Quantification and Modelling of post-seismic deformation consecutive to the 24/09/2013 Mw 7.7 earthquake in Makran region

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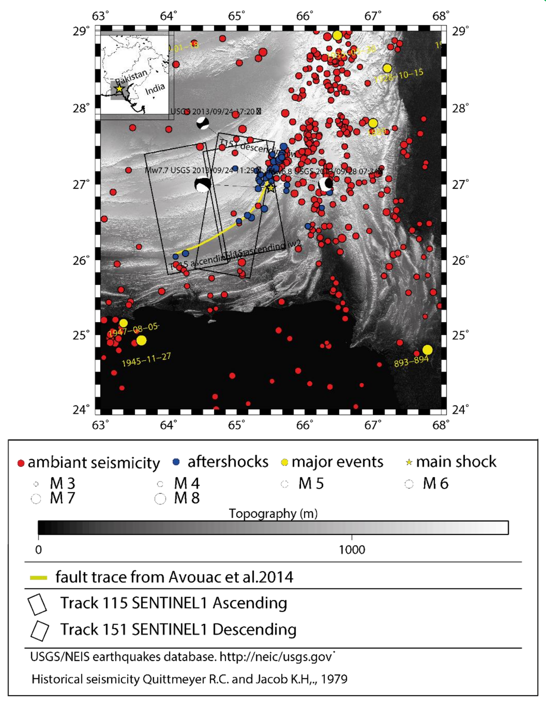
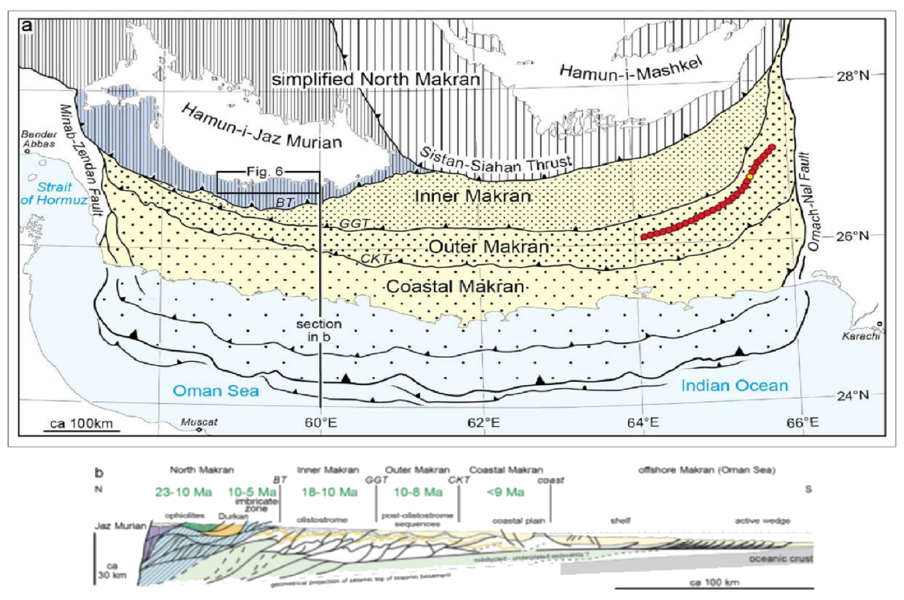
Introduction

The 24 October 2013 Mw 7.7 earthquake (Pakistan) took place in the transition zone between the Chaman Fault zone and the Makran accretionary prism. 3 years of Sentinel 1 time series reveal that postseismic deformation consecutive to this earthquake is not linear though time. We have tested two hypothesis to explain this postseismic deformation: afterslip or a combination of afterslip and of a viscous relaxation controlled by a deep viscous body along the décollement level of the Makran prism.



Geological settings,Data & methods



(a) Synthesis of geological settings (Burg, 2018):
- Yellow: onshore part of the accretionary wedge; Red: Hoshab fault affected by the Mw 7.7 earthquake.
(b): Synthetic cross section across the Makran accretionary prism.
(a) and (b): and BT=Bashakerd thrust; GGT=Ghasr Ghand Thrust; CKT=Chah Khan Thrust.

If we make the hypothesis that postseismic deformation is controlled by afterslip, we can propose, considering this structure, that afterslip is located along the Hoshab Fault, affected by the main shock, but also along the décollement level of the accretionary prism located at 20-30 km depth.
If we suppose that a viscous relaxation can explain a part of postseimic deformation, we can also make the hypothesis that this one is controlled by a viscous body along this décollement.

DATA:
Sentinel-1A SAR images, acquisition geometries and dates.

Acquisitions	Angles	acquisition dates
Descending track D151, IW3	ϕ' = -167.4° Θ = 43°	50 images from 20141212 till 20171208
Ascending track A115, IW1 A115,IW2	ϕ' = -12.5° Θ = 33° Θ = 38°	41 images from 20141012 till 20171221

To simulate postseismic deformation with the Relax software we have considered as input the coseismic slip distribution proposed by Avouac et al.(2014), the geometry of the Hoshab fault used by these authors, and a décollement level supposed to be at the base of the accretionary prism.

METHODS:

With Relax software we tested different depths for this décollement level and the space parameters controlling afterslip: friction coefficient (0.075 – 0.8) and initial afterslip rate (10 – 1000 mm/year). For the mixed hypothesis, afterslip and viscous relaxation, we have considered the Hoshab fault geometry and a viscous body along the décollement level. We have explored the space parameters formed by the thickness of this body (2-8 km), supposed to be at 26 km depth, and its viscosity (10^{16} to 10^{19} Pa.s).

Process of S1 ascending and descending images with NSBAS chain (Doin et al, 2011,2012)

Ascending and descending Time series images from 20141212 till 20171223 in LOS direction

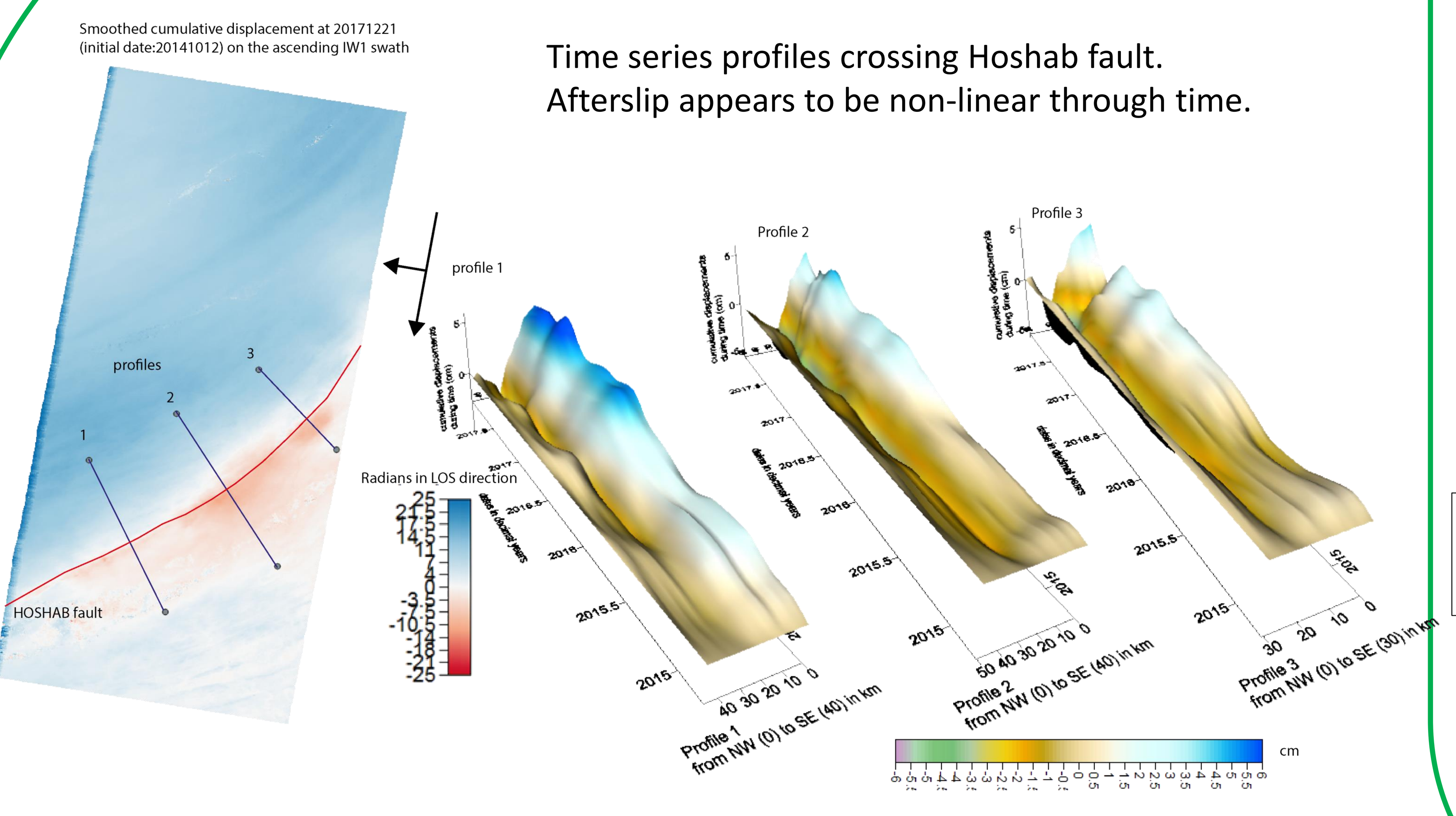
Output in Est, North, Up

Transformation in LOS direction

Calculation of WRMS between data and output simulation

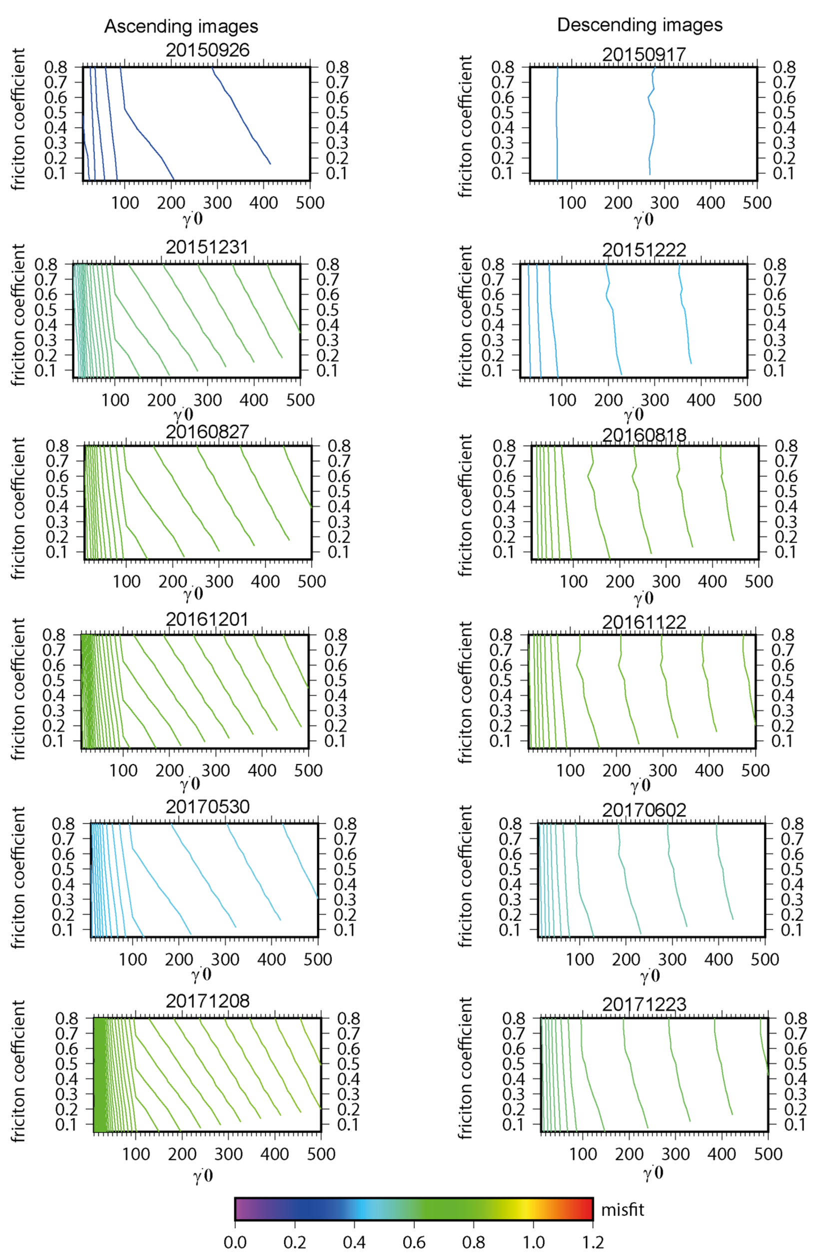
Results & simulation

Time series profiles crossing Hoshab fault.
Afterslip appears to be non-linear through time.

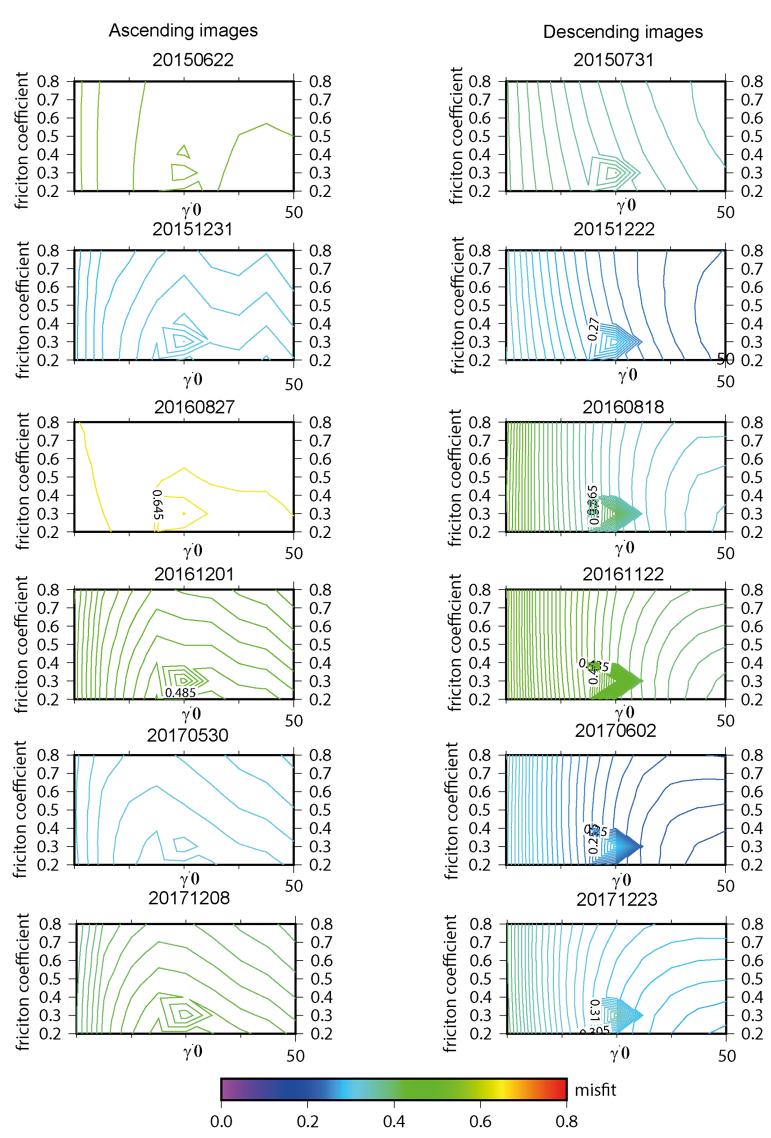


Simulations with RELAX 1.0.7 software

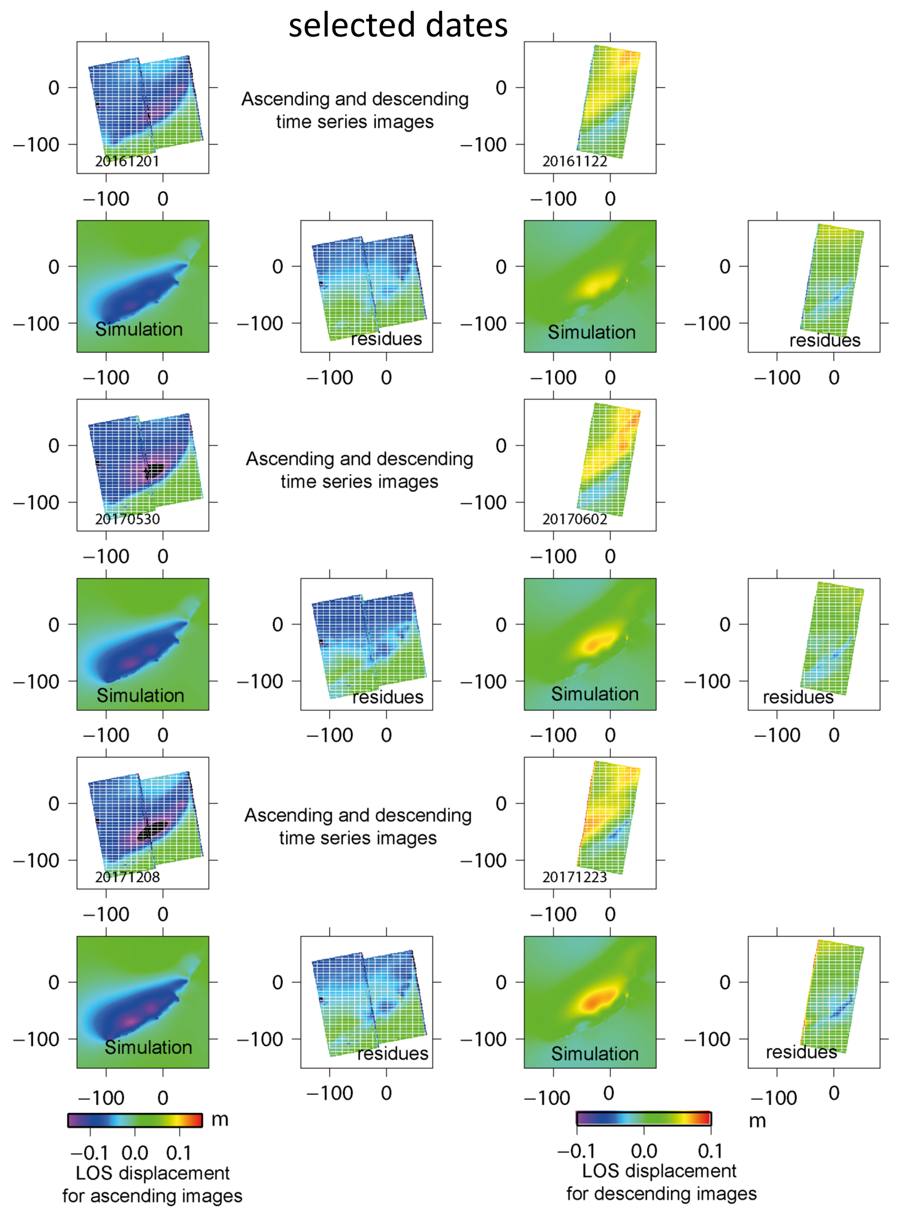
Afterslip only along the Hoshab fault (no flat): no good fit between simulations and observations



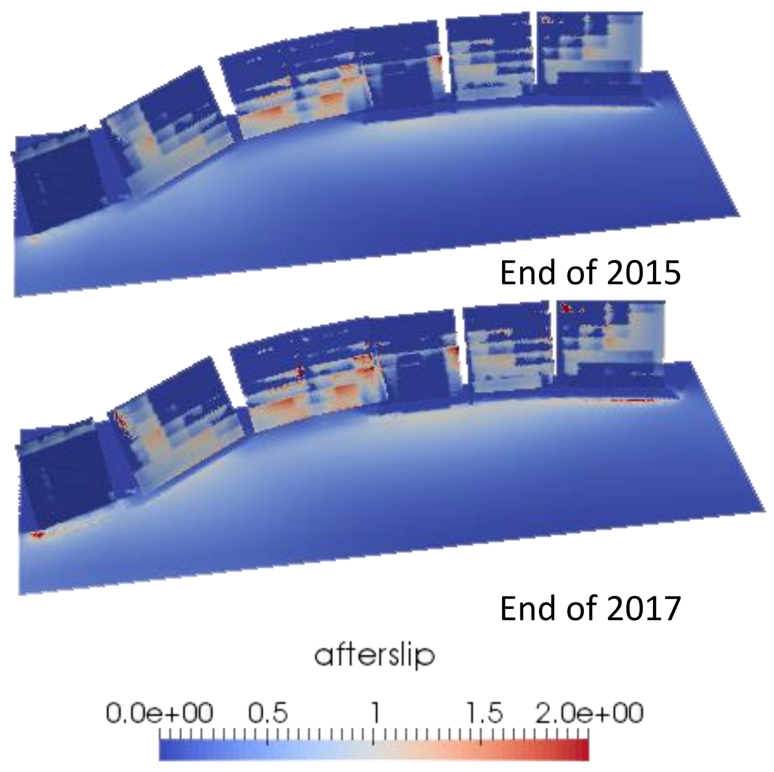
Afterslip along Hoshab fault and a flat at 26 km depth:
Best fit for $\dot{\gamma}_0$=30 mm/year and for a friction coefiecient of 0.3



Afterslip along the Hoshab fault and a flat at 26 km depth:
$\dot{\gamma}_0$=30mm/year , friction coeficient of 0.3
Map of observations/simulations and residues for 3 selected dates



Representation of afterslip along the Hoshab fault and along the décollement level for the best solution (flat at 26 km, friction coeficient of 0.3 and $\dot{\gamma}_0$=30mm/year).



We simulate slips up to 2 m extending down dip from the rupture on the fault affected by the main shock, and afterslip up to 1 m along the décollement level. This pattern, in which afterslip occurs down-dip and along a flat, has also been shown in numerous cases: 1995 Chi-Chi earthquake (Yu et al., 2003; Perfettini and Avouac, 2004), and 2005 Balakot-Bagh earthquake (Jouanne et al., 2011; Wang and Fialko, 2014).

Discussion

- The analysis of various simulations shows that a flat is necessary to explain the postseismic surface deformation and its evolution through time.
- We assume that this flat is representing the basis of the sedimentary accretion prism. The difficulty lies in the positioning of this flat and its features. The calculation of WRMS for all data, for each hypothesis of depth for the flat, indicates that the best simulation is obtained for a 26 km depth.
- The simulation with afterslip is not able to fully simulate the surface deformation observed over time. We have then tested the hypothesis that a viscous relaxation controlled by a deep low-viscosity body occurs. This body is supposed to be located along the décollement of the prism. We have tested with various thickness (2 to 8 km) and various viscosity (10^{16} to 10^{19} Pa.s). Even if a minimum is found, misfits are always worse than misfits obtained for afterslip only simulations. A contribution of viscous relaxation in postseismic deformation can then be probably excluded.
- Best solutions indicate a low friction coefficient. This could indicate the existence of a good décollement level, probably formed by over-pressured shales as suggested by the existence of mud volcanoes in the offshore and onshore Makran prism (Khan et al., 2016).

References

Avouac, J.P., Ayoub, F., Wei, S., Ampuero J.P., Meng, L., Leprince, S., Jolivet, R., Duputel, Z., Helmberger, D., 2014. The 2013, Mw 7.7 Balochistan earthquake, energetic strike-slip reactivation of a thrust fault, Earth and Planet. Sc. L., 391 (2014)128-134.
Barbot, S., Fialko, Y., Bock, Y., 2009. Postseismic deformation due to the Mw 6.0 2004, Parkfield earthquake: stress-driven creep on a fault with spatially variable rate-and-state friction parameters. J. Geophys. Res. 114 (B07405)https://doi.org/10. 1029/2008JB005748.
Burg J.P., Geology of the onshore Makran accretionary wedge: Synthesis and tectonic interpretation, Earth Science Reviews 185, 2018,1210-1231
Doin, M.-P., Guillaso, S., Jolivet, R., Lasserre, C., Lodge, F., Ducret, G., Grandin, R., 2011, Presentation of the small-baseline NSBAS processing chain on a case example : the Etna deformation monitoring from 2003 to 2010 using ENVISAT data, Proceedings of the European Space Agency Symposium « Fringe », Frascati, Italy
Doin, M.-P., Lodge, F., Guillaso, S., Jolivet, R., Lasserre, C., Ducret, G., Grandin, R., Pathier, E., Pinel, V., 2012. Presentation Of The Small Baseline NSBAS Processing Chain On A Case Example: The ETNA Deformation Monitoring From 2003 to 2010 Using ENVISAT Data. Presented at the Fringe 2011, p. 98.
Jouanne, F., Awan, A., Madji, A., Pecher, A., Latif, M., Kausar, A., Mugnier, J.L., Khan, I., Khan, N.A., 2011. Postseismic deformation in Pakistan after the 8 October 2005 earthquake: evidence of afterslip along a flat north of the Balakot-Bagh Thrust. J. Geophys. Res. 116, B07401. https://doi.org/10.1029/2010JB007903.
Khan M. R., Hussain A., Sajid M., Javed T., Mud diapirism induced structuration and implications for tehd efinition and mapping of hydrocarbon traps on Makran Accretionary Prism, Pakistan. Search and Discovery Article,#51216,2016.
Perfettini, H., Avouac, J.-P., 2004. Postseismic relaxation driven by brittle creep: A possible mechanism to reconcile geodetic measurements and the decay rate of aftershocks, application to the Chi-Chi earthquake, Taiwan. J. Geophys. Res. 109, B02304.
https: //doi.org/10.1029/2003JB002488.
Wang, K., Fialko, Y., 2014. Space geodetic observations and models of postseismic deformation due to the 2005 M7.6 Kashmir (Pakistan) earthquake. J. Geophys. Res. 119, 7306–7318.
Yu, S.-B., Hsu, Y.-J., Kuo, L.-C., Chen, H.-Y., Liu, C.-C., 2003. GPS measurement of postseismic deformation following the 1999 Chi-Chi, Taiwan, earthquake. J. Geophys. Res. 108 (B11), 2520. https://doi.org/10.1029/2003JB002396.