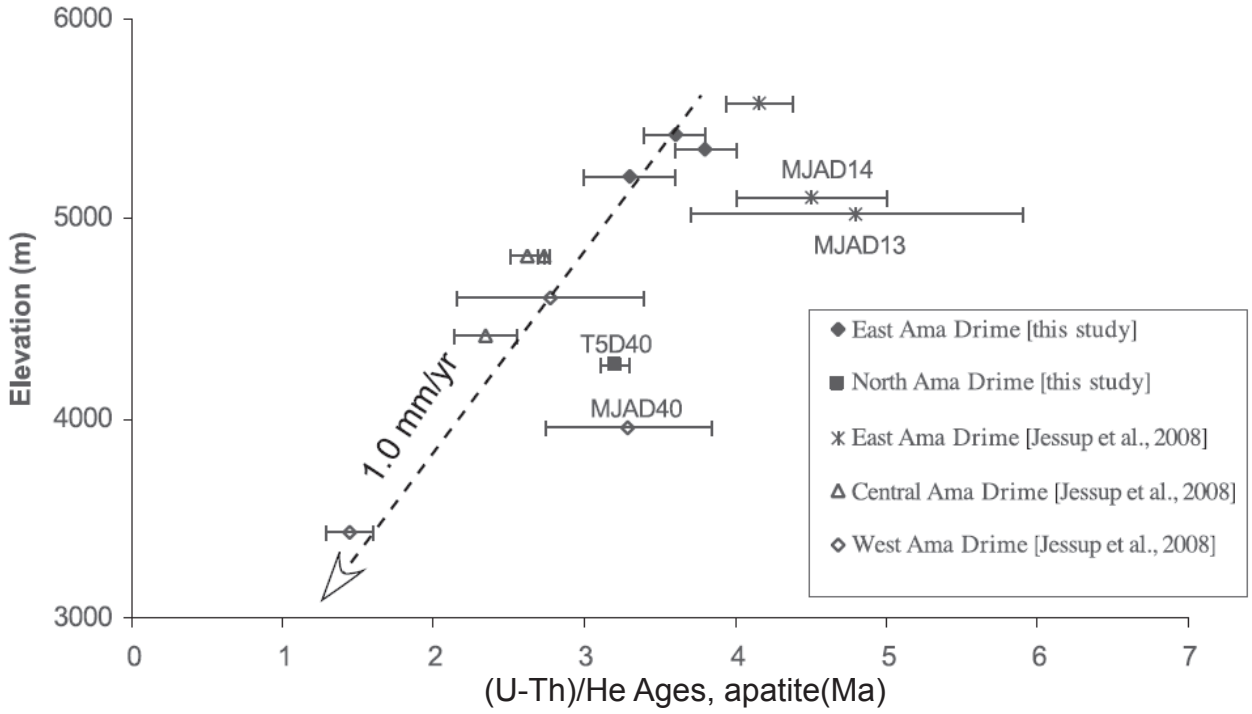


70 ± 20 °C

(U-Th)/He ages, apatites

Jessup et., 2008 + Analysis, CALTECH

Age/Elevation plot



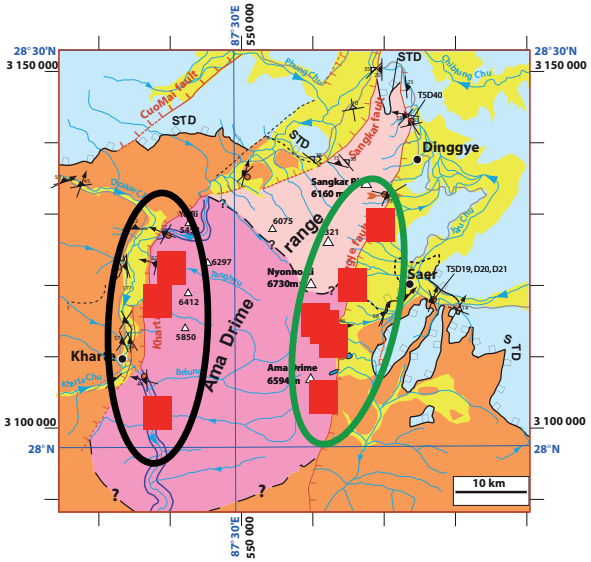
~1 mm/yr since at least 4.2 Ma

Agree with the P-T-t path:

--> ~4 km of vertical exhumation

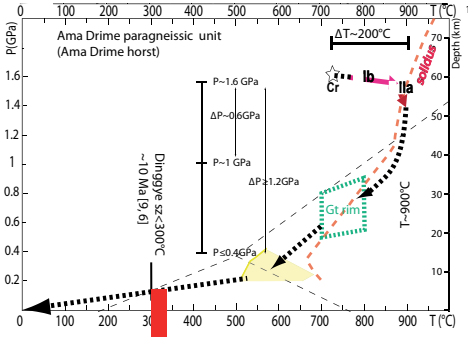
~1.2 mm/an since 12 Ma du to N-S faulting

2. The Ama Drime Massif
Long-Term Deformation



-Biotite from the foliation plane of the ductile normal shear zones.
- Ductile coeval deformation in Dinggye and Kharta shear zone
-Rapid cooling at ~11 Ma in Dinggye
-Slower cooling in Kharta between 10 and 6 Ma

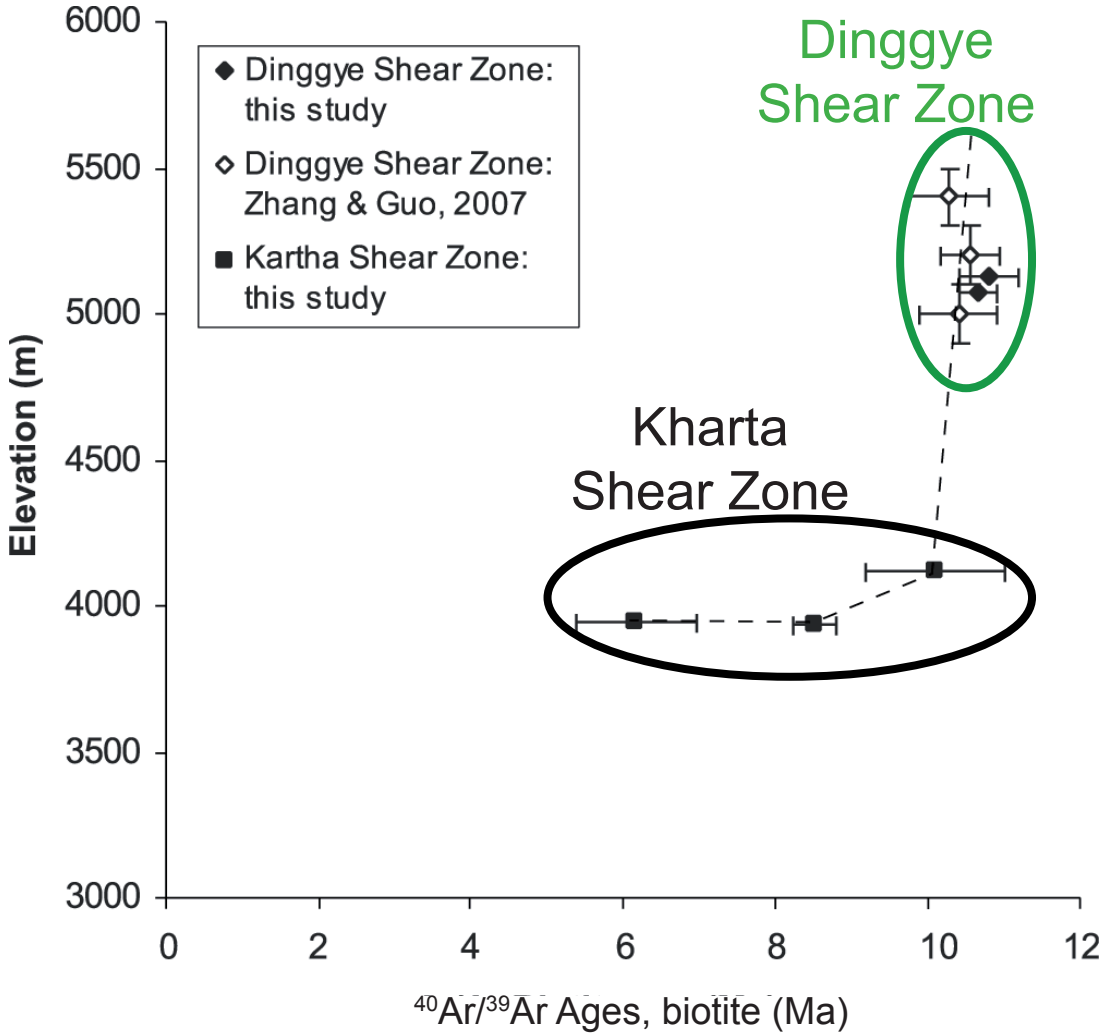
$^{40}Ar/^{39}Ar$, biotite Tc : 320 ± 40 °C
(Harrison et al. 1995)

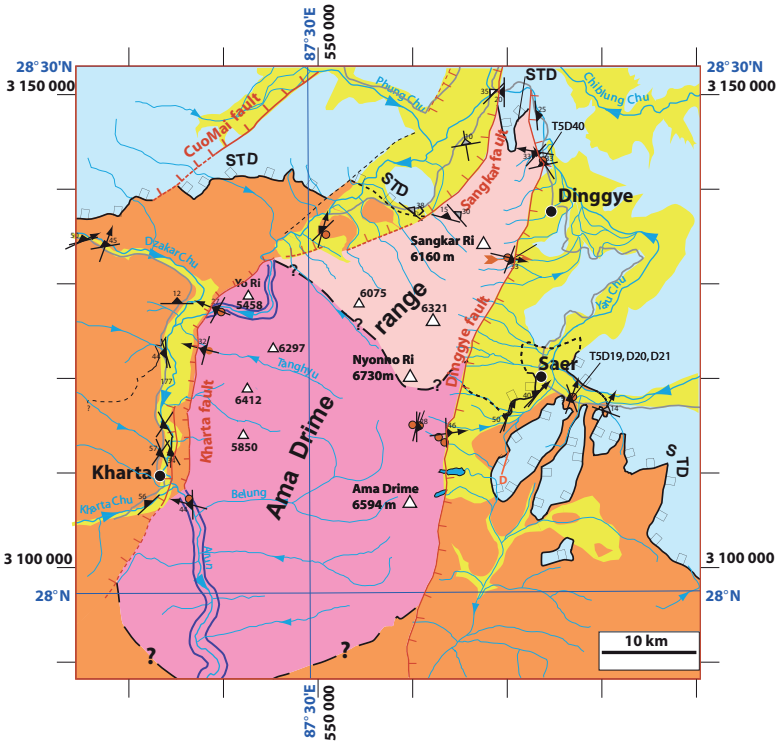


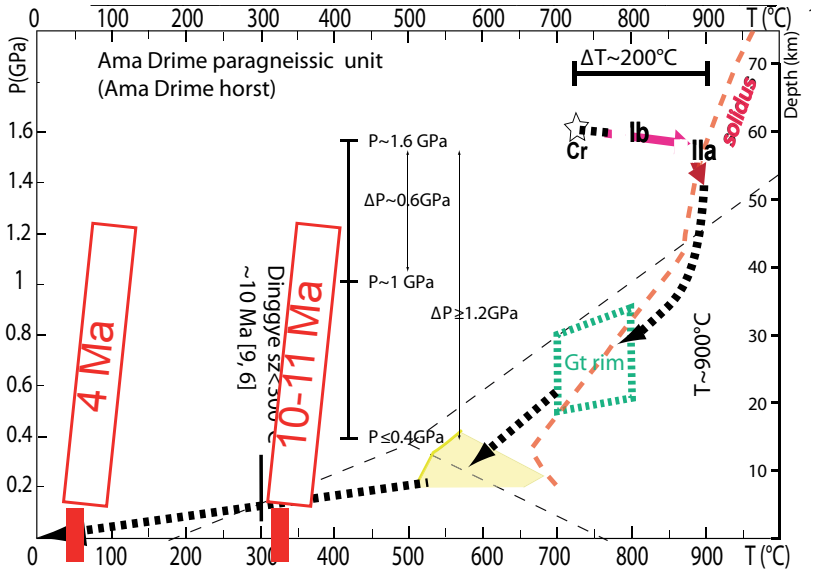
$^{40}Ar/^{39}Ar$ ages, biotites

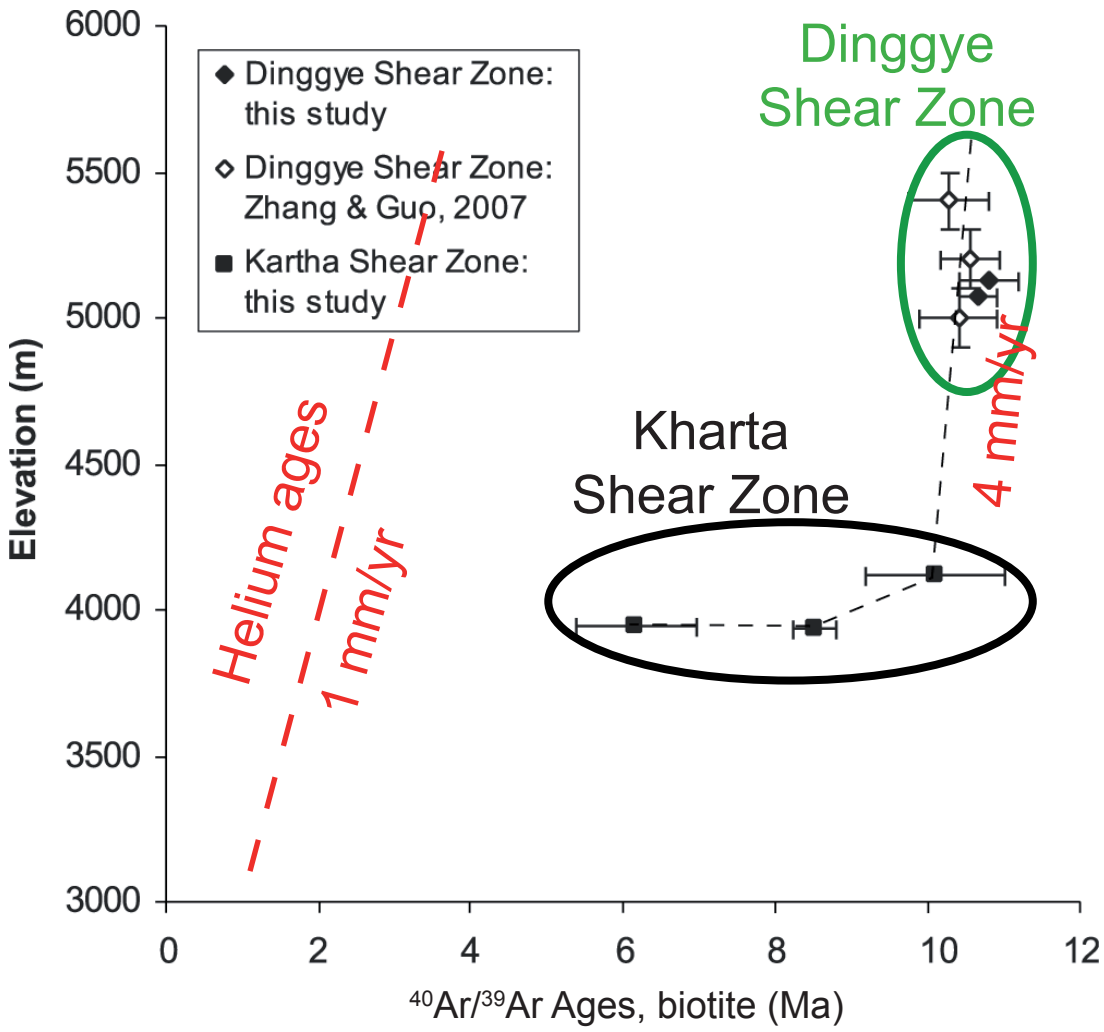
Zhang and Guo 2007 + Analysis, Geosciences Montpellier

Age/Elevation plot

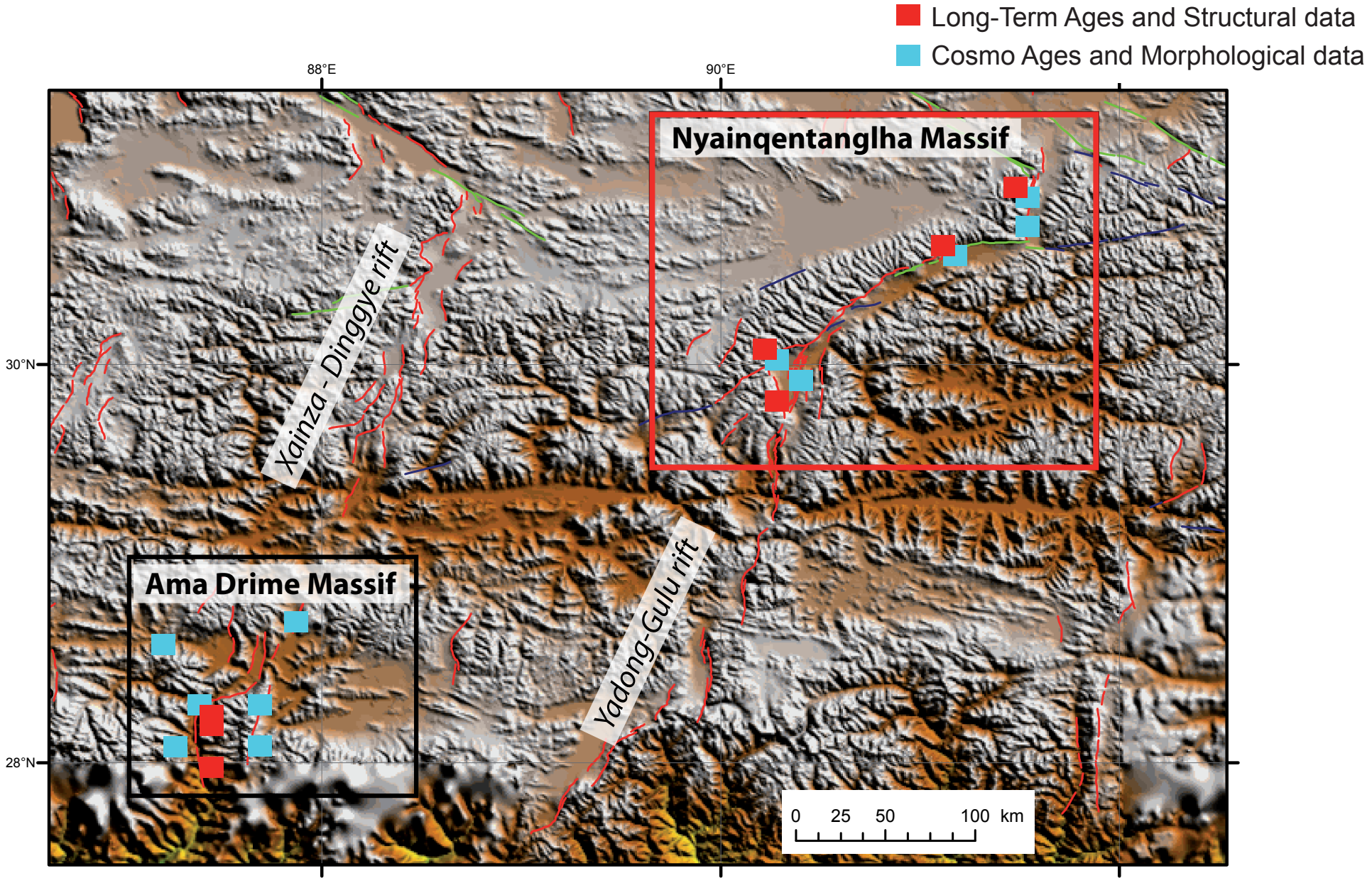


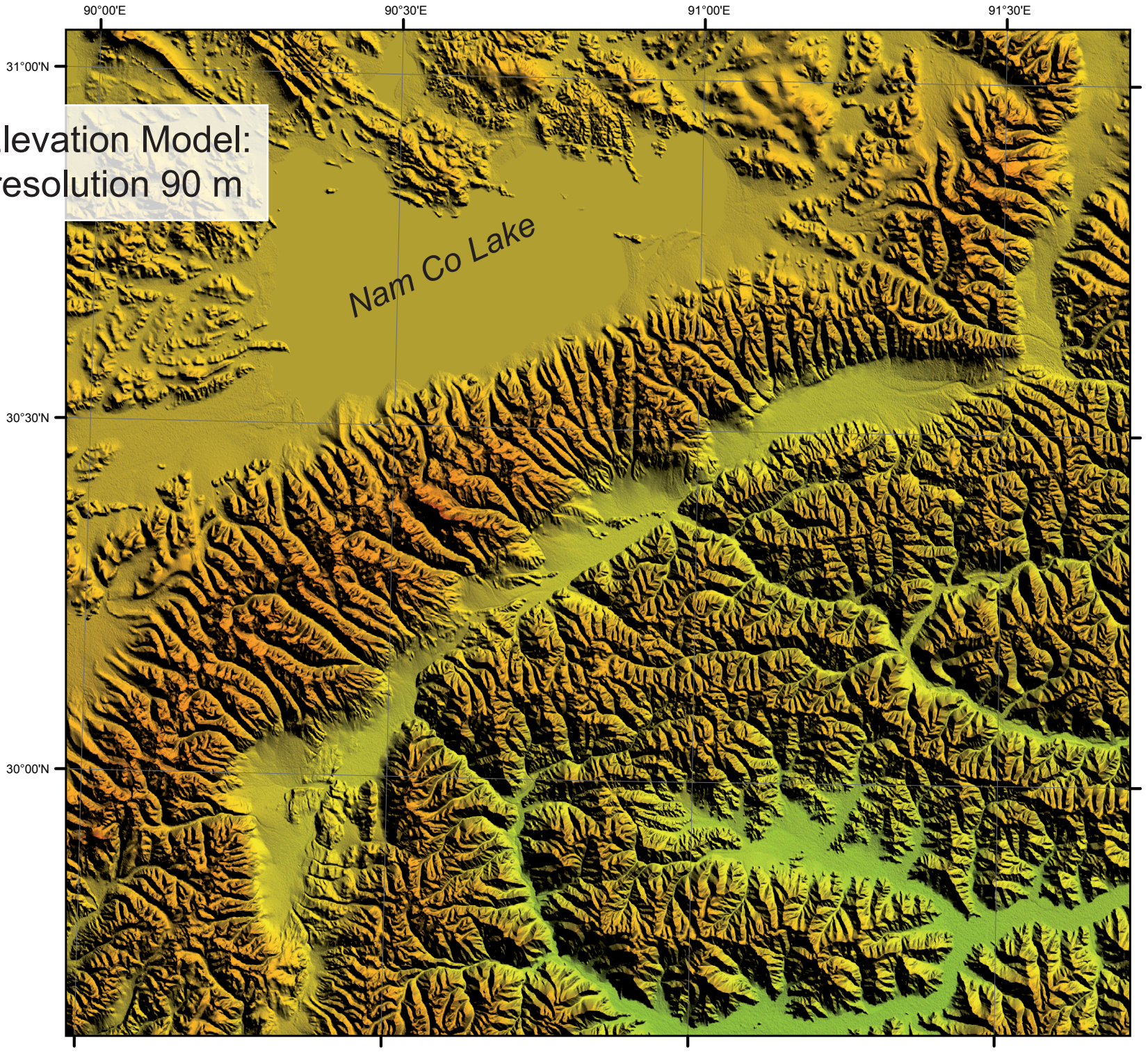

28°30'N
3 150 000
87°30'E
550 000
STD
CuoMai fault
Phung Chu
Chidlung Chu
T5D40
Dinggye
Sangkar fault
Sangkar Ri
6160 m
Dzakar Chu
Yo Ri
5458
6075
6321
range
Dinggye fault
Yo Chu
6297
Nyonho Ri
6730m
Saer
T5D19, D20, D21
Tangshu
6412
Kharta fault
5850
Kharta
Ama Drime
Ama Drime
6594 m
Kipta Chu
Balung
Mulo
3 100 000
28°N
10 km


P(GPa)
T (°C)
Depth (km)
Ama Drime paragneissic unit
(Ama Drime horst)
ΔT~200°C
Cr
Ib
IIa
solidus
P~1.6 GPa
ΔP~0.6GPa
P~1 GPa
ΔP≥1.2GPa
P≤0.4GPa
Gt rim
T~900°C
4 Ma
10-11 Ma
~10 Ma [9, 9]
Dinggye ≤~300°C


Elevation (m)
6000
5500
5000
4500
4000
3500
3000
0
2
4
6
8
10
12
40Ar/39Ar Ages, biotite (Ma)
Dinggye Shear Zone: this study
Dinggye Shear Zone: Zhang & Guo, 2007
Kartha Shear Zone: this study
Helium ages
1 mm/yr
Dinggye Shear Zone
4 mm/yr
Kharta Shear Zone

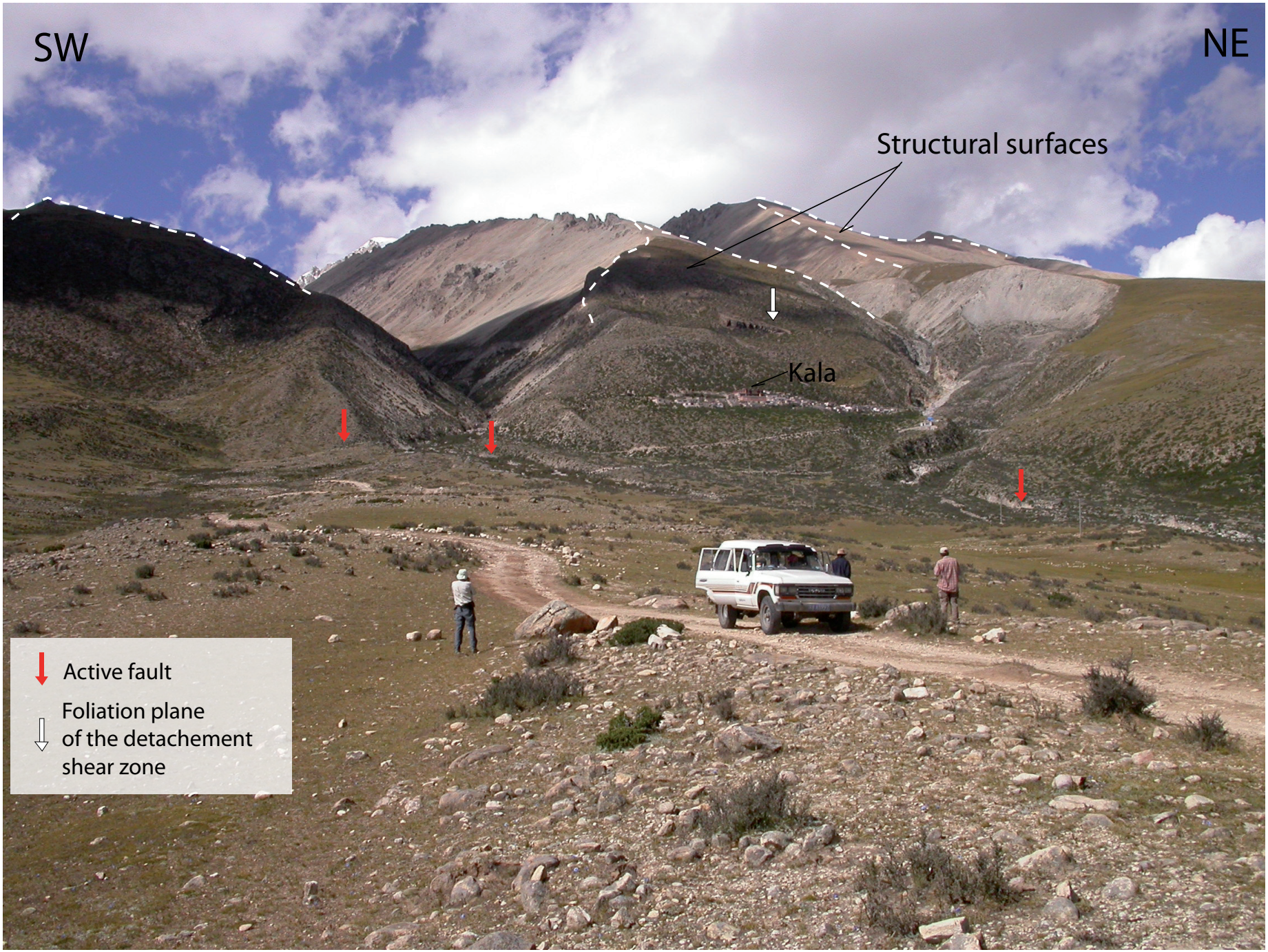
3. The Nyainqentanglha Massif

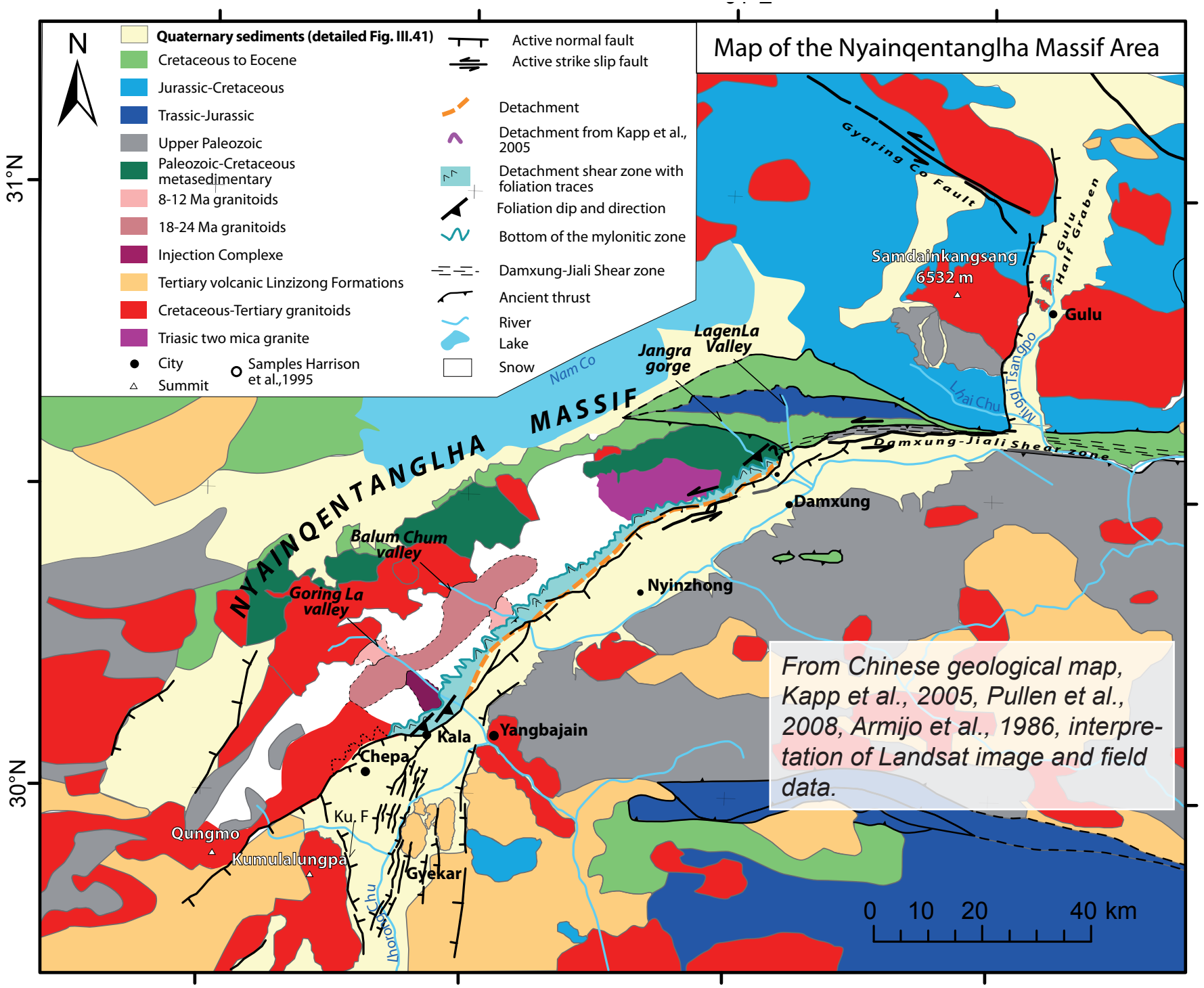


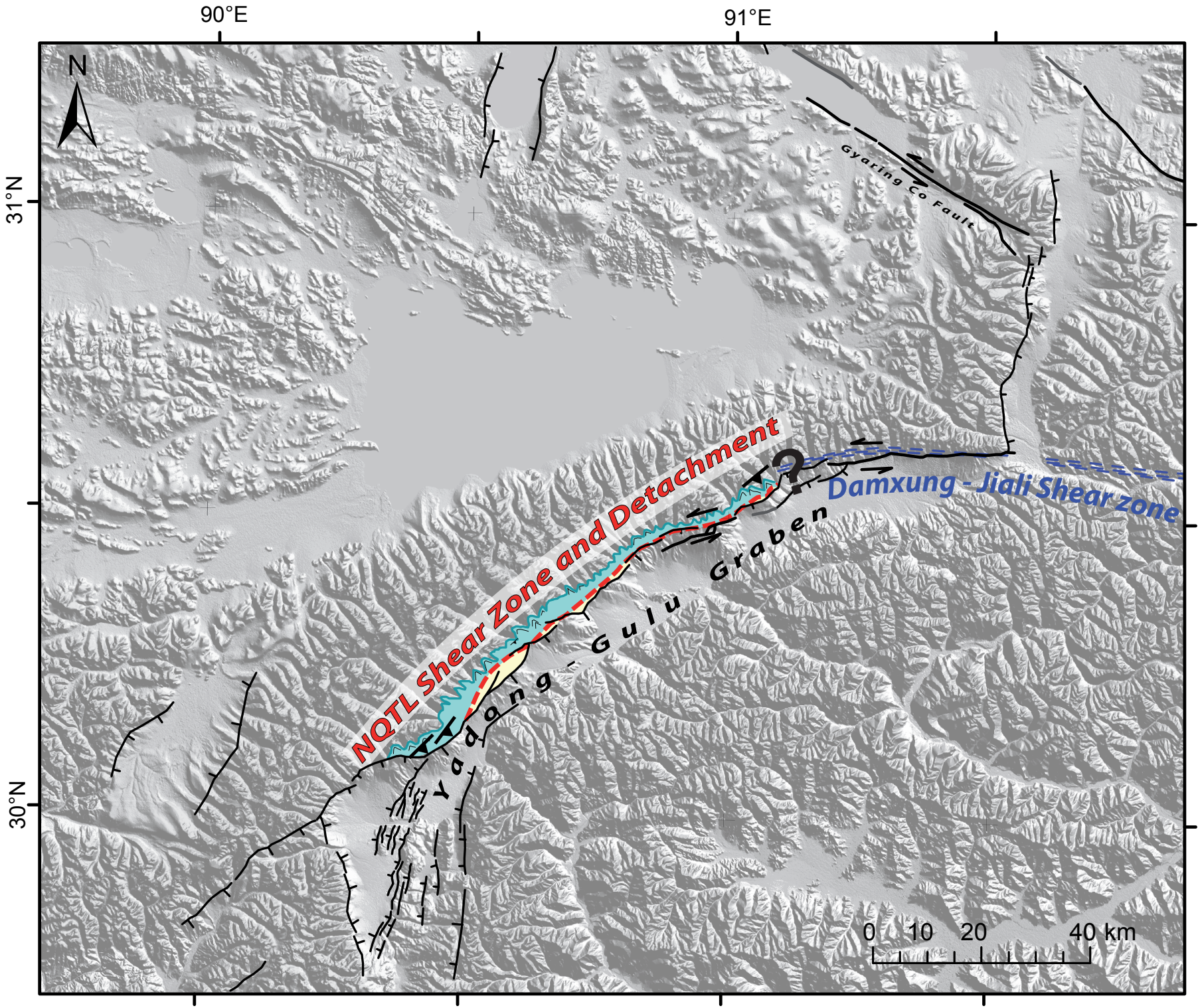


Digital Elevation Model:
SRTM, resolution 90 m

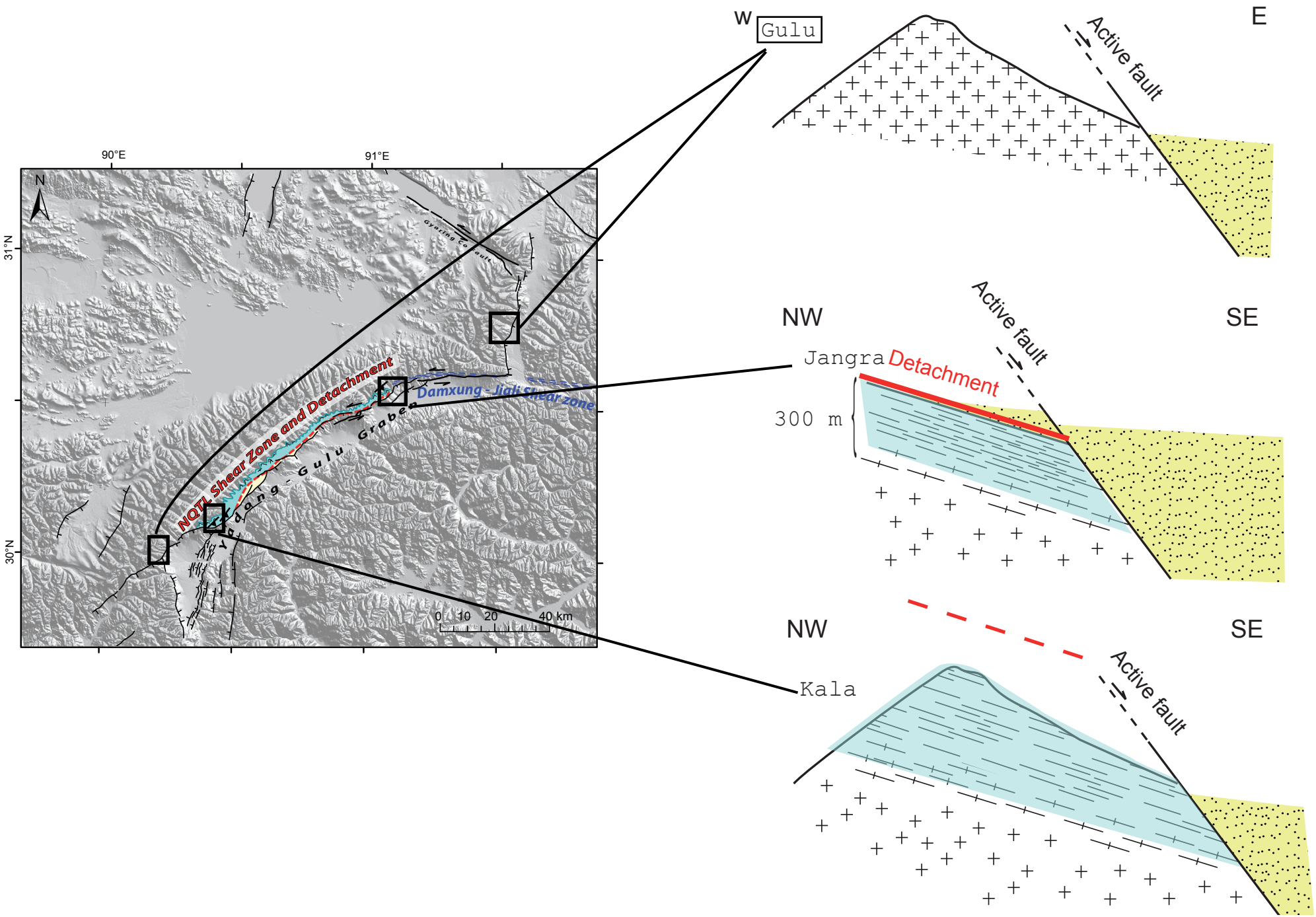
3. The Nyainqentanglha Massif




Map of the Nyainqentanglha Massif Area
N
Quaternary sediments (detailed Fig. III.41)
Cretaceous to Eocene
Jurassic-Cretaceous
Trassic-Jurassic
Upper Paleozoic
Paleozoic-Cretaceous metasedimentary
8-12 Ma granitoids
18-24 Ma granitoids
Injection Complexe
Tertiary volcanic Linzizong Formations
Cretaceous-Tertiary granitoids
Triasic two mica granite
City
Summit
Samples Harrison et al.,1995
Active normal fault
Active strike slip fault
Detachment
Detachment from Kapp et al., 2005
Detachment shear zone with foliation traces
Foliation dip and direction
Bottom of the mylonitic zone
Damxung-Jiali Shear zone
Ancient thrust
River
Lake
Snow
31°N
30°N
NYAINQENTANGLHA MASSIF
Nam Co
Jangra gorge
LagenLa Valley
Gyaring Co Fault
Samdainkangsang 6532 m
Gulu Half Graben
Gulu
Lhai Chu
Damxung-Jiali Shear zone
Damxung
Balum Chum valley
Goring La valley
Nyinzhong
Kala
Yangbajain
Chepa
Ku. F
Qungmo
Kumulalungpa
Gyekar
Lhorong Chu
From Chinese geological map, Kapp et al., 2005, Pullen et al., 2008, Armijo et al., 1986, interpretation of Landsat image and field data.
0 10 20 40 km

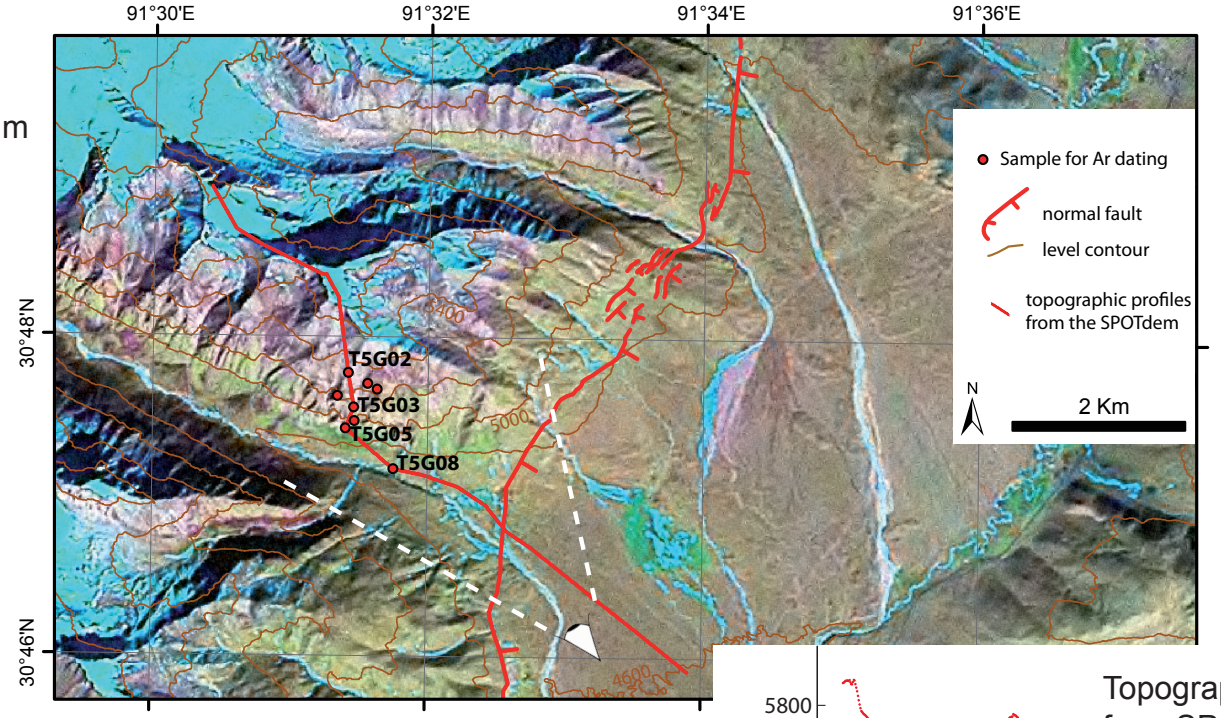

90°E
91°E
N
31°N
30°N
Gyaring Co Fault
NQTL Shear Zone and Detachment
?
Damxung - Jiali Shear zone
Yadong - Gulu Graben
0 10 20 40 km

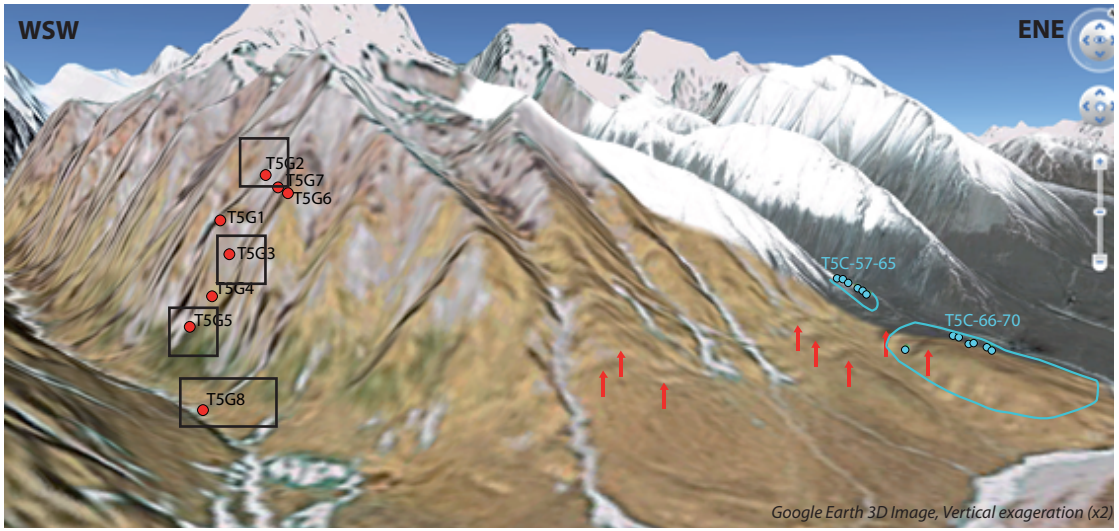
3. The Nyainqentanglha Massif
Long-Term Deformation



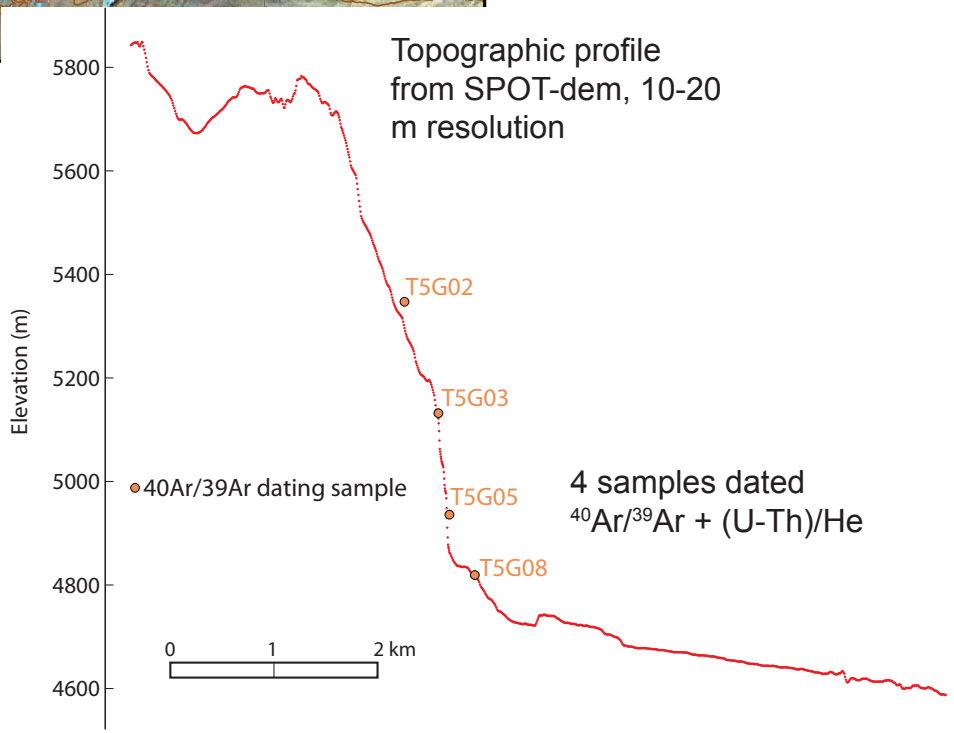
3. The Nyainqentanglha Massif
Long-Term Deformation

Landsat image
Resolution 28.5 m



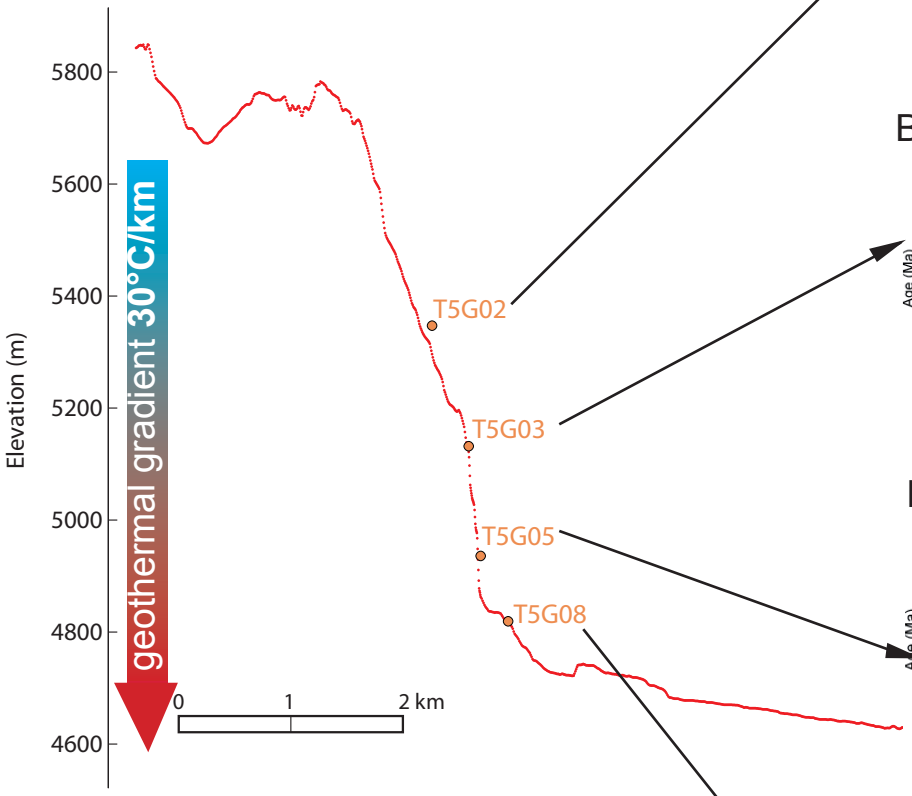


8 samples taken on the vertical profile, 4 dated



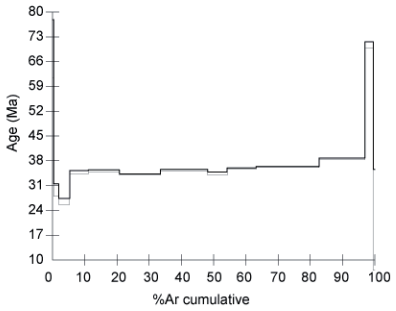
$^{40}Ar/^{39}Ar$, biotite Tc : 320 ± 40 °C
(Harrison et al. 1995)

(U-Th)/He, apatite, Tc : 70 ± 20 °C
(Farley, 2000)

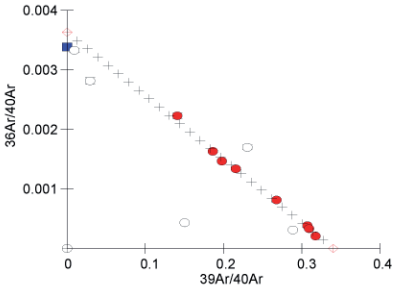


$^{40}Ar/^{39}Ar$ Ages

Biotite



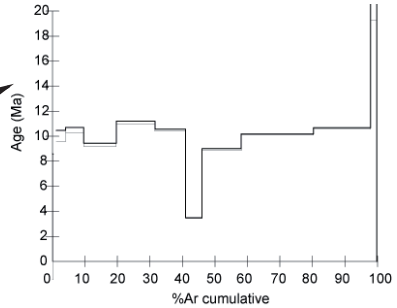
36.39 ± 0.38 Ma



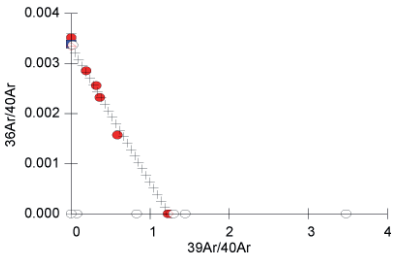
(U-Th)/He Ages apatites

2.15 ± 0.19 Ma

Biotite

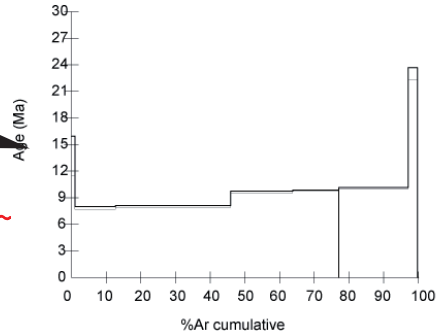


10.10 ± 0.23 Ma

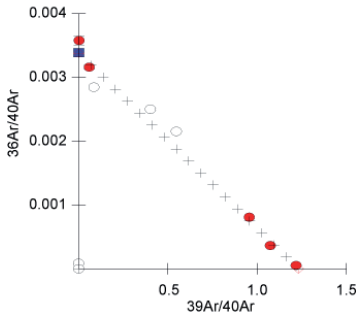


1.63 ± 0.11 Ma

Biotite

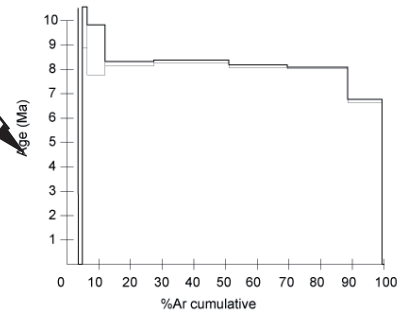


T 10.10 ± 0.21 Ma

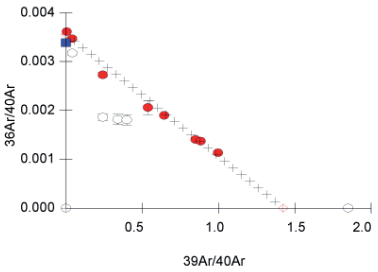


1.53 ± 0.07 Ma

Muscovite



8.74 ± 0.19 Ma



4.42 ± 0.44 Ma

Faulting Initiation in Gulu: ~10 Ma

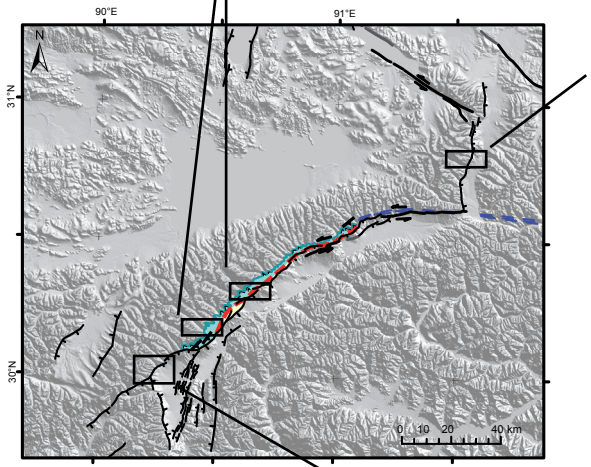
<300°C since >10Ma + 30°C/km
1 mm/yr

Analysis, Geosciences Montpellier

3. The Nyainqentanglha Massif
Long-Term Deformation

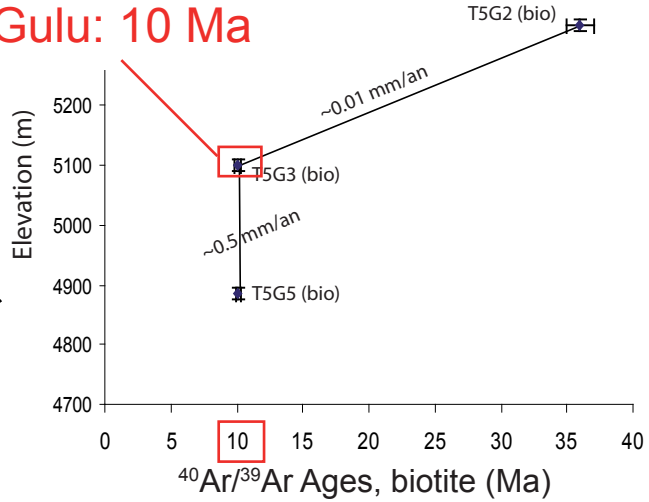
vertical exhumation rate
1.5 mm/yr

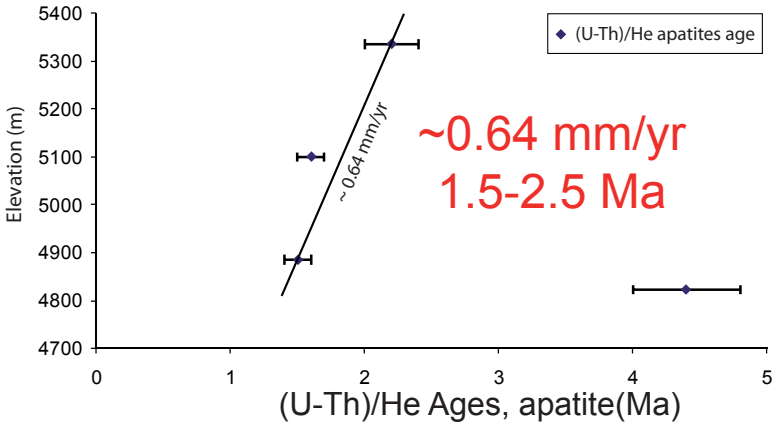
initiation 8 Ma
(Harrison et al., 1995)



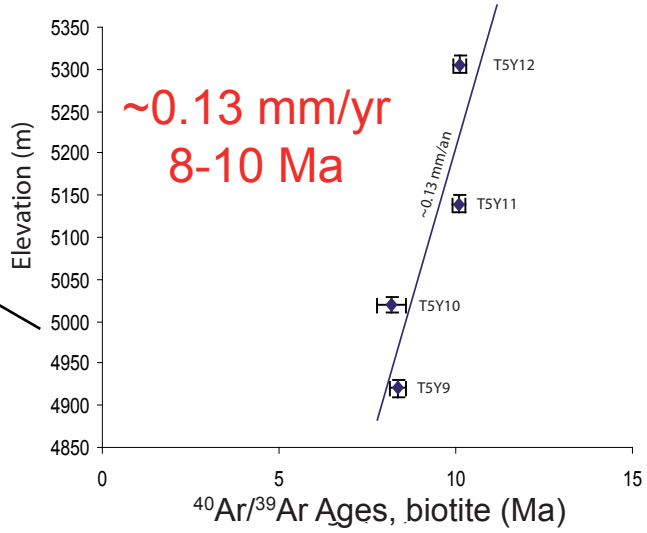
~1 mm/yr averaged
since 10 Ma

Faulting Initiation in
Gulu: 10 Ma

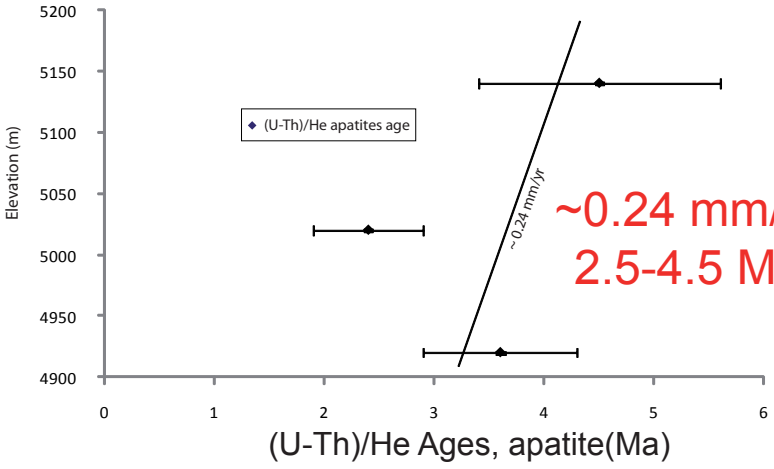




~0.64 mm/yr
1.5-2.5 Ma



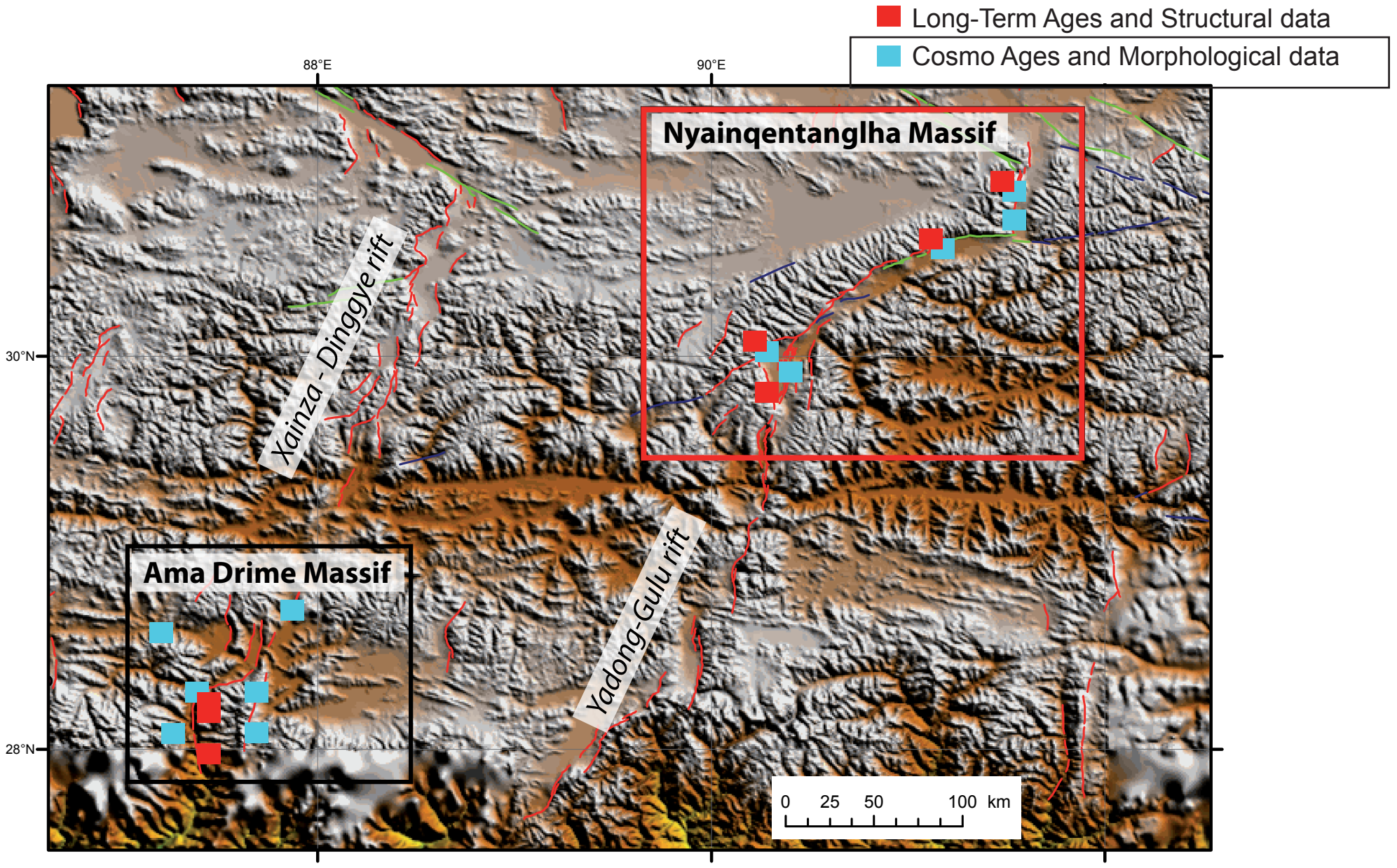
~0.13 mm/yr
8-10 Ma



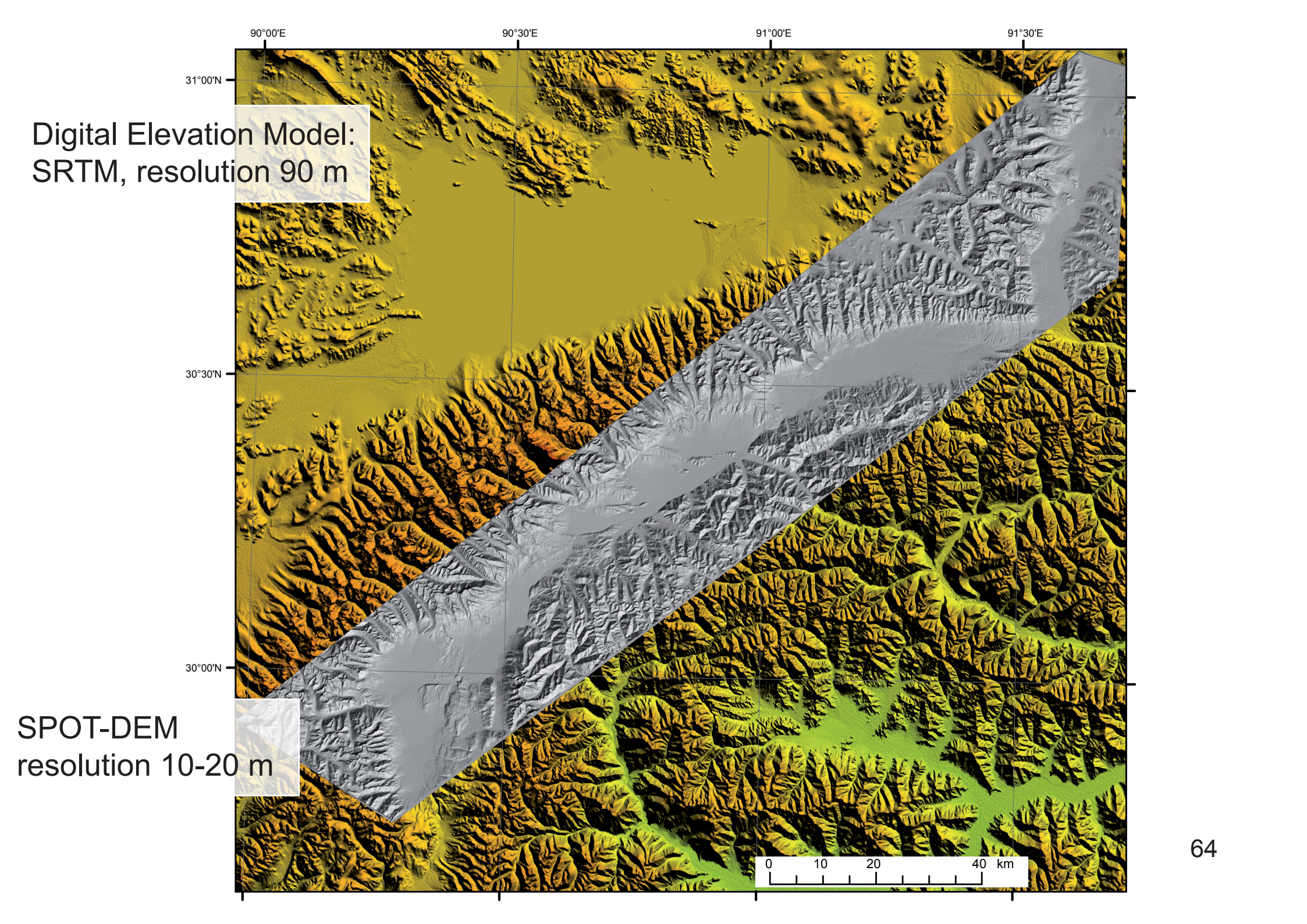
~0.24 mm/yr
2.5-4.5 Ma

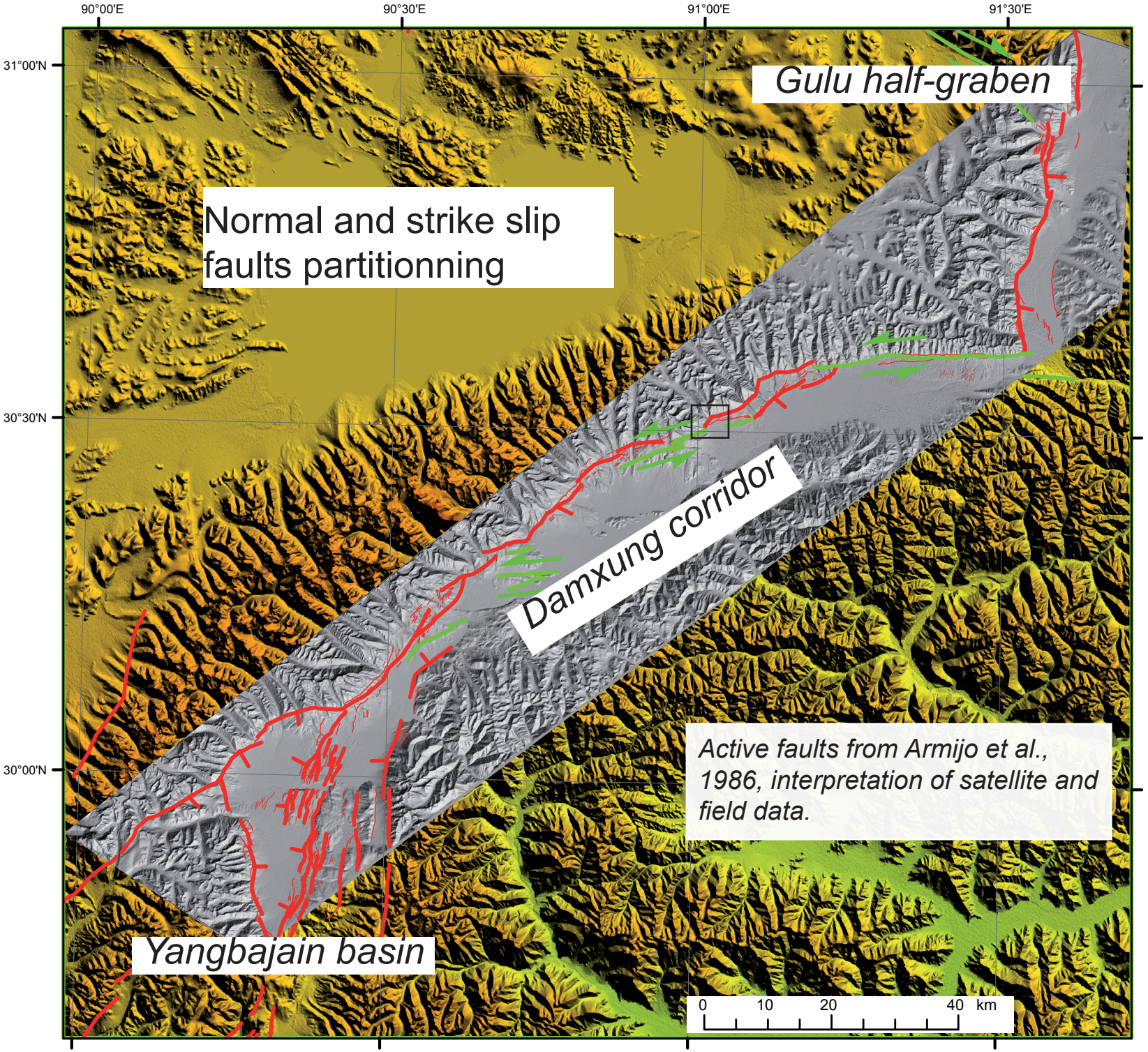
Several exhumation and extension phases ?

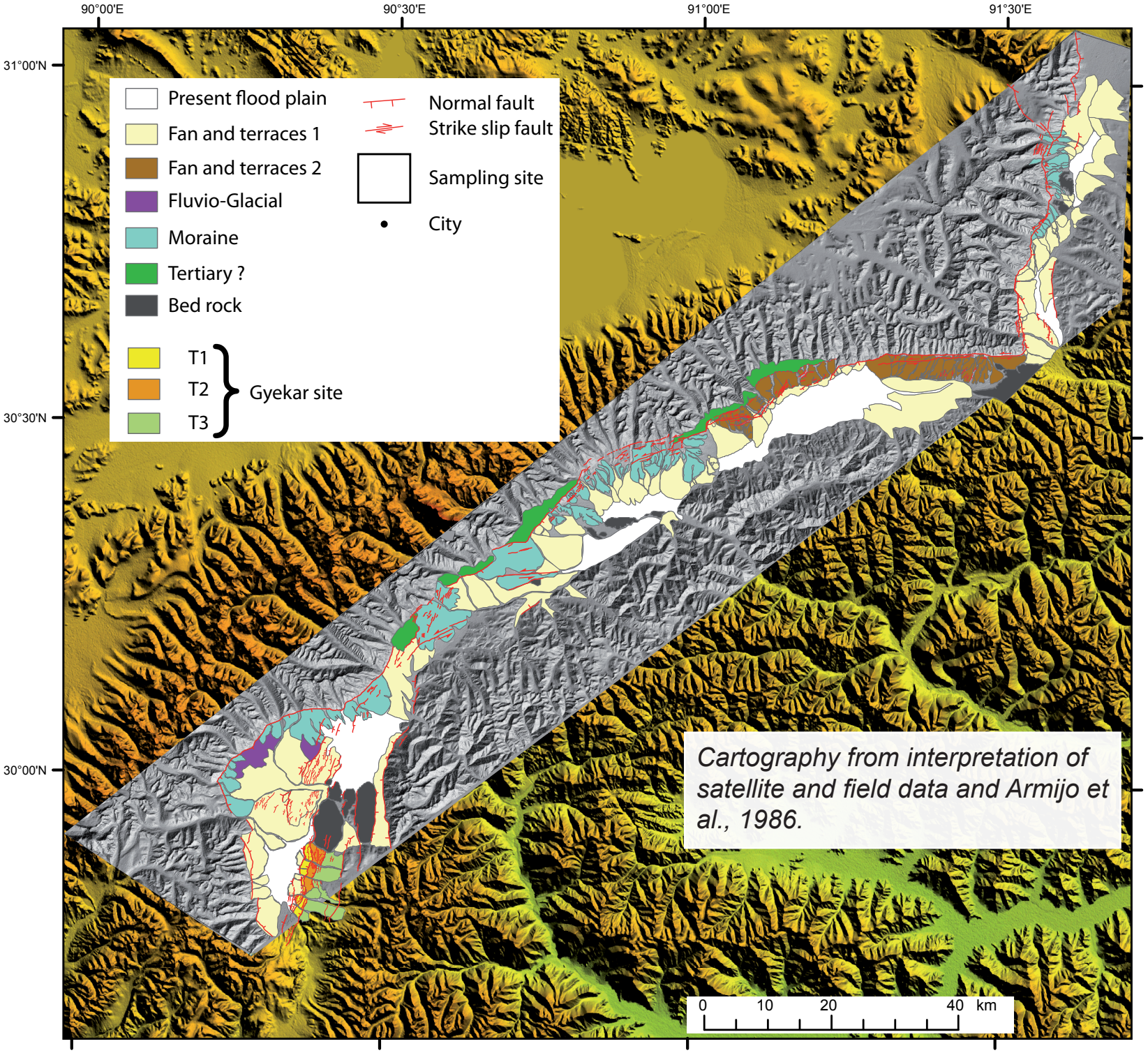
3. The Nyainqentanglha Massif
Short-Term Deformation



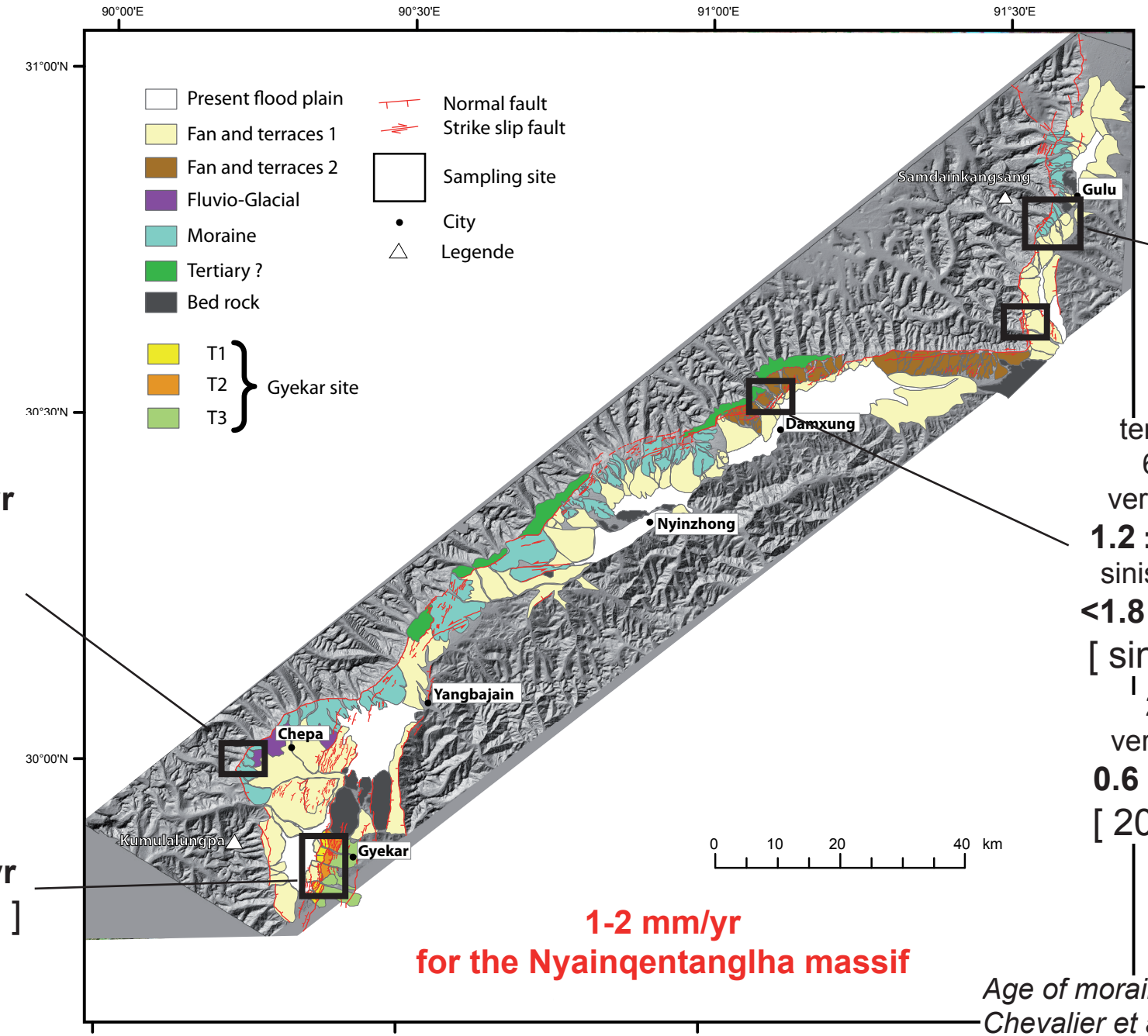
Armijo et al., 1986


90°00'E
90°30'E
91°00'E
91°30'E
31°00'N
30°30'N
30°00'N
Digital Elevation Model:
SRTM, resolution 90 m
SPOT-DEM
resolution 10-20 m
0
10
20
40 km


90°00'E
90°30'E
91°00'E
91°30'E
31°00'N
30°30'N
30°00'N
Gulu half-graben
Normal and strike slip faults partitionning
Damxung corridor
Yangbajain basin
Active faults from Armijo et al., 1986, interpretation of satellite and field data.
0 10 20 40 km


90°00'E
90°30'E
91°00'E
91°30'E
31°00'N
30°30'N
30°00'N
Present flood plain
Fan and terraces 1
Fan and terraces 2
Fluvio-Glacial
Moraine
Tertiary ?
Bed rock
T1
T2
T3
Gyekar site
Normal fault
Strike slip fault
Sampling site
City
Cartography from interpretation of satellite and field data and Armijo et al., 1986.
0
10
20
40 km

Quaternary Slip Rates



moraine dating
15 samples
2.2 ± 0.8 mm/yr
[16 - 21 ka]

terrace dating
6 samples
vertical slip rate
1.2 ± 0.2 mm/yr
sinistral slip rate:
<1.8 ± 0.1 mm/yr
[since ~17 ka]

moraine dating
27 samples
1.1 ± 0.7 mm/yr
[22 - 56 ka]

2 samples
vertical slip rate
0.6 ± 0.2 mm/yr
[200- 320 ka]

terrace dating
5 samples
0.6 ± 0.2 mm/yr
[190 - 290 ka]

1-2 mm/yr
for the Nyainqentanglha massif

Age of moraine from Chevalier et al. (subm)

Main Results

AMA DRIME

STDS : 2-3 mm/yr [30-12Ma]

INITIATION
12 Ma

~ 1 mm/yr
[since 4 Ma]

~ 1.2 mm/yr
[since 12 Ma]

or

polyphased extension :
4 mm/yr [12 - 9 Ma]
& **1 mm/yr** [4 - 0 Ma]

1.2 ± 0.6 mm/yr
[since ~ 140 ka]

NYAINQENTANGLHA

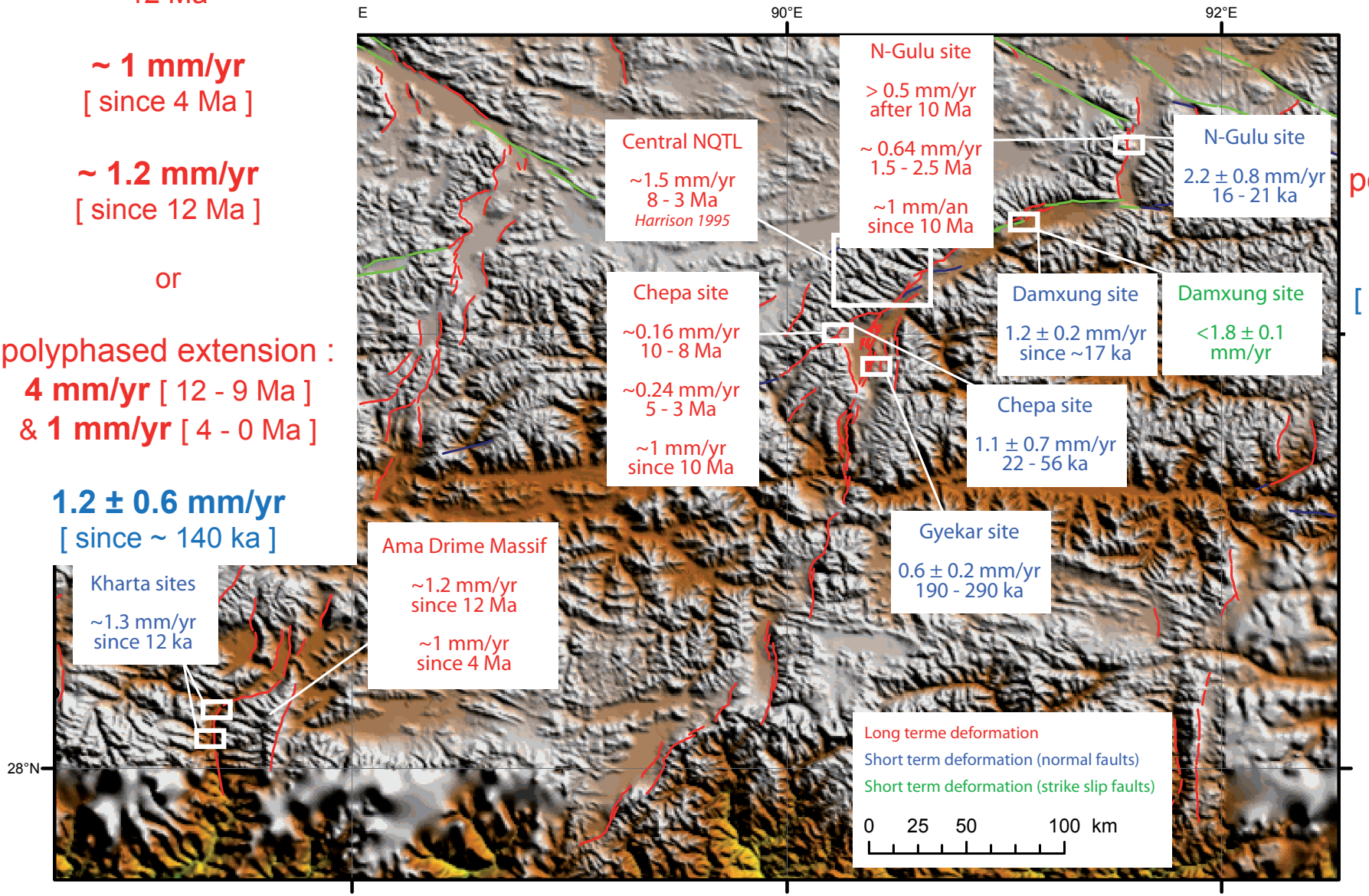
INITIATION
10 Ma Gulu

1 - 1.5 mm/yr
[since 10 Ma]

or

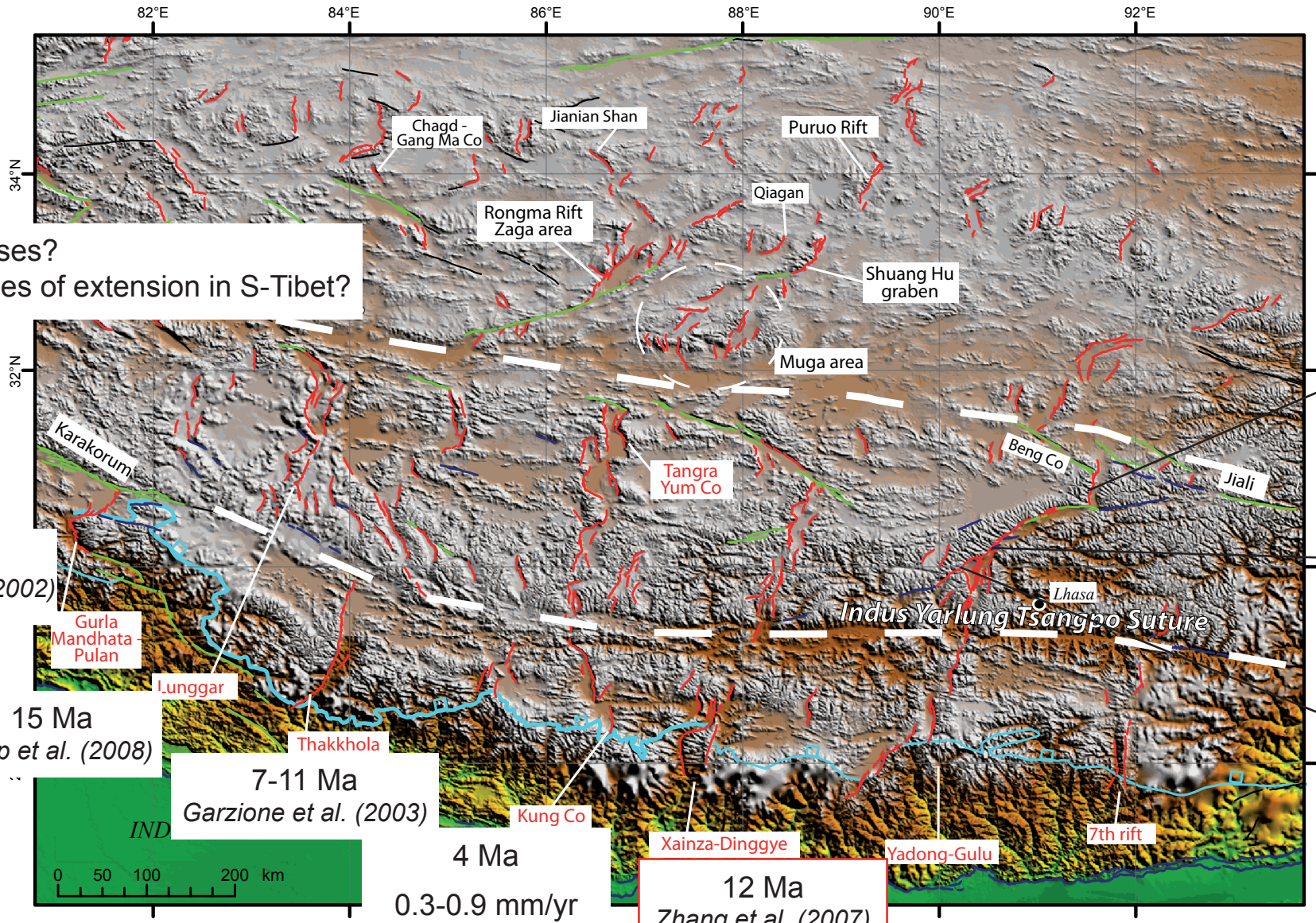
polyphased extension

1.1 - 2.2 mm/yr
[since ~ 40 ka (300ka)]



4. Conclusion

Long-term deformation



Initiation phases?
Several phases of extension in S-Tibet?

> 9 Ma
Murphy et al. (2002)

15 Ma
Kapp et al. (2008)

7-11 Ma
Garzione et al. (2003)

4 Ma

0.3-0.9 mm/yr
Mahéo et al. (2007)

12 Ma
Zhang et al. (2007)
This study

~1mm/an
two phases
This study

5-7 Ma
Stockli et al. (2002)

10 Ma
This study

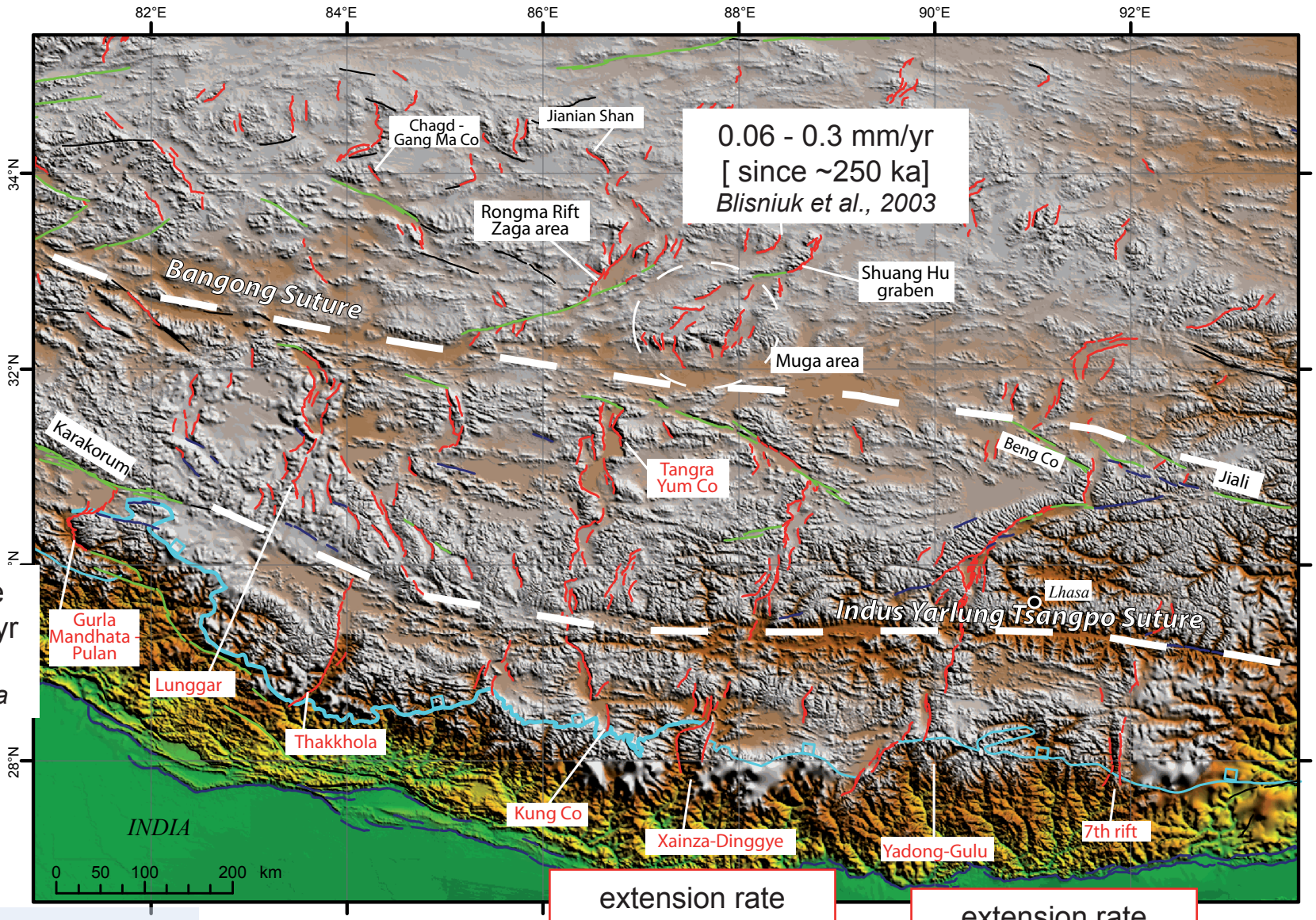
~1 mm/an
+phases
This study

8 Ma
1.5 mm/an
Harrison et al. (1995)

~1 mm/an
+phases
This study

4. Conclusion

Short-term deformation



extension rate
1.7 ± 0.2 mm/yr
[since 34 ka]
unpublished data

extension rate South-Tibet
~10 mm/yr
[since 40-60 ka]

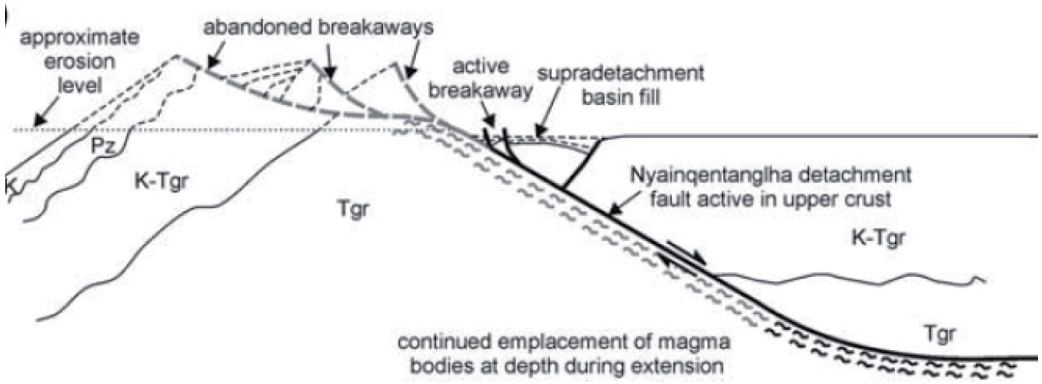
extension rate
1.3 ± 0.2 mm/yr
[since 40 ka]
this study

extension rate
1.4 ± 0.6 mm/yr
[since 60 ka]
this study

Long-term deformation + **Short-term deformation**

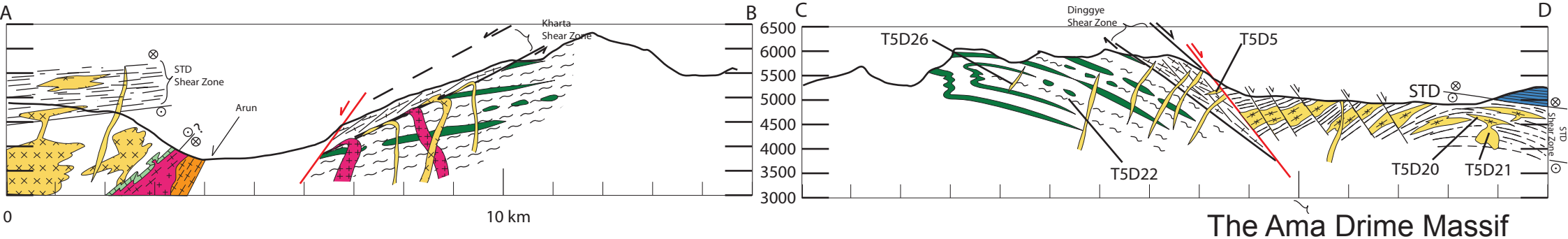
Mechanisms of extension, for each rift? The same for all Tibet?

Model of «rolling hinge» proposed by Kapp et al. (2005, 2008) for the Nyainqentanglha Massif and the Lunggar Rift, generalisation to South-Tibet?



Kapp et al., 2005

Jessup et al., 2008, Cottle et al., 2009, Languille et al., 2010, defined two detachments on each side of the Ama Drime horst. How the geometry of the massif allows such extension system (with two opposite detachments)?



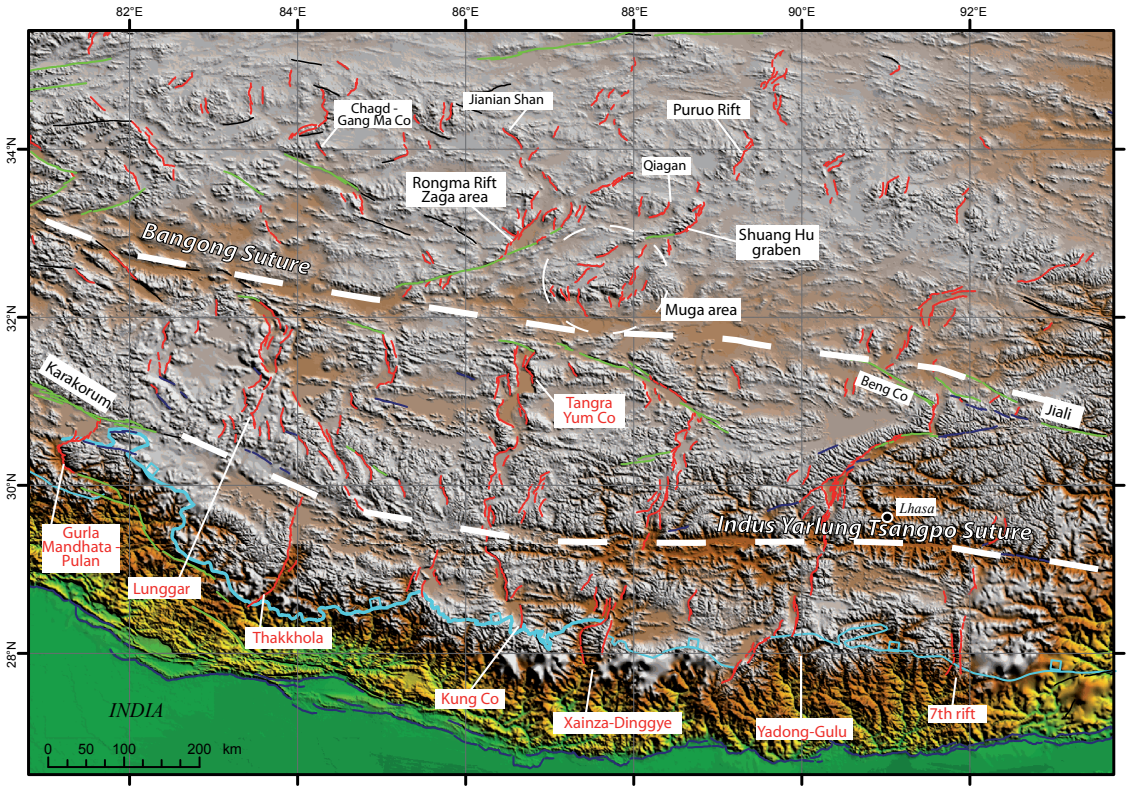
The Ama Drime Massif

Discussions-Perpectives

- Increase the thermochronological data

- Thermo-mecanical modelisation to confirm apparent exhumation rates and link long-term to short term deformation

- The same approach for the other rifts, South (Thakkhola, Lunggar, South of Yadong-Gulu) and North-Tibet.




Merci pour votre attention!