Quantitatively deciphering paleostrain from digital outcrops model and its application in the eastern Tian Shan, China

Xin Wang, Feng Gao

State Key Laboratory for Geomechanics and Deep Underground Engineering, China University of Mining and Technology, Xuzhou, China

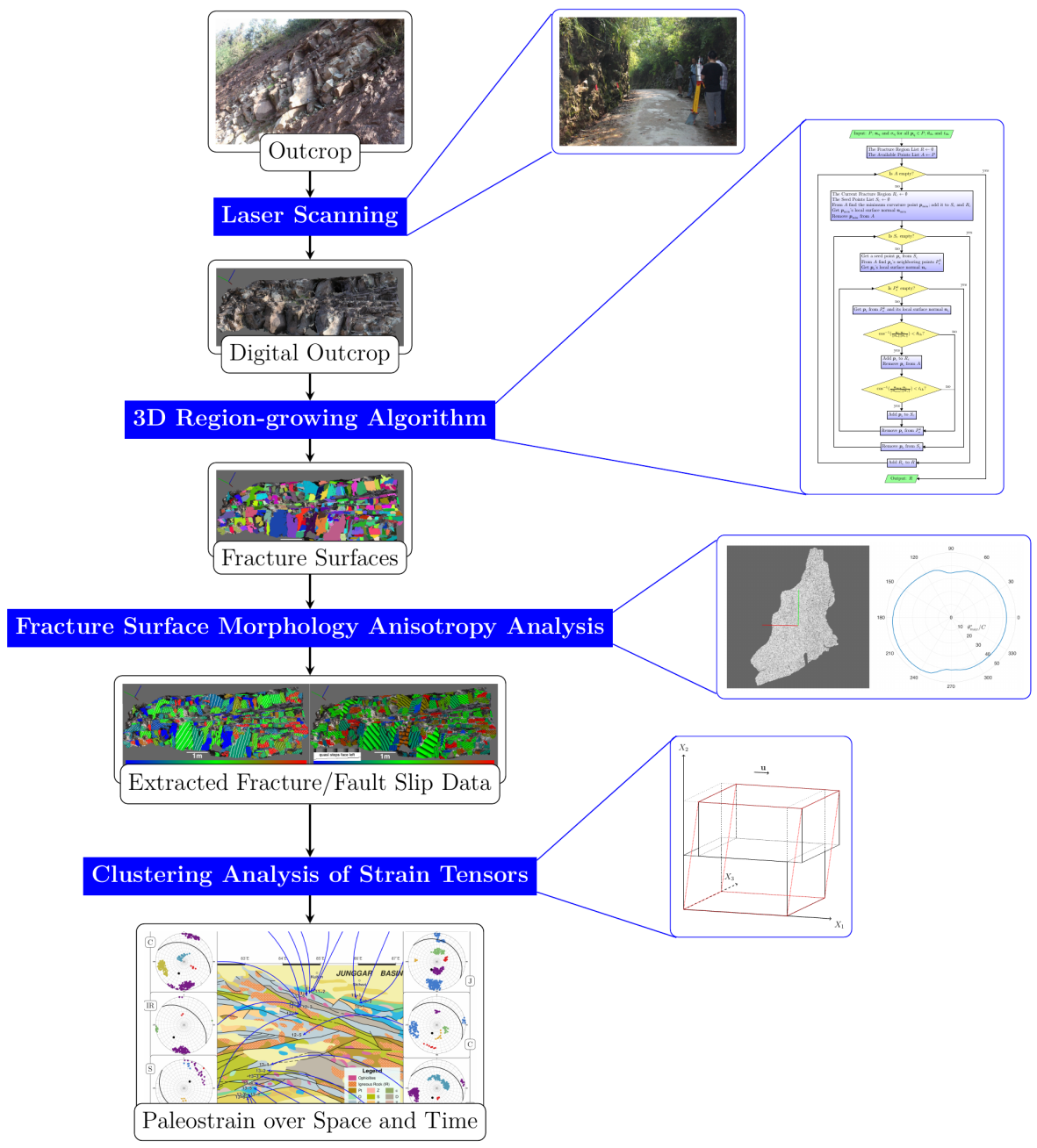
Keypoints

- Fully automatic and quantitative methods for deciphering paleostrains from digital outcrops model are developed.
- The application in the eastern Tian Shan shows the paleostrain variation over space and time.
- The geodynamic cause and meaning of the change in the strain regime are discussed.

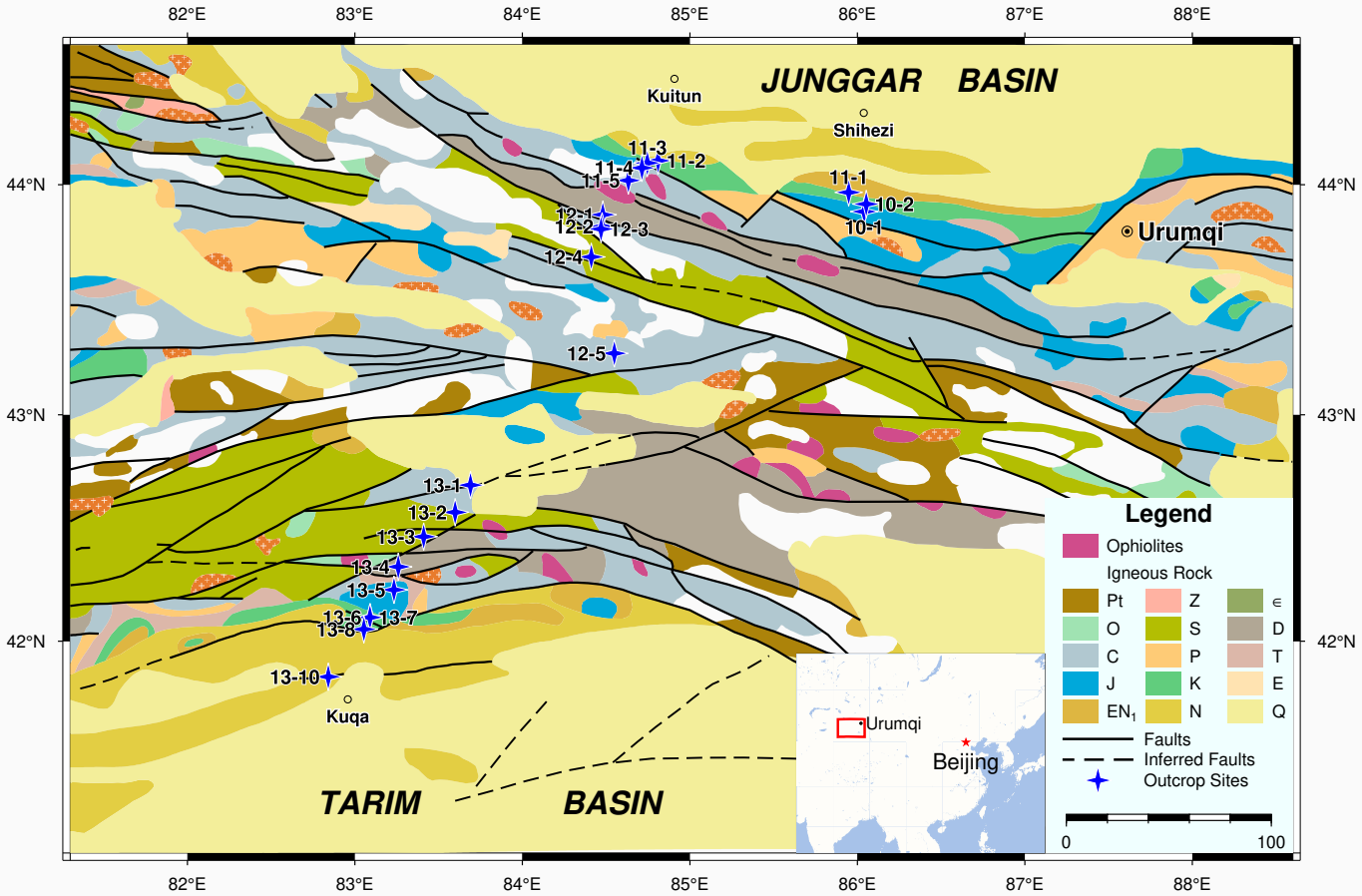
Motivations

- Traditional paleostress inversion methods use manually collected data in the field and their assumptions are to some extent controversial.
- Recent development of techniques can easily and automatically provide thousands of high quality fracture/fault slip data from just one single outcrop, which provides much more detailed information about the strain of the outcrop.
- A good opportunity to develop quantitative methods for deciphering more realistic paleostrains.

Technical Overview



The study area and the digital outcrop datasets

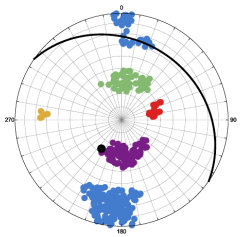
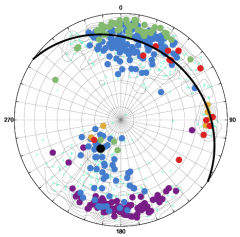
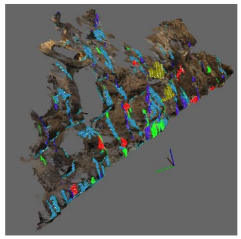
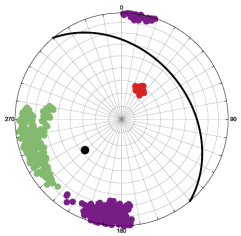
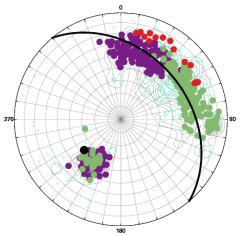
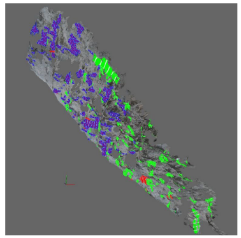
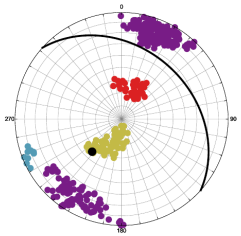
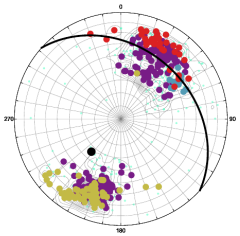
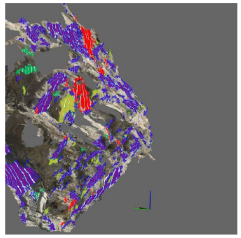
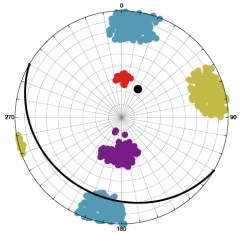
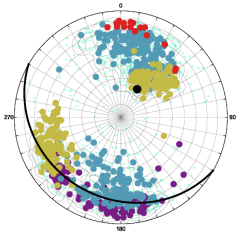
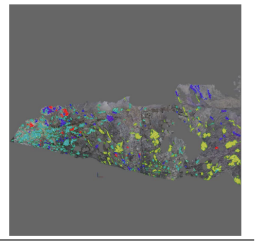
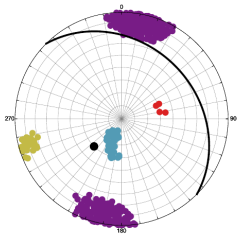
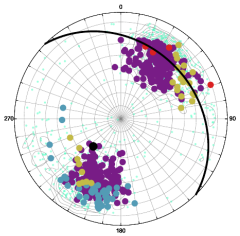
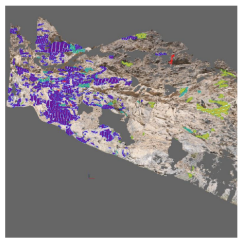


- Eastern Tian Shan is an ideal area for rock fracture system development and tectonic paleostrain researches.
- Outcrop sites where we acquired digital outcrop datasets are marked with blue quadrangular stars.

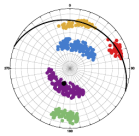
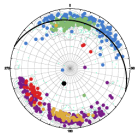
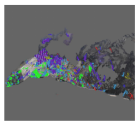
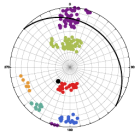
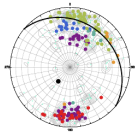
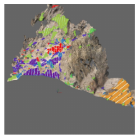
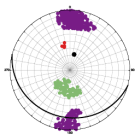
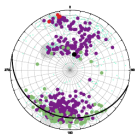
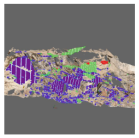
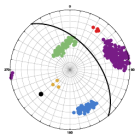
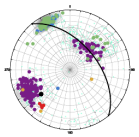
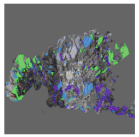
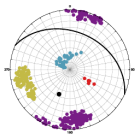
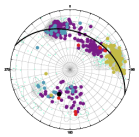
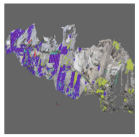
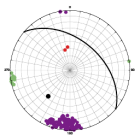
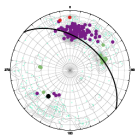
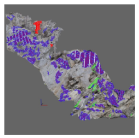
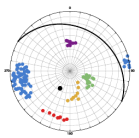
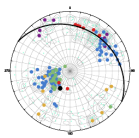
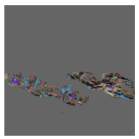
Methodology Overview

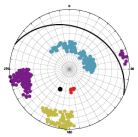
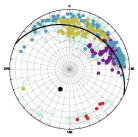
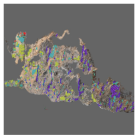
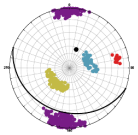
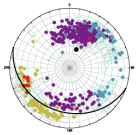
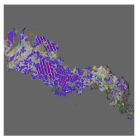
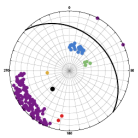
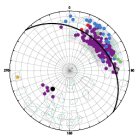
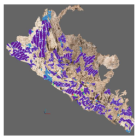
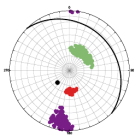
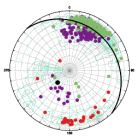
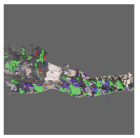
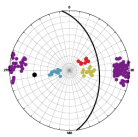
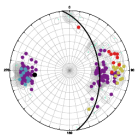
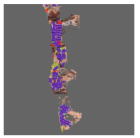
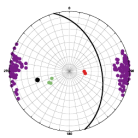
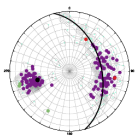
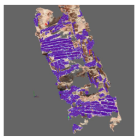
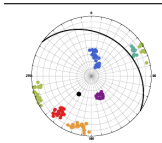
- The local strain tensor is calculated for slip on each fracture from the outcrop;
- Then the local strain tensors are grouped into populations corresponding to different strain events using a clustering analysis technique called DBSCAN.
- Code available from: https://github.com/EricAlex/structrock.

Results

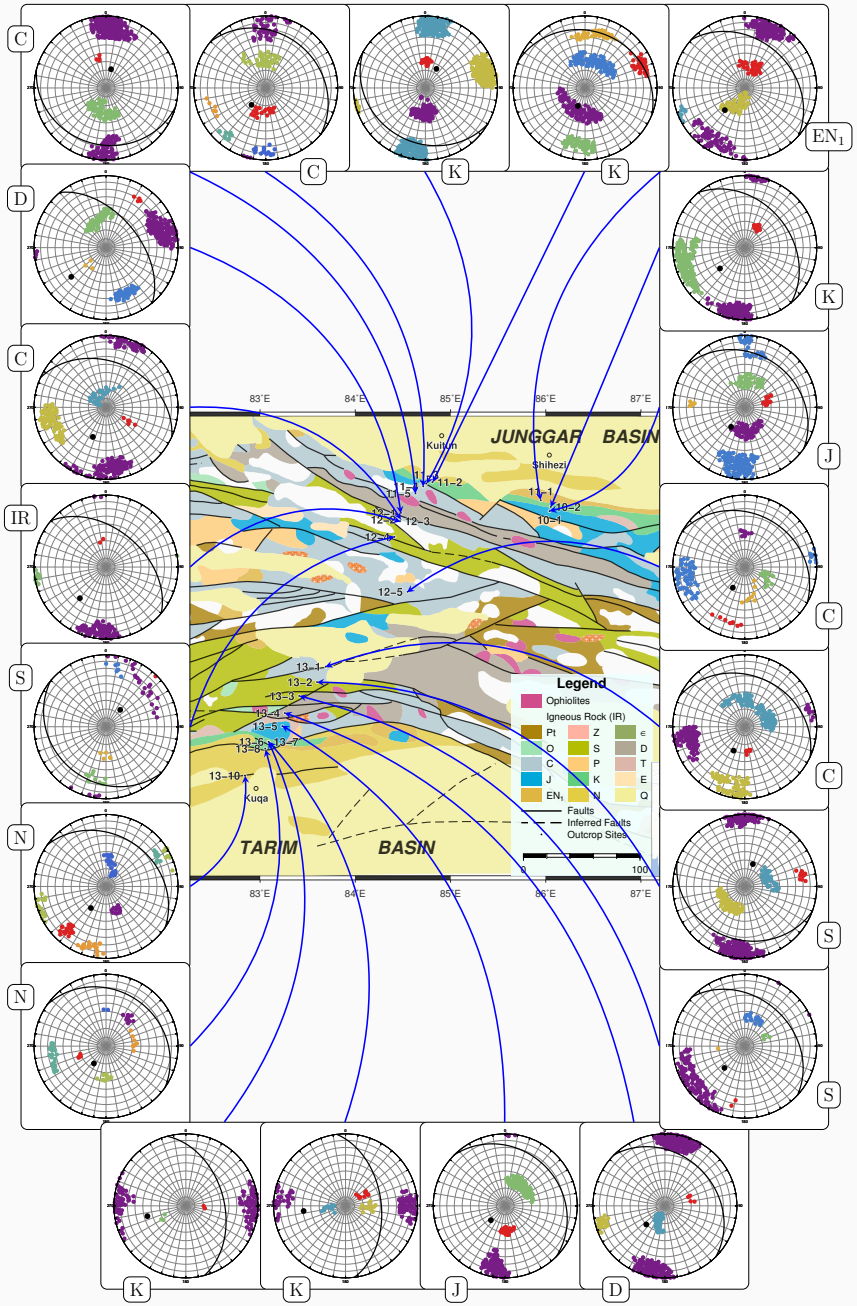
Datasets	Clusters of shortening directions	Clustered fractures in poles plot	Clusters projected onto the outcrop
10-1			
10-2			
11-1			
11-3			
13-4			

Results

Clusters of shortening directions	Clustered fractures in poles plot	Clusters projected onto the outcrop	
			Outcrop 11-2
			Outcrop 11-4
			Outcrop 11-5
			Outcrop 12-1
			Outcrop 12-2
			Outcrop 12-3
			Outcrop 12-5

Clusters of shortening directions	Clustered fractures in poles plot	Clusters projected onto the outcrop	
			Outcrop 13-1
			Outcrop 13-2
			Outcrop 13-3
			Outcrop 13-5
			Outcrop 13-6
			Outcrop 13-7
			Outcrop 13-10

Results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Shihezi
Kuqa
Legend
Ophiolites
Igneous Rock (IR)
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Faults
Inferred Faults
Outcrop Sites
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Discussions

- The current crustal movement velocity field derived from GPS measurements [Yang et al., 2008] agrees more with the near horizontal N-S shortening groups, which may imply that this is the shortening directions of the latest shortening events.
- The high angle shortening groups may be explained by that some of the more steeply dipped thrusting faults changed into normal faults when the ratio of the vertical stress to the horizontal tectonic stress becomes large enough.
- In space, the high angle shortening groups correlating with the N-S shortening events are more developed near the northern edge of Tian Shan. This may be supported by the fact that the current shortening rate (horizontal tectonic stress) near the northern edge is smaller than that of the southern edge of Tian Shan
  [Yang et al., 2008, Zubovich et al., 2010].

Discussions

- In time, the high angle shortening groups correlating with the N-S shortening events are more developed than that correlating with the NE-SW shortening events. The increase of vertical stress may be the cause of the change in the strain regime (see also [Vergnolle et al., 2007, Delvaux et al., 2013]).
- [Qiao et al., 2017] identifies a rapid increase in sedimentation rate after 2.6 Ma that could be related to the uplift of Tian Shan, i.e. the increase of vertical stress.
- The far-field shortening directions in eastern Tian Shan changed from NE-SW during the early Pleistocene to N-S since the Middle Pleistocene. And the strain regime change could be related to the Tian Shan uplift since early Pleistocene.

Discussions

- Although the current crustal movement velocity field presented by [Yang et al., 2008] reveals that 80% - 90% of the N-S shortening was absorbed by young faults along the southern and northern edges, and relatively little deformation was accommodated by reactivated faults within the interior, the characteristics of the regional strains are very well recorded in ordinary outcrops all over the study area.
- This study greatly enriches the data sources available for deciphering paleostrain in various applications.

Discussions

- In the cases of high angle shortening groups, the stress states are similar, but a slight variation of the fault plane's occurrence may result in opposite slip directions, and traditional paleostress inversion methods would get two vastly different stress states.
- The inversion from paleostrain to paleostress (such as traditional paleostress inversion methods) need to consider more heterogeneous and complex models.

References i

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Thank you!

Questions?