新的密集观测的GPS观测给出的巴颜喀拉块体东北缘三维地壳运动场及其构造意义

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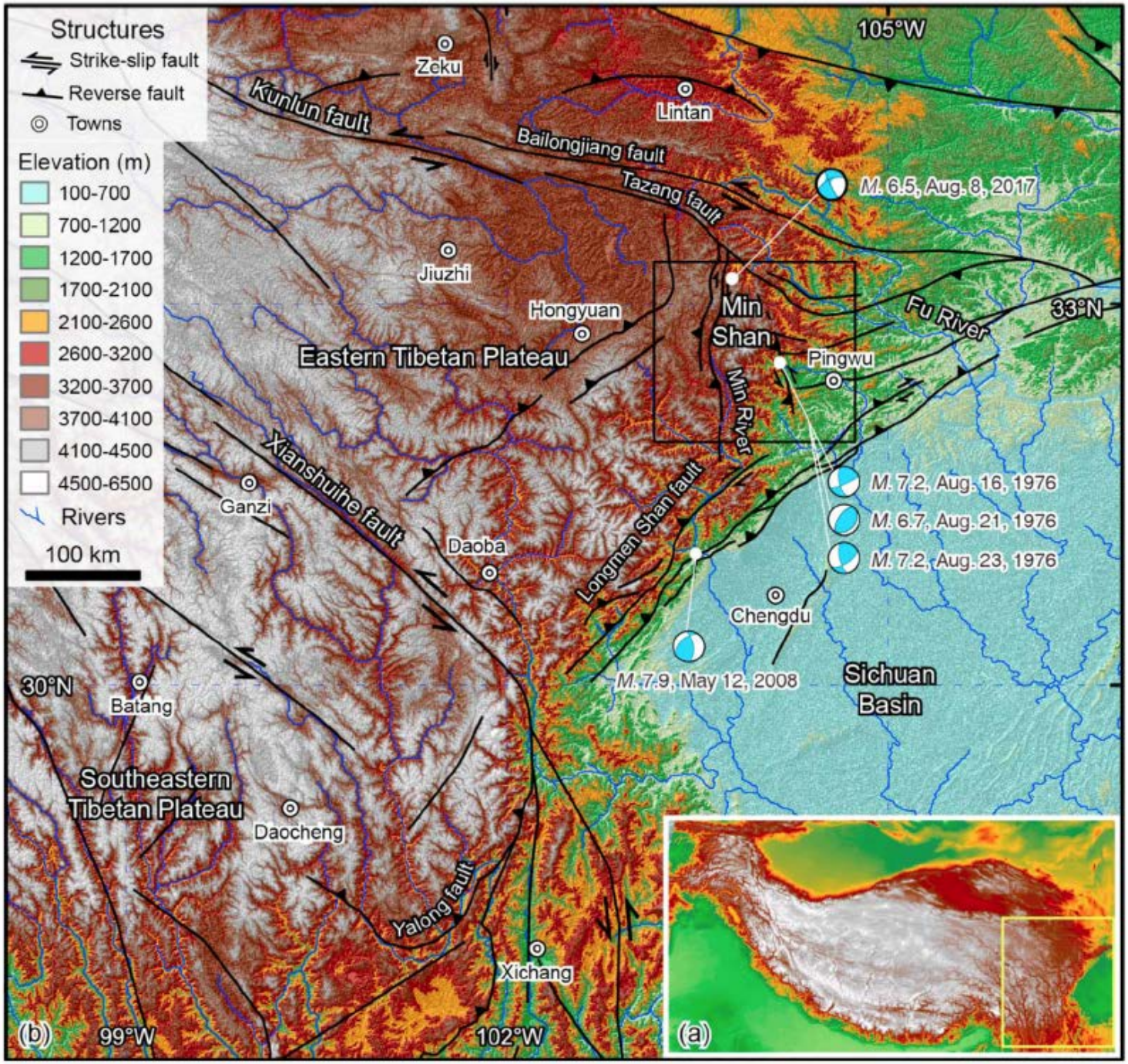
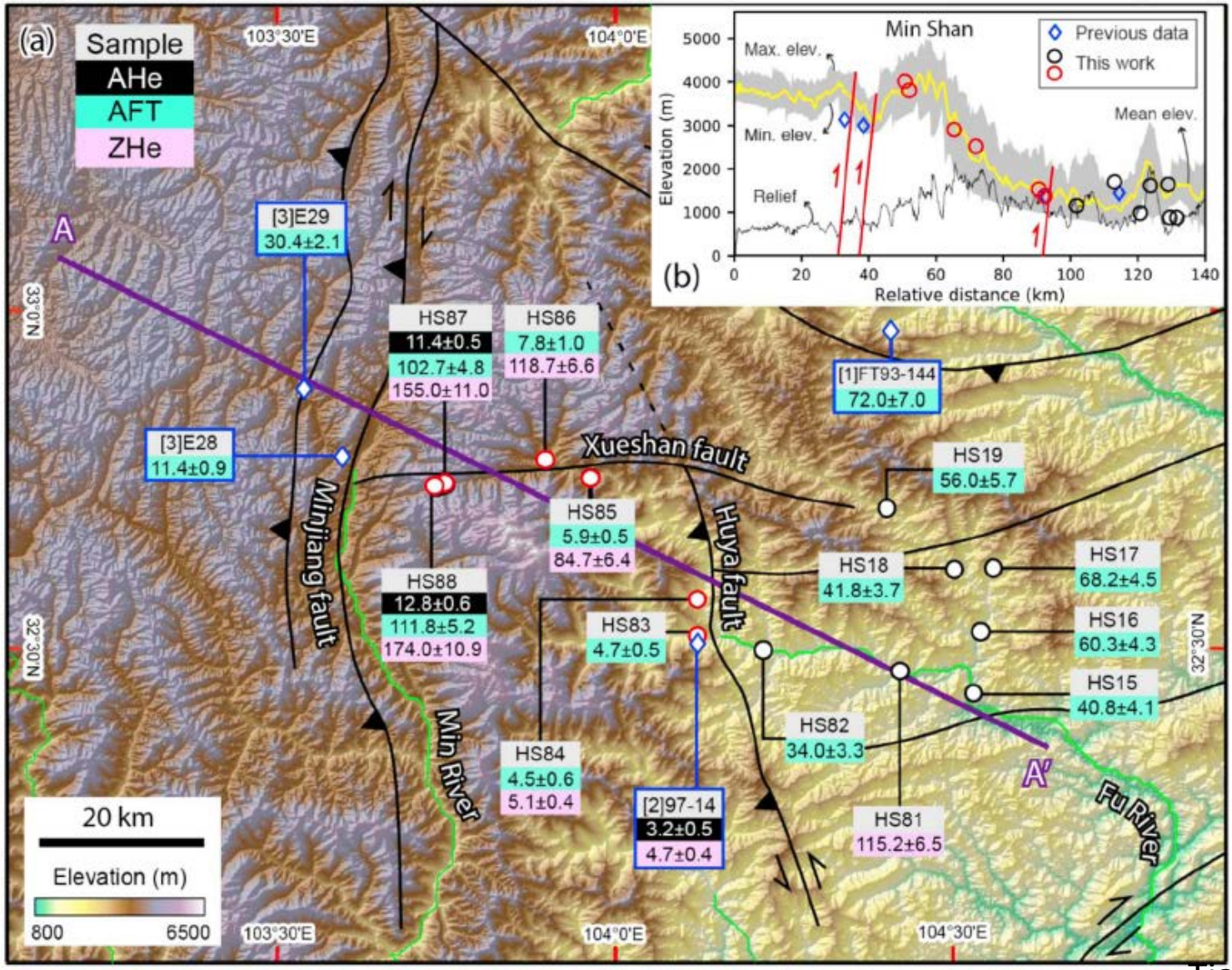


东昆仑断裂带主体带平均左旋走滑速率为11.5±0.0 mm/yr，但玛沁以东段落的滑动速率明显减小。

Tian et al,2018

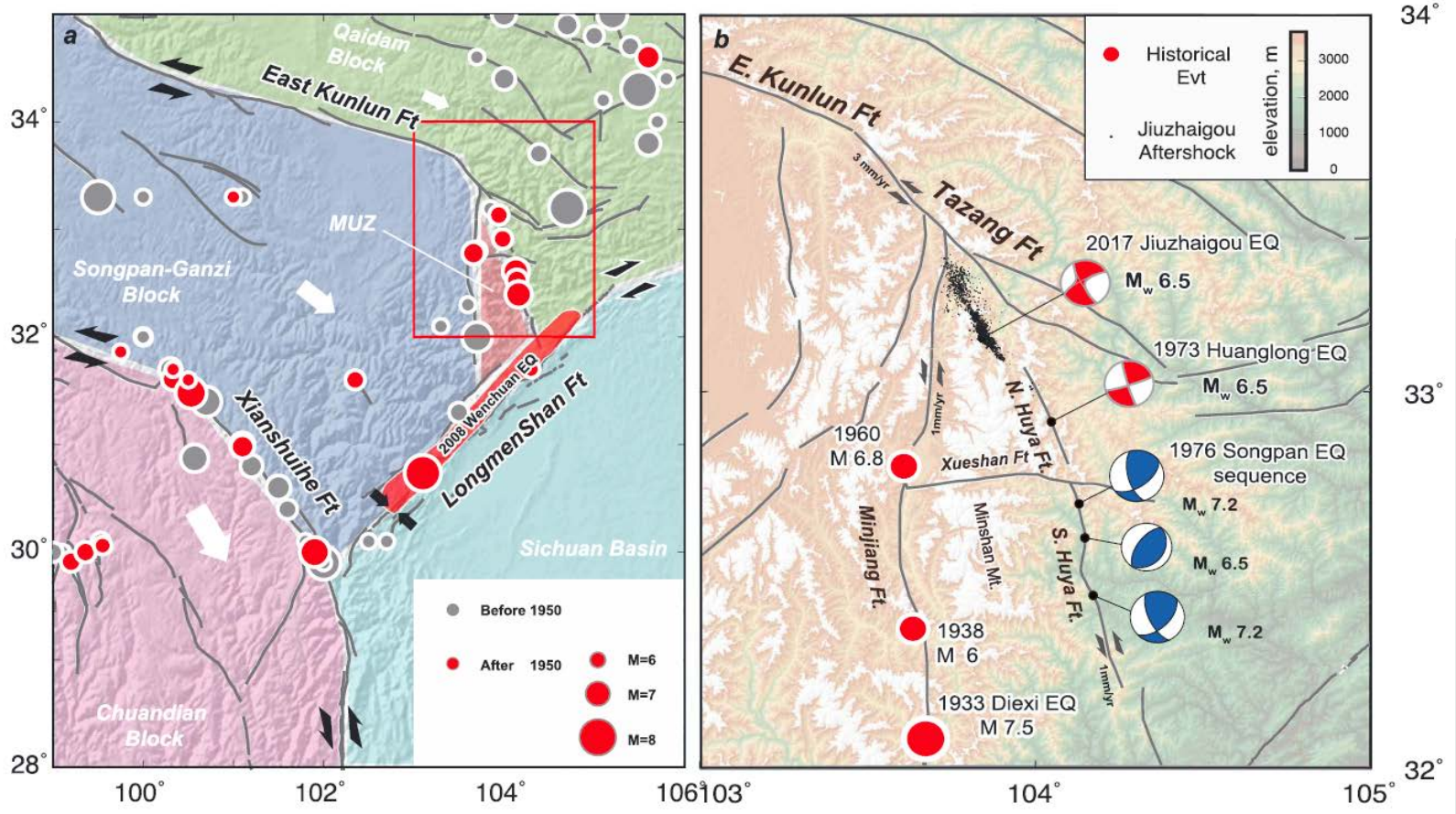
岷山隆起区东西两侧地形的差异



Tian et al,2018

研究意义

岷山隆起区地震活动频繁



自17世纪早期至汶川地震的近400年中，巴颜喀拉地块东边界北段的岷江与虎牙断裂上发生了11次6级以上的强震和大地震。2017年九寨沟Ms 7.0地震发生在虎牙断裂的北段。

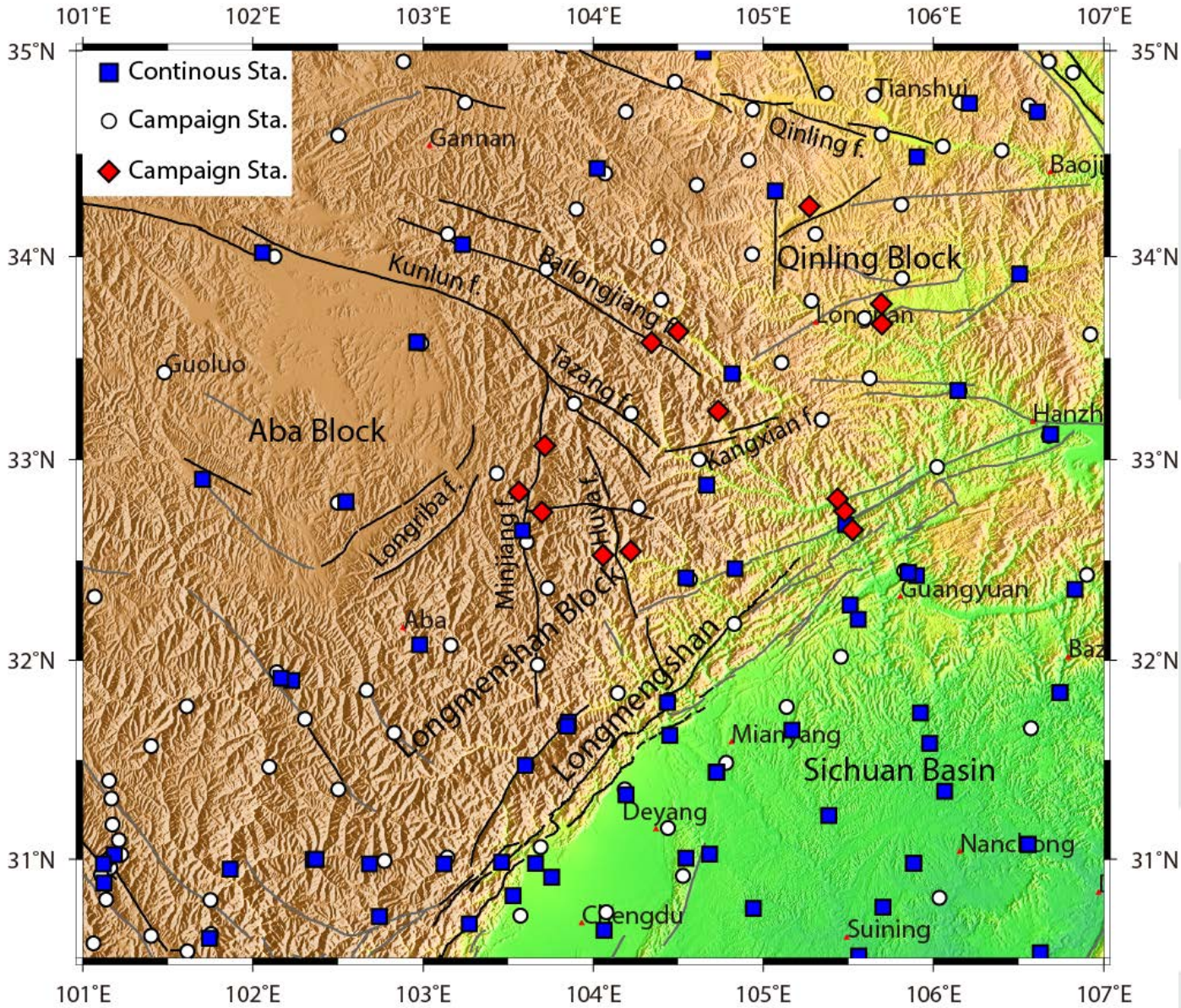
巴颜喀拉东北角的边界是不清楚的！

Sun et al,2018

从以下几个方面分析

- 断裂的连通性；
- 地震活动性；
- 应变积累特征。

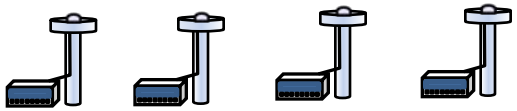
巴颜喀拉块体东北缘GPS观测



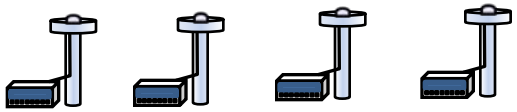
2009、2010、2011、2014、2016、2017年进行了观测

GPS数据处理流程

Regional or local geodynamic GPS network



Global GNSS network (IGS)



Auxiliary data stemming from IGS, CODE, SOPAC, JPL, CDDIS and etc.

A-priory positions
GPS equipment characteristics
other auxiliary information

Daily raw (RINEX) data files

Daily raw (RINEX) data files

External auxiliary data - EPH-, ERP-, H-, ION-, TRP-, BLQ-, PCV-files and etc.

Internal auxiliary data - INFO-, ABB-, STA-, VEL-, SITTBL-files and etc.

SOFTWARE (GAMIT/GLOBK)

- Estimation of satellite’s orbits, satellite's and receiver’s clocks, ZTD and etc.
- Solving for phase ambiguities and baseline components between regional geodynamic network and IGS sites

- Estimation of daily positions of geodynamic network sites and their variance-covariance matrix
- Reference frame realization for coordinates and velocities (Free, ITRF or other system)

- Daily coordinate time series in predefined reference frame and their variance-covariance matrixes
- Combination of daily positions and site’s velocity estimation

GPS 时间序列分析

- mathematical model:

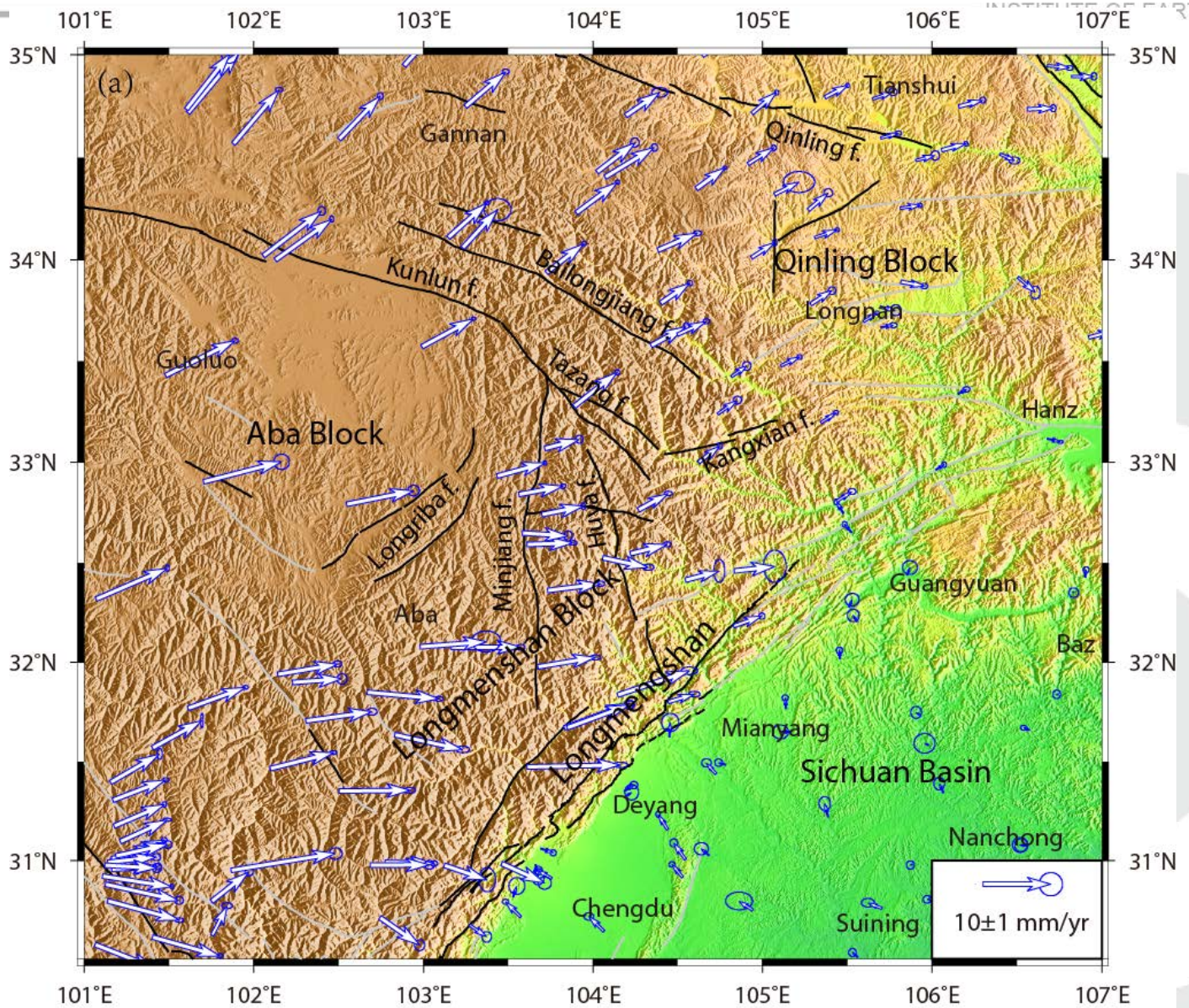
d=
$$d_0 + vt + d_{epr} \cdot \sin(2 \cdot \pi \cdot t + p_{epr}) + d_{gap_i} \cdot H_i(t)(i = 1 \cdots m) + v_{slip}\tau_{ln} \cdot \left(ln\left(1 + d_{gap_i}\left(\frac{t-t_{eq}}{\tau_{ln}} - 1\right)\right) - (t - t_{eq})/\tau_{ln}\right) + d_{exp} \cdot \left(1 - e^{-\frac{t-t_{eq}}{\tau_{exp}}}\right)$$

Number of parameters：8+m，m are the number of offset(equipment change、observation environment change、co-seismic displacements，GPS satellite change、unknown reason)

- Parameter estimation：

Posterior probability density :Bayesian method and MCMC sampler

水平向GPS速度场(相对于四川盆地)

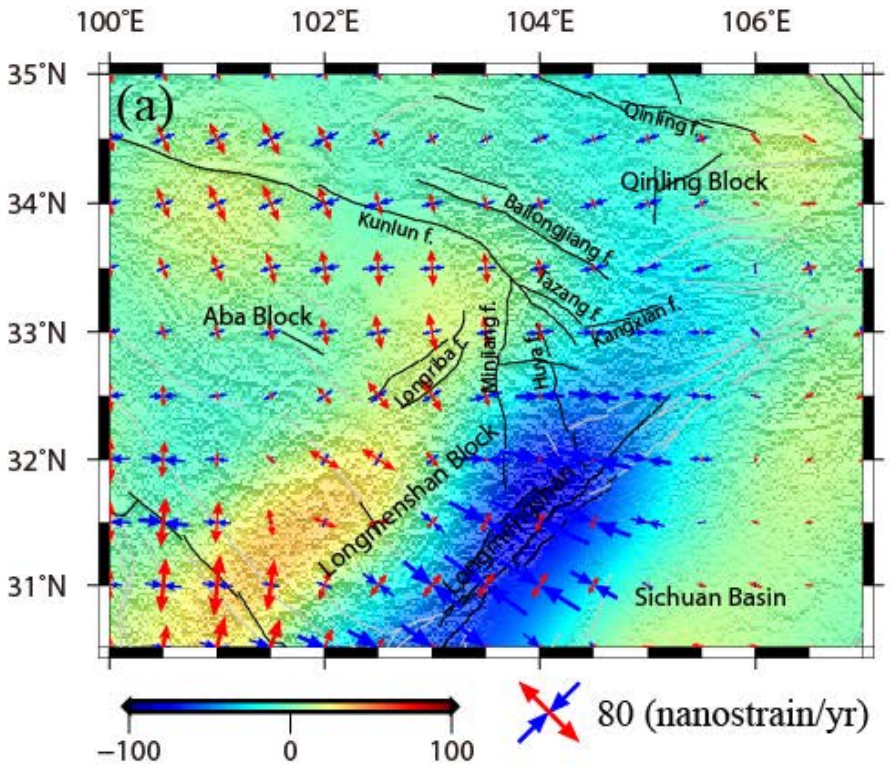


岷山隆起区，也就是岷江断裂和虎牙断裂之间的区域，共有5个测站计算了水平向运动速度，运动量值为5.3~7.9mm/yr。

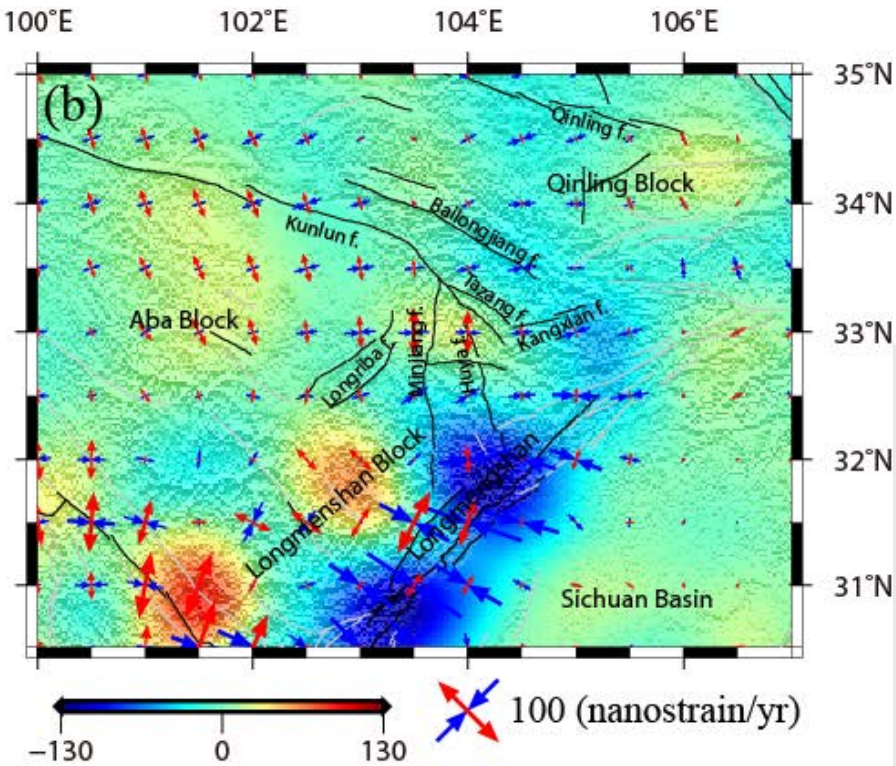
多尺度球面小波方法解算GPS应变率

- 多尺度球面小波方法可充分体现GPS测站不均匀分布的特征；
- 也可通过选择不同的尺度因子，研究不同空间尺度的GPS应变场；

主应变率/面应变率



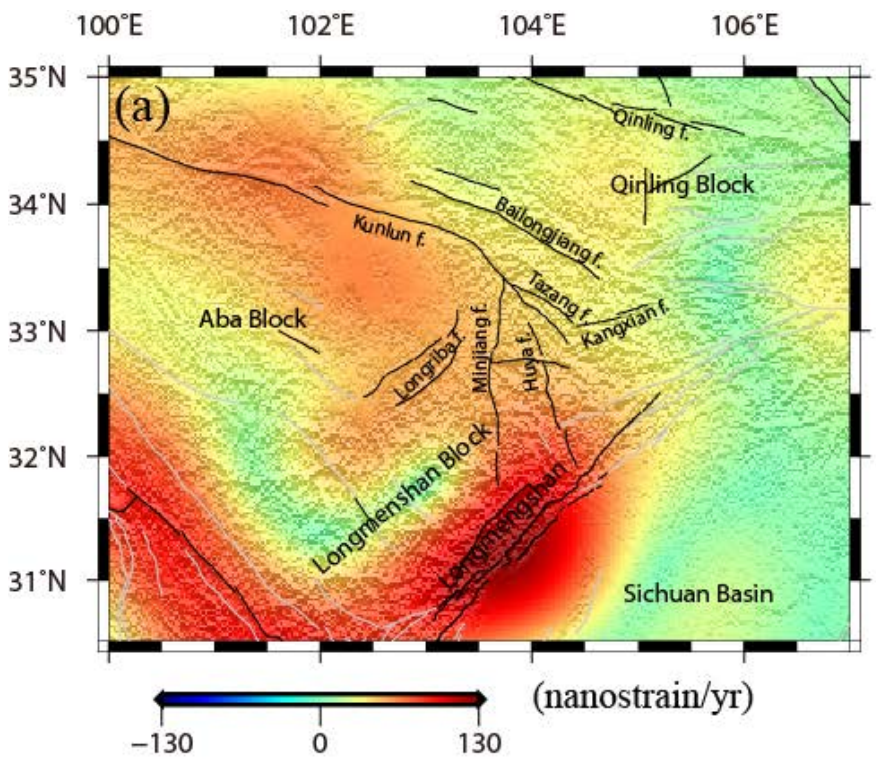
分解尺度为 6



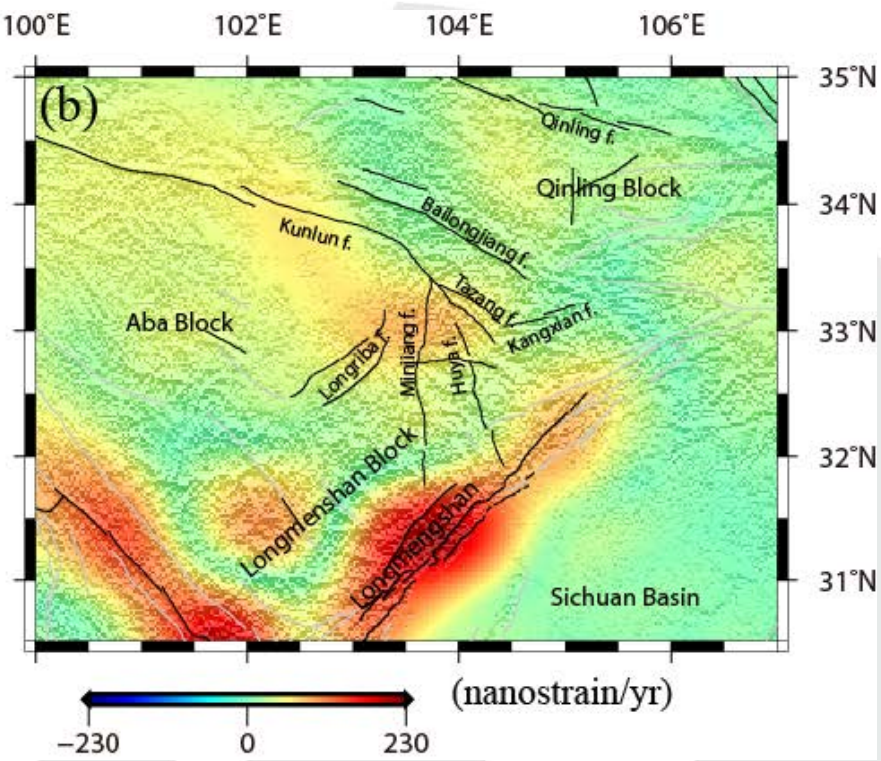
分解尺度 为 7

面应变之和分别为-1.0×10^{-5} /yr和-0.8×10^{-5} /yr，表明巴颜喀拉块体东北缘及其邻区基本的特征就是 以挤压为主

最大剪应变率

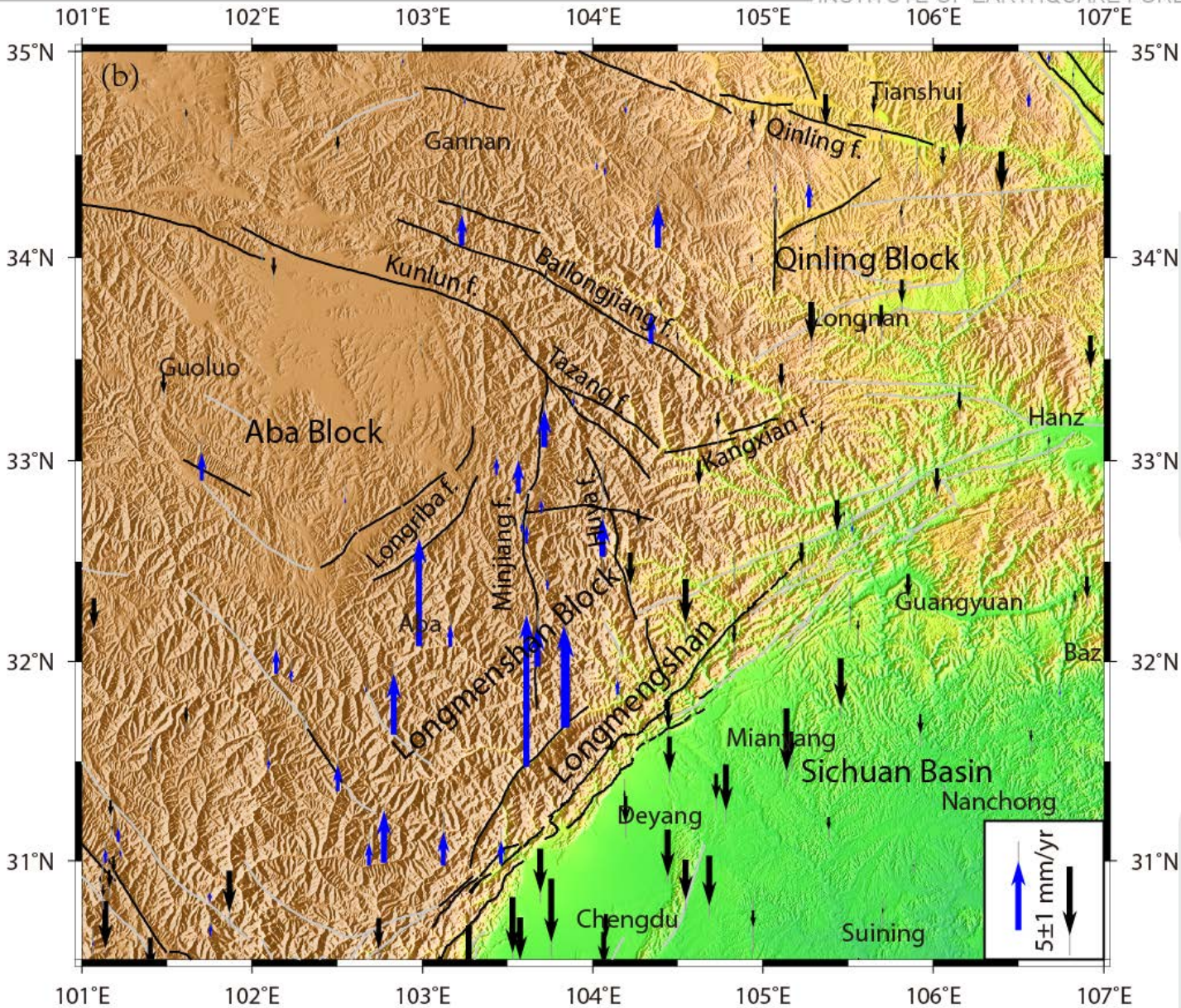


分解尺度为 6

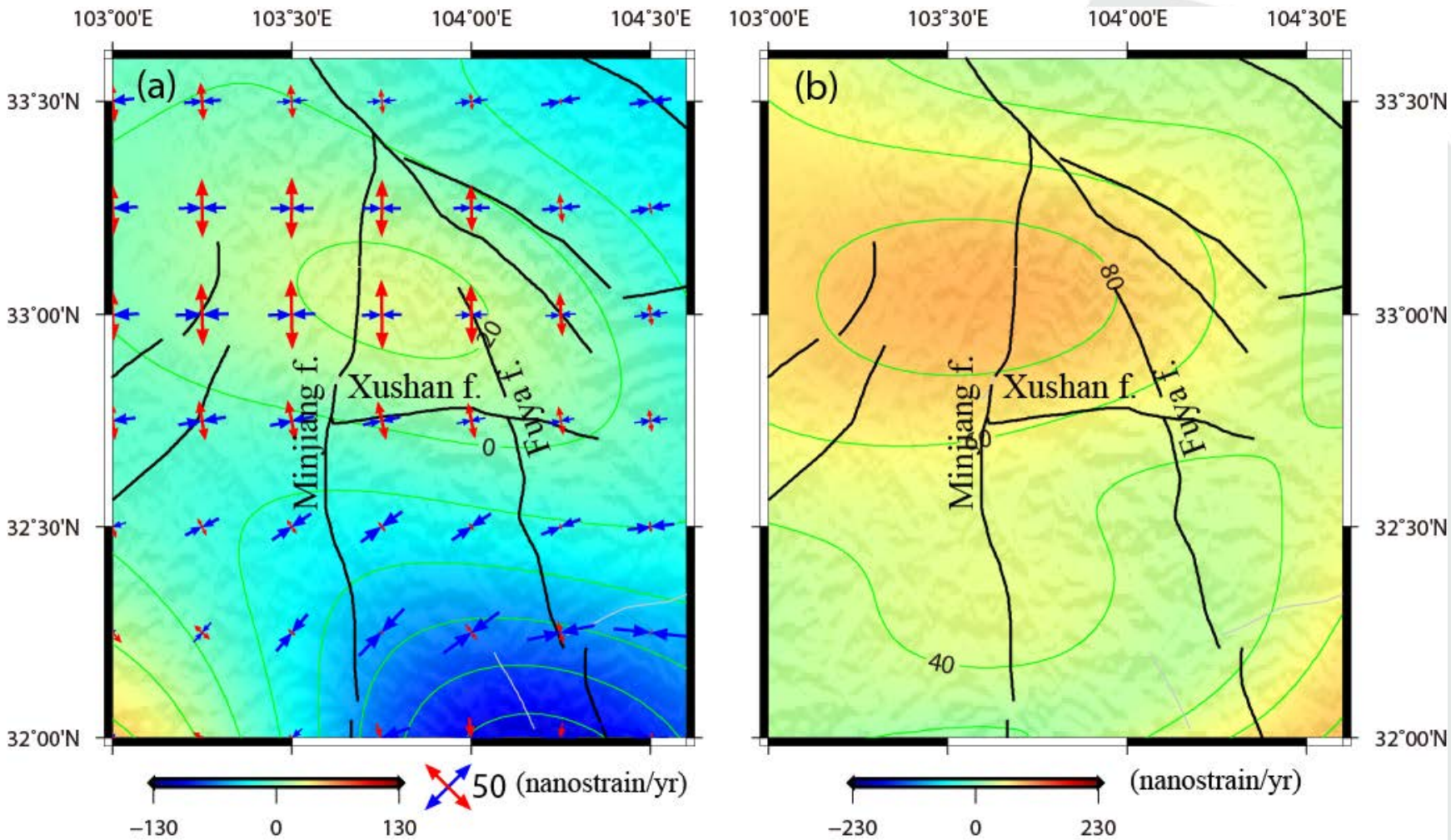


分解尺度 为 7

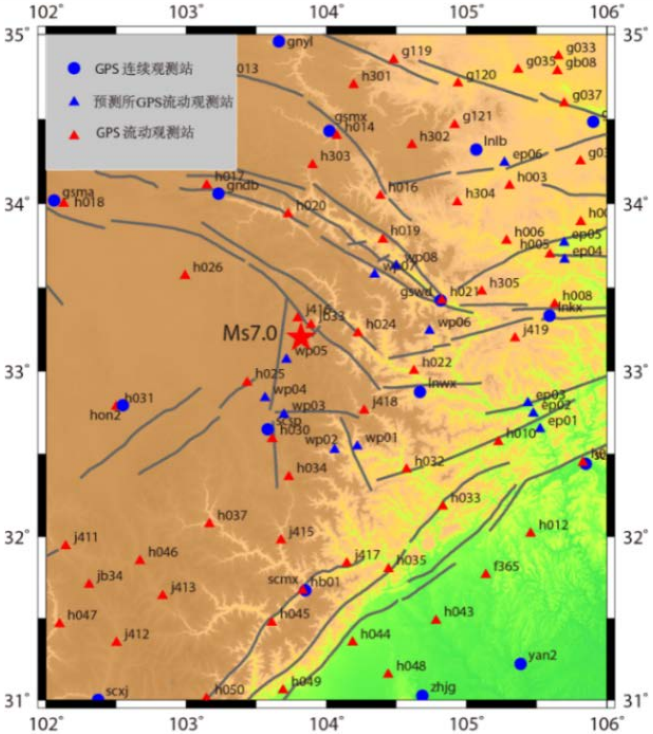
垂向GPS速度场


(b)
101°E
102°E
103°E
104°E
105°E
106°E
107°E
35°N
34°N
33°N
32°N
31°N
Tianshui
Qinling f.
Gannan
Qinling Block
Kunlun f.
Bailongjiang f.
Longnan
Guoluo
Tazang f.
Aba Block
Hanz
Kangxian f.
Longriba f.
Minjiang f.
Huya f.
Guangyuan
Aba
Longmenshan Block
Longmengshan
Baz
Mianyang
Sichuan Basin
Nanchong
Deyang
Chengdu
Suining
5±1 mm/yr

岷山隆起区应变率场

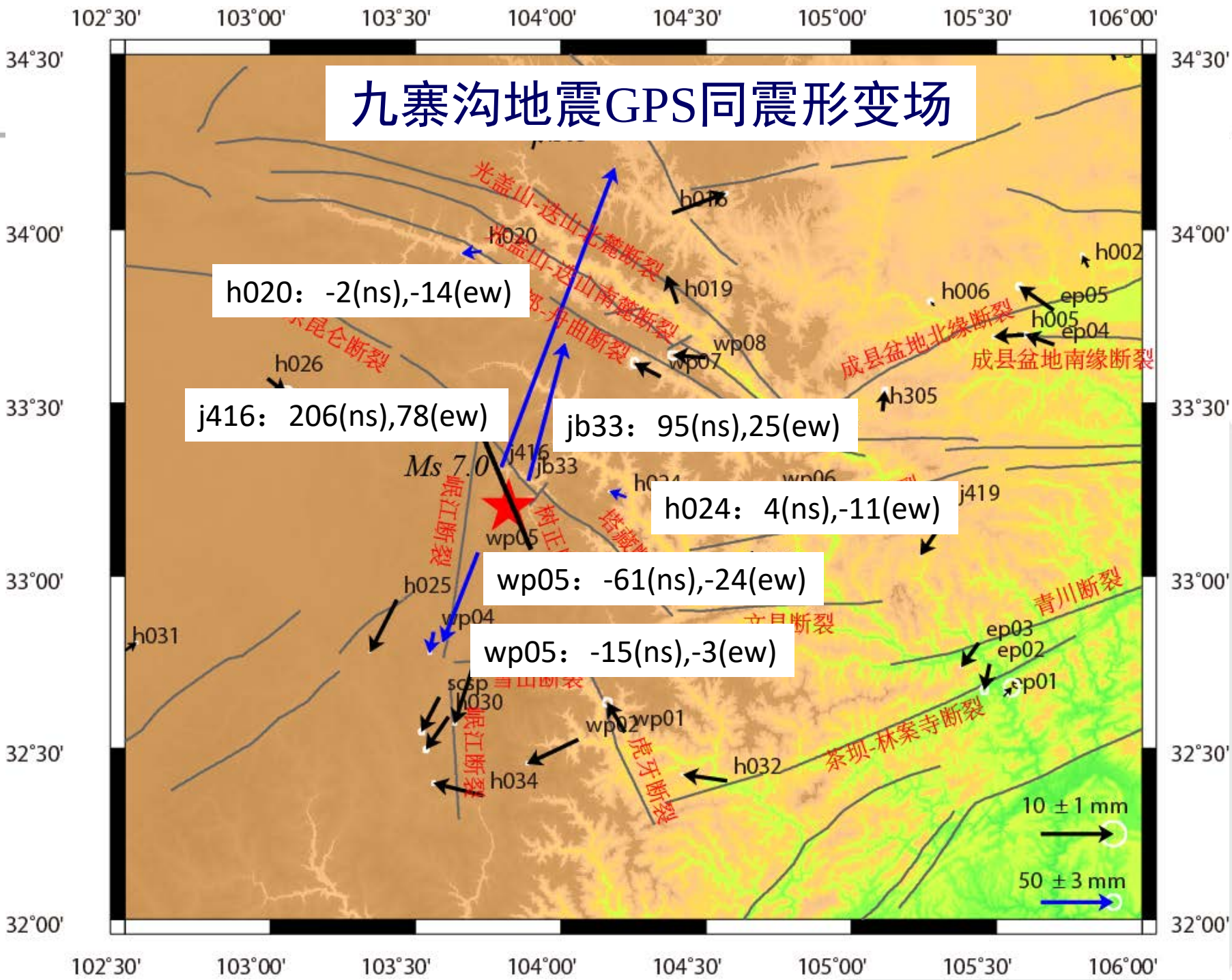

103°00'E
103°30'E
104°00'E
104°30'E
33°30'N
33°00'N
32°30'N
32°00'N
(a)
Minjiang f.
Xushan f.
Fuya f.
0
50 (nanostrain/yr)
−130
0
130
(b)
80
40
(nanostrain/yr)
−230
0
230

九寨沟地震后应急观测

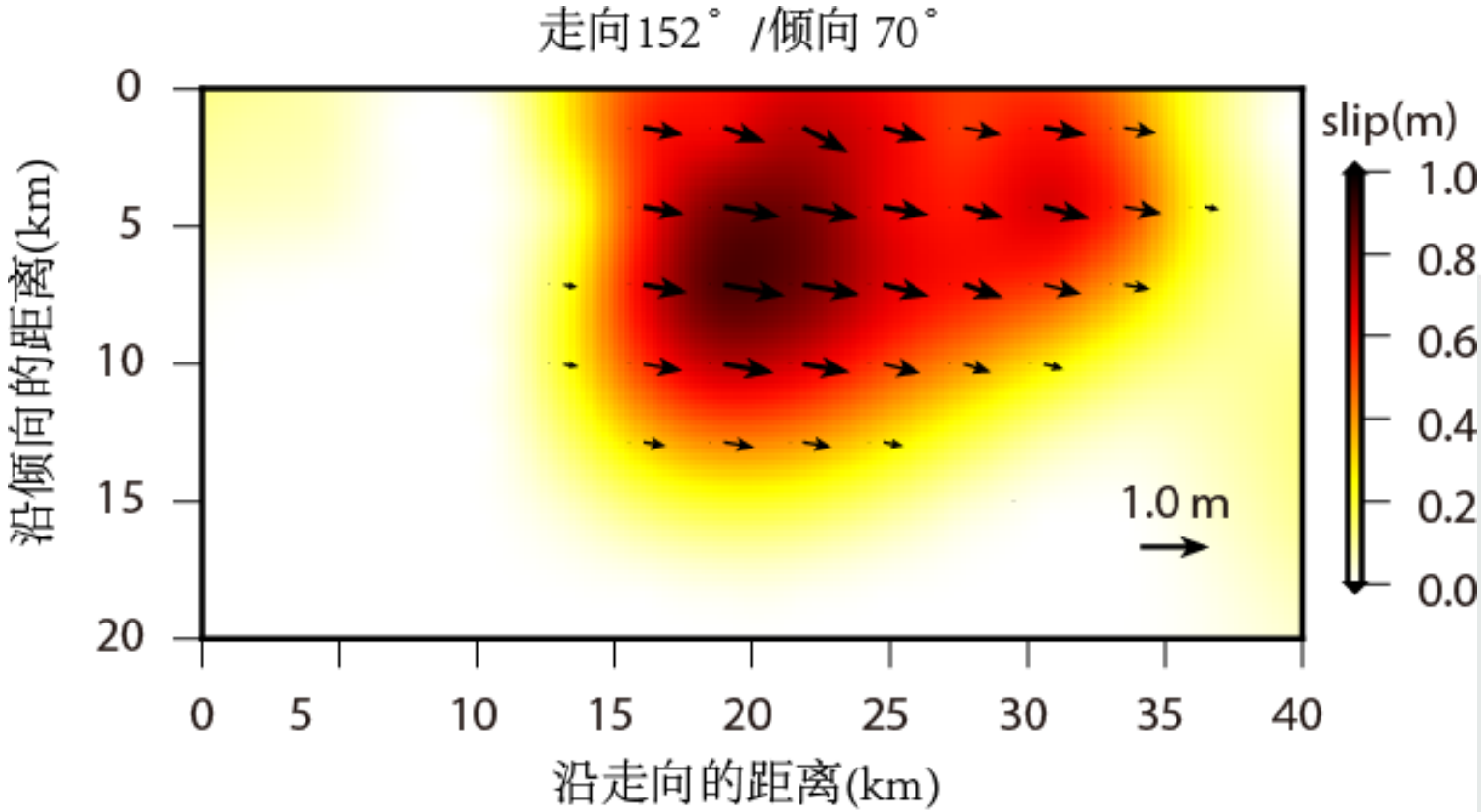


- 预测所和四川局共同完成；
- 8月11号开始观测，9月16号完成观测。
- 共观测45个测站，每个测站连续观测48个小时。这些测站均在本年度6月份进行过一期观测

九寨沟地震GPS同震形变场

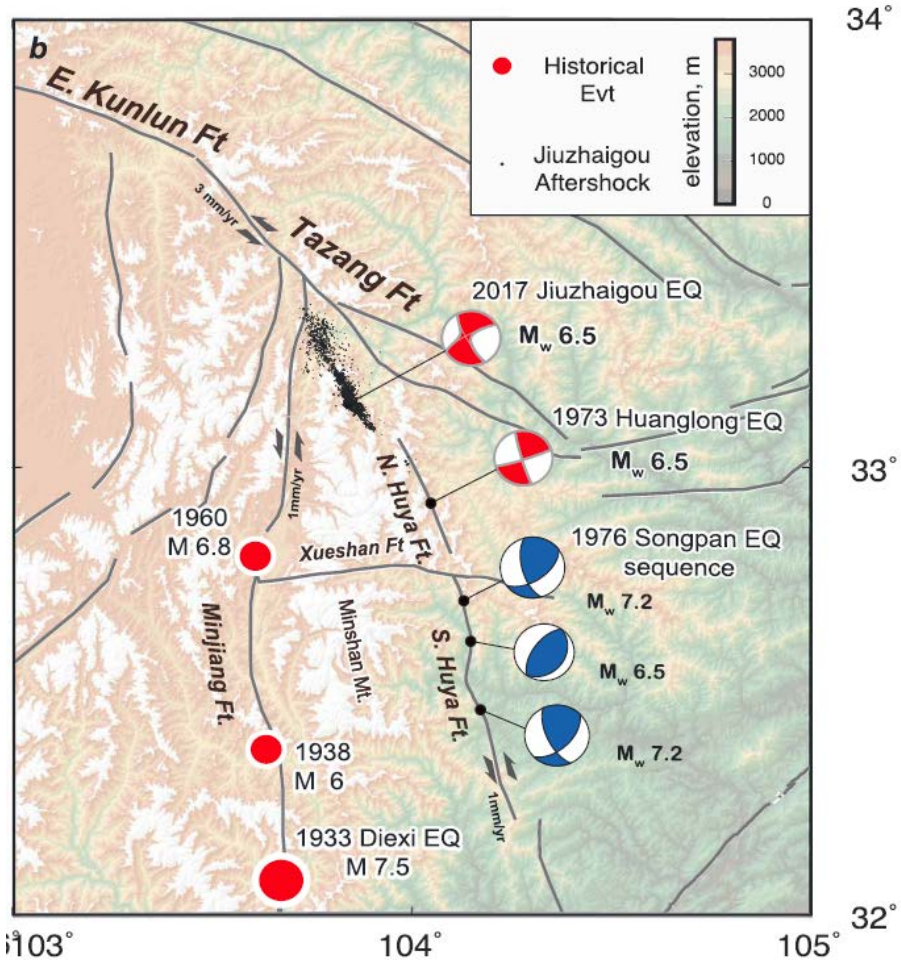


2017年九寨沟地震同震滑动分布

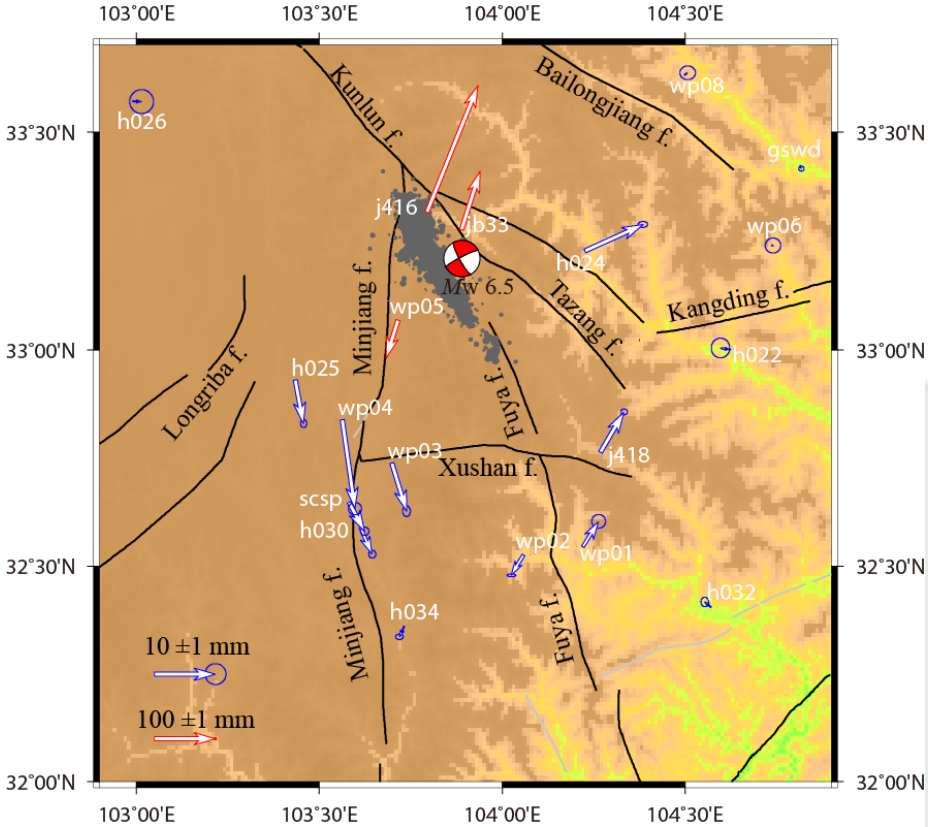


最大同震滑动量为0.96 m，平均滑动角为 -13度，M_W=6.42

2017年九寨沟地震同震形变场

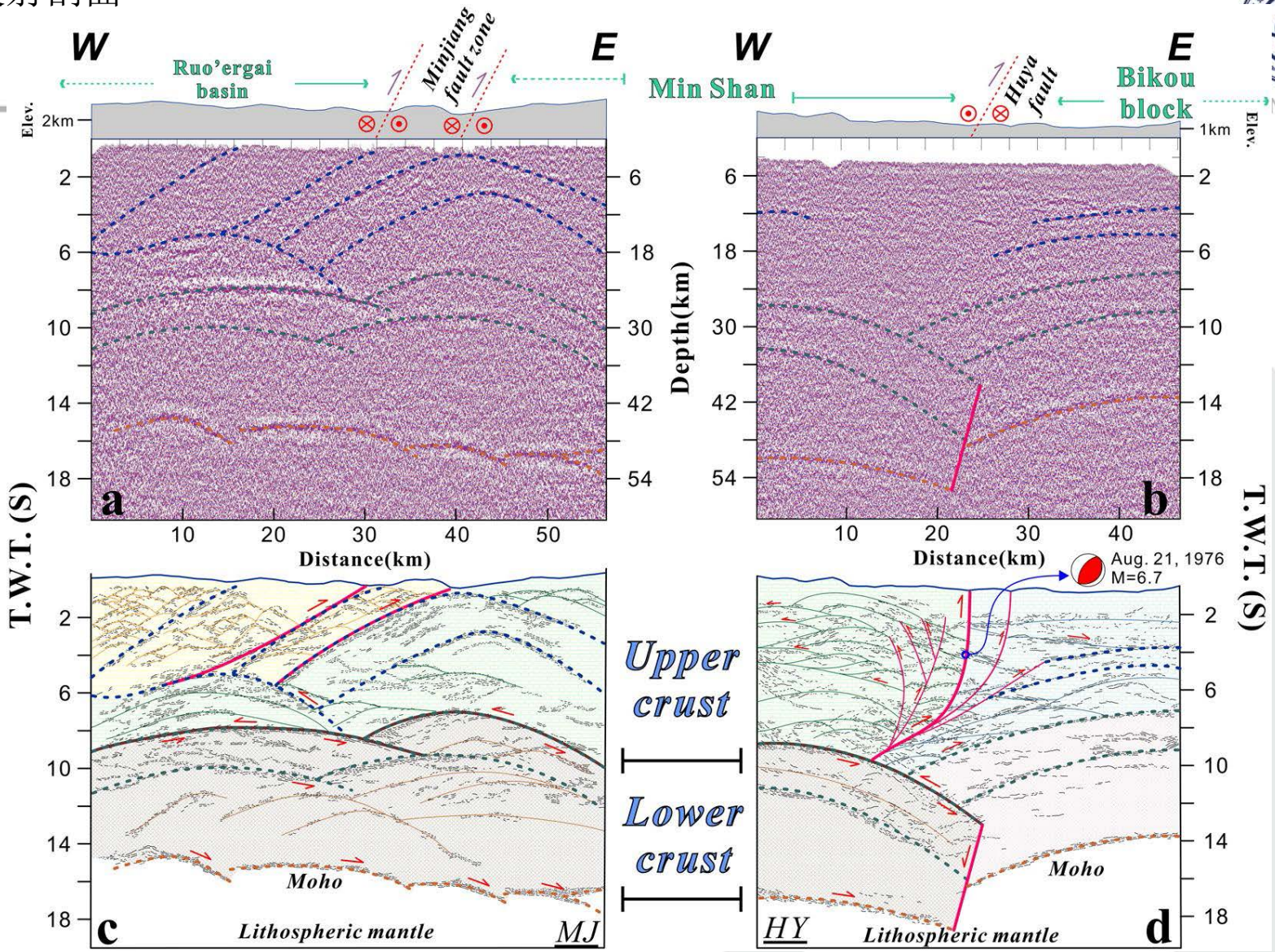


Sun et al,2018



九寨沟地震同震变形

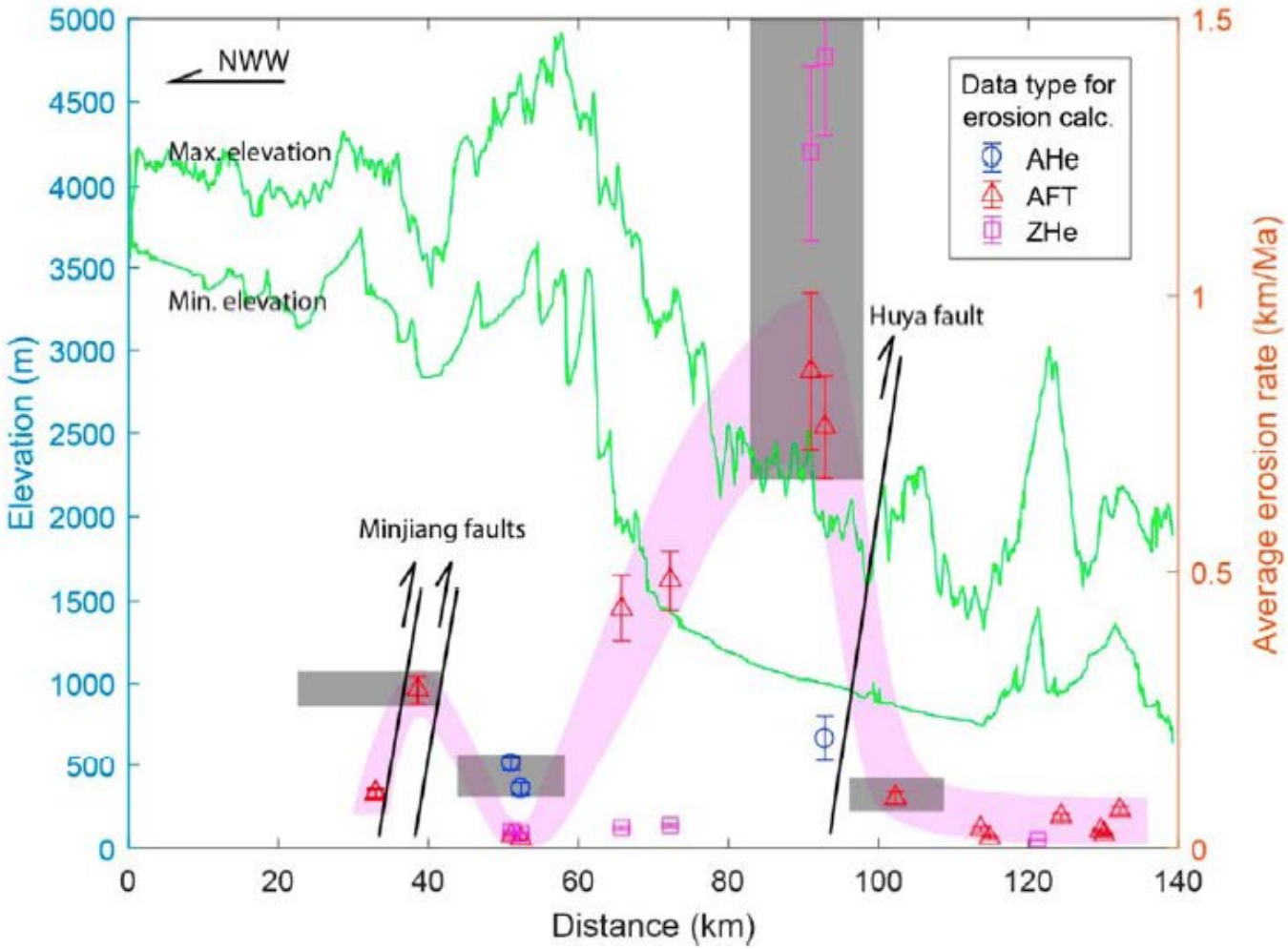
地震反射剖面



Two main faults merge into a detachment at a depth of ~20 km

Xu et al.,2017

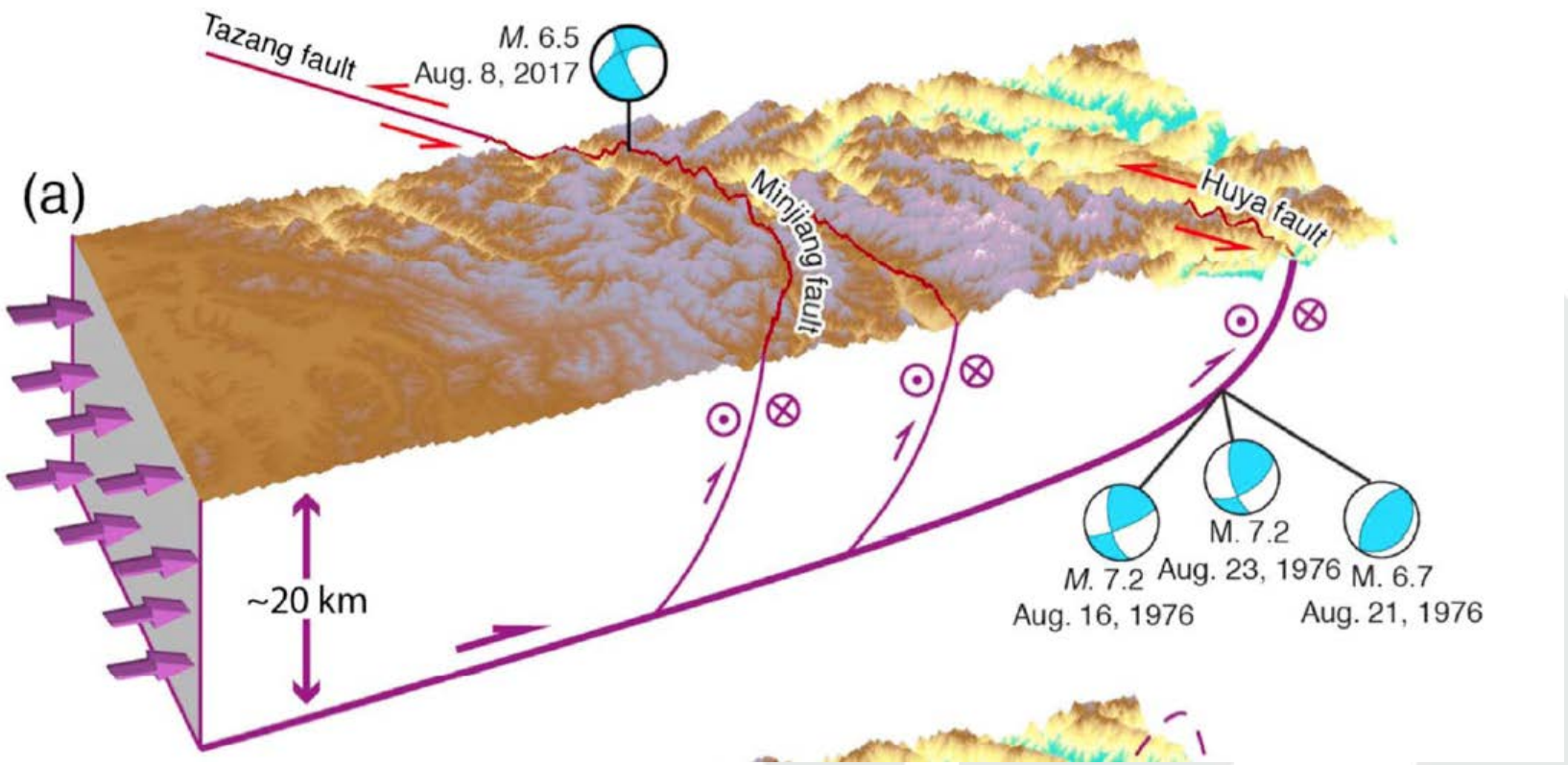
剥蚀速率的差异



虎牙断裂东侧：~0.1 km/my； 西侧：> 0.7 km/my

Tian et al., 2018

构造模式



Tazang-Minjiang-Huya-Longmen Shan fault system

Tian et al., 2018

小结

- 相对于四川盆地刚性整体运动的GPS速度场显示，巴颜喀拉块体东北缘及其周边区域大范围的地壳缩短变形；
- 龙门山断裂的应变积累区截止于虎牙断裂与龙门山断裂交汇的区域；
- 虎牙断裂和龙门山断裂是垂向变形的一个边界带，其东侧为地壳下沉区而西侧为地壳隆升区；
- 九寨沟地震的破裂带和余震分布填补了虎牙断裂北段分布的不明确；
- 虎牙断裂可能是巴颜喀拉块体东边界主要的边界断裂。