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Neotectonics of Zindapir Anticline and Sulaiman Fold and Thrust Belt: Inferences from SRTM DEM

[1]Jahanzeb Qureshi, [1]Syed Amer Mahmood, [1]Muhammad Khubaib Abuzar, [1]Amer Masood, [2]Muhammad Shafiq

[1]Department of Space Science, University of the Punjab, Quaid-e-Azam Campus, Lahore, Pakistan
[2]Pakistan Space and Upper Atmosphere Research Commission, SUPARCO Road, Karachi, Pakistan

*****Email: jzebqureshipu@gmail.com

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Abstract: The current study deals with the significance of surface dynamics (SDs) and its relationship to tectonics and active erosion in Zindapir Anticline (ZPA) and neighboring Sulaiman Fold and Thrust Belt (SFTB) which is a direct result of transform plate movement between Indo-Pak continent and Eurasia. The Shuttle Radar Topographic Mission Digital Elevation Model SRTM DEM with 30 m resolution was employed to compute SDs; Isobase (IBL), drainage density (DD), relative relief (RR) and vertical dissection (VD) thematic maps for the study area. The results obtained show that the DD, RR, VD and IBL have higher values in north west, central segments and south west of the SFTB, whereas the Zindapir anticline represents dextral movement on its east side while sinistral sense of movement is observed on its western edge. High values of RR and VD correspond to highly incised topography with great surface roughness. The enhanced values of IBL and DD in the northwest, south west and central SFTB correspond to uplifted active topography segments and can trigger medium level earthquakes in this region. The conjugate movement of ZPA is an indication of its neotectonic nature and recent uplift is causing surface deformation which needs to be understood in the context of SFTB development as a result of India-Eurasia transform movement.

Keywords: Drainage density, Isobase level, relative relief, vertical dissection, Zindapir anticline.

Introduction

The surface deformation of Zindapir Anticline (ZPA) can be compared by different aspects in the context of internationally cited famous anticlines (Unita mountains in the USA and Ronda in Spain). Hence, ZPA is a direct result of very deeply seated sub-surface sinistral faults. The synthetic analysis of recent earthquakes in this region, ground validation data and similar neighboring structures reported globally, palm-tree like structural model is suggested for the tectonic deformation for ZPA (Sylvester, 1984). Due to subduction of Indo-Pakistan beneath Eurasian plates, the former plate was segmented into many tectonic blocks (Fig.1). Due to movement of these blocks with continuing collision numerous tectonic patterns were formed on the individual basement block (Bannert and Raza, 1992; Afzal et al., 2009; Peresson and Daud, 2009; Reynolds et al., 2015; Khan et al., 2018).

The study area lies towards the east of SFTB and Sulaiman depression is located in the east of the study site, while towards the west of Zindapir lies Barthi syncline (Fig. 2). Zindapir is the southern trend of Koh-Safed culmination. It is the most uplifted and broader structure. The SFTB is a main tectonic feature in the proximity of collision zone therefore may have a great number of disturbed anticlinal features. The northward directed Eastern Sulaiman Fold and Thrust Belt (ESFTB) is comprised of narrow and relatively linear anticlines. It is interpreted as a large-scale distributive wrench fault including Ranikot Formation (Paleocene), Pab and Sembar-Lower Goru formations (Cretaceous) sand-stones and it is assumed that ZPA is due to the tectonics conjugation (Treloar et al., 1992; Shazia et.al., 2014, 2015).

The consistent Sanghar Lahar Back Thrust (SLBT) all along the eastern edge of ZPA proposes that it is undergoing an analogous active deformation. Sporadic sinistral movements may be credited to the curvi-linear natural shape of ZPA. This similarity can be seen in various places in the southern segments of ZPA. The border regime to ESFTB included in this investigation area is distinct from ZPA and is separated by Barthi synclinal zone (Bannert et al., 1995). The base of Barthi synclinorium obducts towards the eastern and the frontal segment of the ESFTB alongside the back-thrust (Humayon et al., 1991). The topographic evolution of relative uplifts of ZPA suggests that it is a younger and emerging landscape.

Materials and Methods

SRTM DEM 30 m was used which is a proficient data to delineate neo- tectonics and landscape investigation. Digital elevation model (Jarvis. et.al, 2008) provides a prospect to compute topographic SDs in the context of variable elevation and its splays (Jarvis. et.al., 2008). Detailed methodology is shown in flowchart (Fig.3). Following methods were used in the present study for the extraction of structural features and geomorphic indices.

The famous D8 algorithm (O'Callaghan and Mark, 1984) is the most frequently used technique to approximate flow directions on a topographic surface. This technique tracks "flow" from each pixel to one of its eight neighborhood pixels. Though, it is established on two simplifying assumptions:

i. The use of eight distinct flow angles

ii. Each pixel has a single flow direction, which does not capture the geometry of divergent flow over hillslopes.

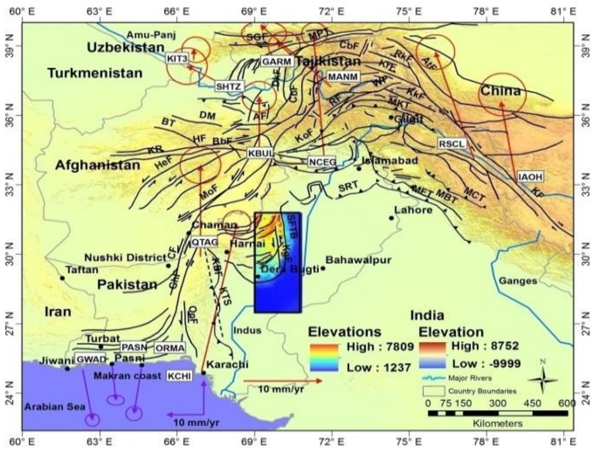

Fig. 1 Regional tectonic framework (ZPA and Eastern Suleiman fold and thrust belt) with inset showing the study area. Sources: (Lawrence et al. 1981; Wheeler et al. 2005; Doebrich and Wahl 2006; Mahmood and Gloaguen 2011).

D8 algorithm is used to compute the standard uni-lateral flow angles. It just links the contributing area for an individual pixel to the surrounding pixel along the steep slope. The surrounding pixel is known as the pixel down-stream of the central pixel. D8 technique is an extensively used process for analyzing the cumulative area, though it may not model the dispersion of flow angles. In D8 method, a matrix of flow angles is the direction to the least elevation pixel (Fig. 4).

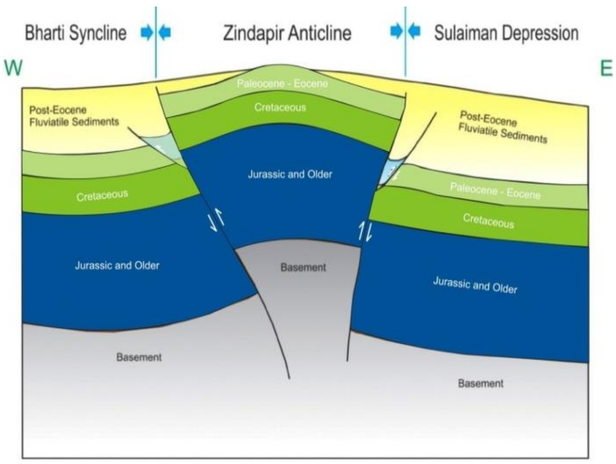

Fig. 2 Schematic cross-sections across Sulaiman depression, Zindapir anticline and Bharti syncline showing structural pattern associated with transpressional regime (modified after Nazeer et al., 2012, 2013).

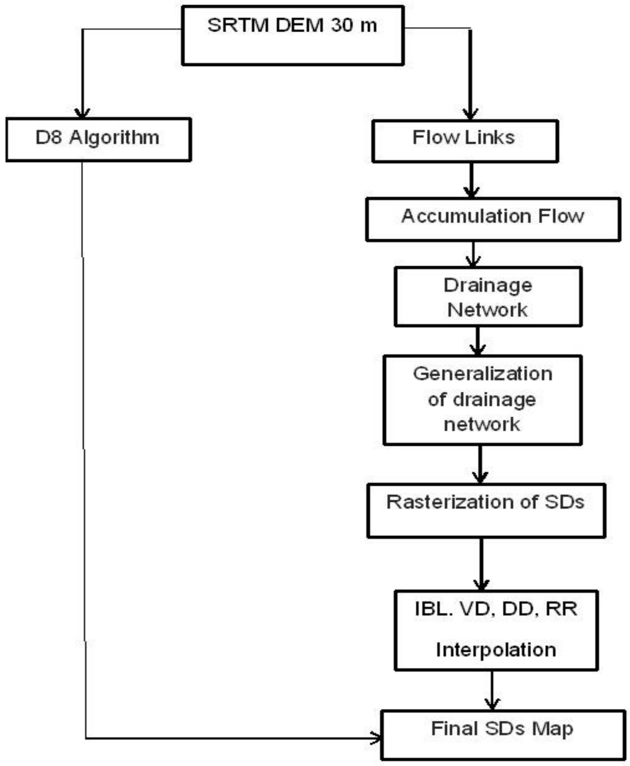

Fig. 3 Flowchart showing the methodological sequence

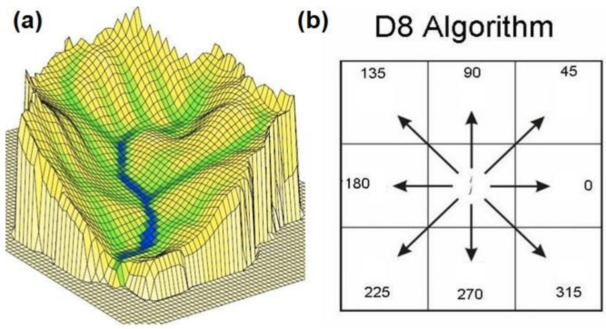

Fig. 4 (a) Digital terrain model showing flow accumulation of water (b) Mechanism of automatic river extraction through D8 algorithm.

Drainage Density (DD) is the ratio between the total length of all the streams divided by the contributing area of the study area. Higher DD shows neotectonic surface deformation while lower DD accounts for active sedimentation. Relative Relief (RR) of topography is computed such that one valley and one ridge should be covered, if the valley part is ignored the slope of the ridge will be left. High RR means complex formation/uplift while lower RR corresponds to relatively peneplain/smooth/plain topography. Higher slope values always affect the topography because of higher erosion and rapid runoff (Rizvi and Aslam, 2018). The RR parameter relates to the topographic incision or localized relief, that in general has no acknowledged description, but basically it corresponds to relative elevations (Evans, 1972). The criterion of computation of SDs (DD, RR, VD) was executed in the context of a variable moving window size such that the large and small valleys in the study area are covered both at small and large scale to give a real time scenario being developed in terms of recent uplift in SFTB.

In the current investigation the RR calculation is established on a fixed size moving square window big enough for the generation of matrix for the entire DEM size, where all pixel elevations tend to approach -9999. The calculation of relative relief is subjected to the size and shape of the moving window (Klinkenberg, 1992; Guzzetti and Reichenbach, 1994; Ascione et al., 2008). To include at least two major ridges and/or valleys the moving window cell should be large enough else the outputs shall not be representing localized relief, and just the slope gradient (Evans, 1972; Shahzad and Gloaguen, 2011). Now considering the DEM size and movable size window, the operator is prepared corresponding subset of the DEM which is extracted by shifting the window on each possible pixel of the DEM. The minimum and maximum difference of elevation is allotted to the cell for which the SDs map was generated at the final implementation of the D8 algorithm. Vertical Dissection (VD) is the ratio between the flat surface area to the real surface area. Higher VD values correspond to severely deformed regions/tectonic activities, while lower VD values represent relatively calm and subsided topography.

Isobase level (IBL) map represents various topographic stages with equal lines of uplift. In earth sciences, the term “isobase” gives the idea of a “line of equal uplift” (Leverington et al., 2002). A base level is a level “below which no further erosion takes place in the context of dry land. In general, the sea level can be regarded as the final IBL, but the idea of IBL stands vital in terms of various temporal/ climatological/ geotectonic settings on a regionalized gauge or in a given basin (Grohmann et al., 2007, 2011). Base-level maps reproduce an association between landscape and valley ordering. In a drainage basin the respective stream segments position is powerfully related to the landscape and valley ordering, whereas the same orders stream connects to similar geo-tectonic incidents and have the same topographic age (Golts and Rosenthal, 1993). The geomorphology of different stream order and landscape changes can be measured through IBL (Fig. 8). An IBL map is related to similar erosive events, and may be taken as a result of recent erosional and neo-tectonic settings (Garrote et al., 2008).

IBL map identifies neotectonics/ erosionalscarps in the context of either vertical fault movement or change of host bedrock. ISO base map can be prepared manually that needs proper scale good quality topographic sheets but the process is quite time taking. One can automatically extract huge data and stream order recognition through DEM in a proficient way. High IBL values represent relatively uplifted zones/ neotectonic activity while lower IBL values represent fluvial and alluvial deposits in relatively smooth topographic zones. The boundary between higher and lower IBL values may be due to fault scarp/erosional scarp that can be verified from the underlying geology type/ lineaments (modified after Nazeer et al., 2012, 2013)

Results and Discussion

High RR and DD values are revealed in the DD map towards NNW, west, SW and SE parts of the study area. (Fig. 5 a,b,c,d). It is assumed that these parts are experiencing a significant uplift and hence, indicating high values of DD that correspond to neo-tectonic activity in this region.

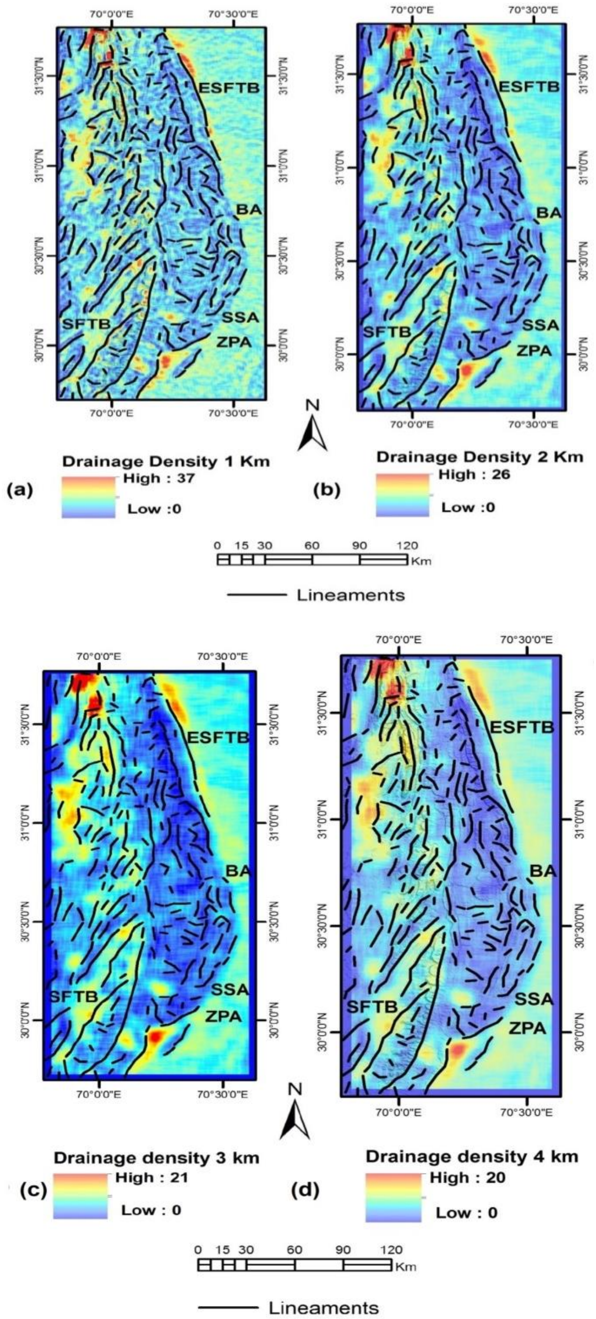

Fig. 5(a) Drainage Density map for 1 km grid size, (b) Drainage density map for 2 km grid size, (c) Drainage density map for 3 km grid size, (d) Drainage density map for 4 km grid size

The RR map has been prepared for ZPA and suburbs. An attempt has been made for the co-relation of RR uplift map with the current ongoing topographic evolution process. RR map indicates relatively variable uplifts in various portions of the investigation site. The NW, central west, SW and ZPA show higher RR values comparable to the eastern portion of the investigation site (Fig. 6 a,b,c,d).This clearly suggests that the NW, central ESFTB, SW SFTB, ZPA and Bharti Anticline BA are highly incised. ZPA is also uplifting along its central fold axis as compared to the NE-SW edges. The western edge of ZPA anticline is uplifted more as compared to its eastern edge.

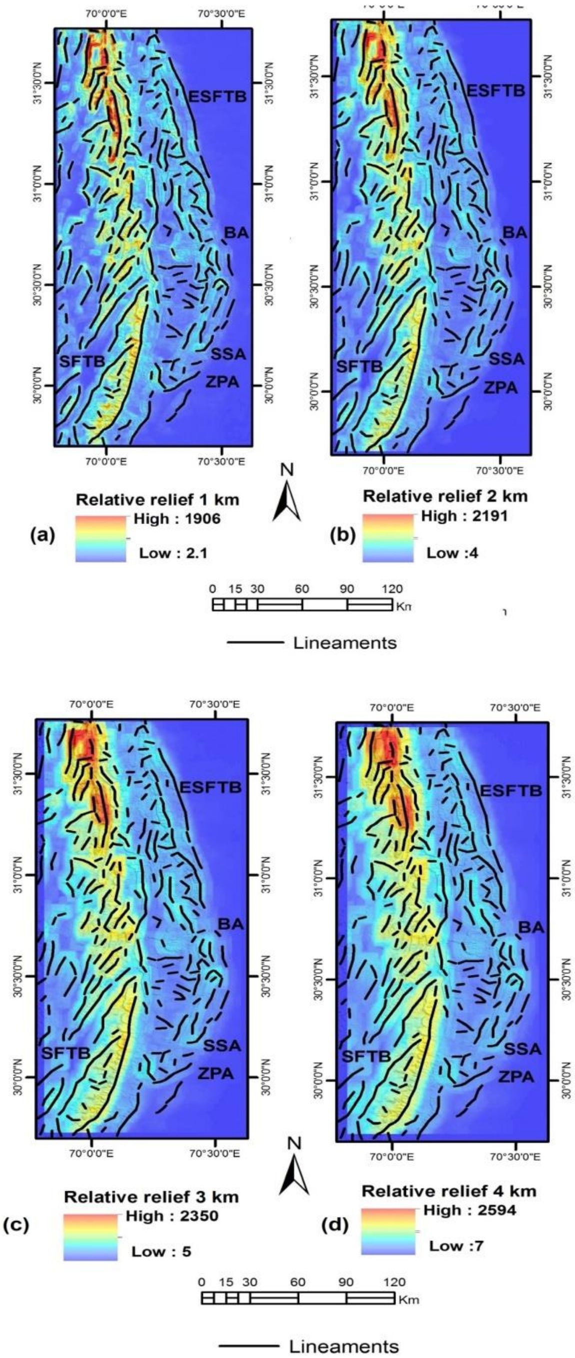

Fig. 6(a) Relative relief map for 1 km grid size, (b) Relative relief map for 2 km grid size, (c) Relative relief map for 3 km grid size, (d) Relative relief map for 4 km grid size.

The topographic VD defines how narrowly and deeply erosion has dissected it. The VD map indicates heterogeneous spatial distribution with colored bands of lower and higher VD values, that are shown as lines of separation among least and high rugged regions. Hence, these bands of least and high VD values are understood as relatively uplifted tectonic blocks located along either side of the ZPA specifically in its eastern and western boundaries, NNW, central parts and SW parts of SFTB (Fig.7 a,b,c). The high TSR values also correspond to abundant lineaments that indicate younger topographic evolution because of neotectonics in the investigation region. Lower VD values represent comparatively smooth, least incised, low relief regions with most recent active sedimentations. Lineament density along NW, central, SW of SFTB and along ZPA, Sakhi Sarwar Anticline (SSA) and Barthi Anticline (BA) segment is more which indicates that these parts of the region show tectonic deformation as compared to the NE, east and SE parts of the investigation site.

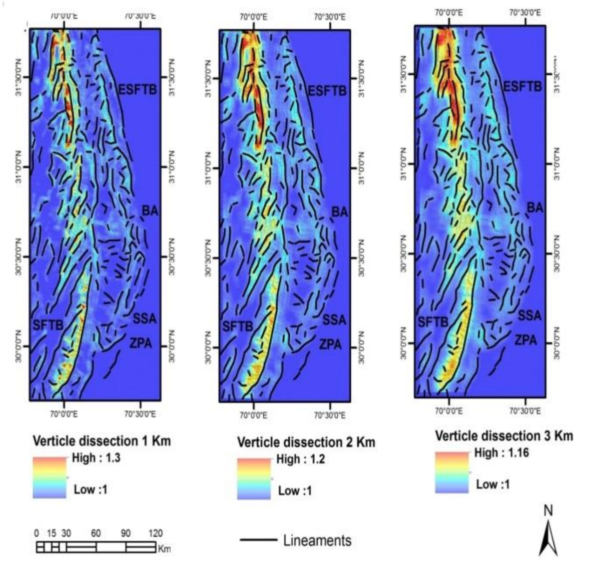

Fig. 7(a) Vertical dissection map for 1 km grid size, (b)Vertical Dissection map for 2 km grid size, (c)Vertical Dissection map for 3 km grid size.

The isobase map was found good to reveal the excellent results. The deflection of lineaments is clearly observed that are NW and SW oriented with some parts of the investigation site. The red and yellow isobase codings show higher uplift rates which means higher surface deformation, while the blue color coding that is NE-SE oriented show lower uplift rates i.e. relatively smooth topography (Fig. 8). The spatial distribution of IBL values are representative of various surface deformation stages in connection with various geological events and uplift episodes in the past. The ZPA shows dextral sense of movement in its eastern border as compared to the sinistral movement in its western boundary, which is an indication of conjugate/complex tectonic movement that has clearly created a prominent offset of the hill torrent passing through ZPA (Fig. 9). This conjugate movement is also an indication of emerging topography within ZPA and is responsible of earthquake activities in the main context of SFTB.

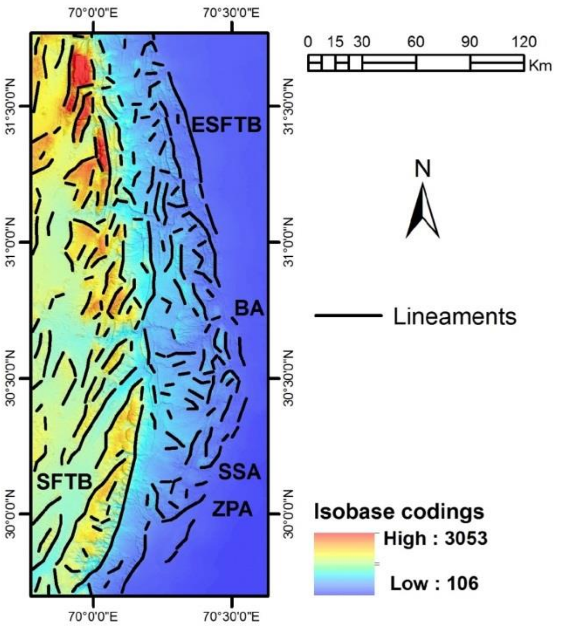

Fig. 8 Isobase map showing differential and spatial coding of various topographic evolutions in the past

Fig. 9 High resolution imagery from google earth (annotated) clearly showing conjugate tectonic movement (both dextral and sinistral) represented by red arrows. The hill torrent offset is also visible because of this conjugate sense of movement (google earth pro).

Conclusion

RS/GIS techniques are time efficient and very helpful to study active structures based on SRTM DEM from the space shuttle (Jarvis. et.al, 2008). Results obtained from DD, RR, VD and IBL coding's provide interconnected, mutually validating and precise information regarding the growth of ZPA in particular and ESFTB in general. SFTB shows an overall sinistral sense of movement. The deformation process in Zindapir Anticlinorium (ZPA) is associated with Sulaiman basement sinistral fault. ZPA flower-like structure is a result of sinistral behaviour while the main SFTB has formed due to thin- skinned tectonics and an offshoot of regional strike- slip (both sinistral and dextral) tectonics. This study will provide integration between DEM derived SDs, GIS and their morphometric analyses, its quickness, precision and evaluation of necessary parameters. Apart from being cost effective, use of free and open source data and tools ensures the guaranteed access to all researchers and is opening new perspectives in this field of research. It will set a base for future studies to develop and perform mathematical and statistical models to constrain neotectonics and related hazards in the SFTB.

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