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Differential GPS Monitoring to know the Relationship between the Current Stress Field, the Active Tectonic Structures and the Fluids Circulation in the Geothermal Zones of Acoculco and Los Humeros, Puebla, Mexico.

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ABSTRACT

As part of one of several studies carried out within the framework of the GEMex project, differential GPS monitoring has been carried out since April 2017. The measurements are carried out in the geothermal zones of Los Humero and Acoculco. These two geothermal zones are considered volcanic craters with active geothermal and tectonic manifestations, and are located in the eastern sector of the Transmexican Volcanic Belt (TMVB). Measurements are taken every 6 months to describe the regional and local stress field. The method used is a measurement procedure called DGPS (Differential GPS) in which two or more GPS receivers are used. In this mode, there is a reference receiver called a base station, which occupies a point and of which the precise coordinates are known which would allow you to calculate the errors with reference to this and one or more mobile receivers called "rovers" that are located on the point or points we want to obtain the coordinates. The great advantage of this method is that the positioning errors, very similar in both points, are eliminated for the most part. The monitoring network consists of 18 control points, strategically distributed along the fault structures that affect the boilers of Acoculco and Los Humeros. Preliminary results show that horizontal displacement vectors have movements between 2 mm and 50 mm, most of these vectors have a preferential NW-SE displacement orientation. The secondary or local NW-SE, NE-SW and E-W structures present in the study area could respond to the regional stress field, which according to the orientation of the vectors seems to have a NW-SE extension and to be controlling the current circulation of groundwater and hydrothermal fluids. Some hydrothermal alterations in Acoculco are found in structures that fit this field of endeavor.

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1. INTRODUCTION

Understanding ground deformation is of great importance in the exploration of a geothermal field with geothermal potential and an operating geothermal field, because knowing the geological structures in the area of interest and understanding their current deformation regime will be of great help (along with other studies) in knowing which structures are favorably oriented to the current stress field for fluid circulation and thus efficiently exploit the geothermal resource, whether it is an enhanced geothermal system or a conventional geothermal system. To help solve this problem, and as part of one of several studies that have been carried out in the framework of the joint Mexico-EU collaboration program, called GEMex, since April 2017 geodetic GPS monitoring is being carried out using the differential GPS technique to know the current stress field, both regionally and locally in the geothermal zones of Acoculco and Los Humeros Puebla.

2. METODOLOGY

2.1 DGPS

The positioning method used is called DGPS (Differential GPS), in which two or more GPS receivers are used. In this mode a reference receiver is used, called a base station, which occupies a point from which the precise coordinates are known and the other receiver (or receivers) is the mobile receiver, also called a mobile station or "rover. It is a technique to improve GPS positioning accuracy. According to Shoel Ahmed, (2014) "Differential GPS is the error correction signal that is transmitted to the surroundings with a maximum range of 1000 km.

The base station obtains information from the satellites, which allows it to make positioning corrections by calculating and eliminating errors with reference to this and one or more mobile receivers, thus obtaining a difference in position, through coordinate increments (baseline) between the reference receiver and the mobile receiver (figure 1). The calculation to make the corrections can be done in two ways: in real time and through post-processing in cabinet work.

The great advantage of this method is that positioning errors at both points have no influence on coordinate increments. The errors it eliminates are selective availability (SA), ionospheric delay, tropospheric delay, error in the ephemeris and errors in the satellite clocks and receiver.

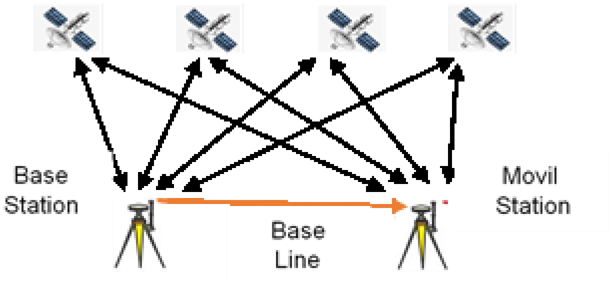

Figure 1: DGPS positioning method.

2.2. FIELD CAMPAIGN PLANNING

The GPS point monitoring network was planned with the help of google Earth satellite images, where fault structures, locations and access roads were identified to make data acquisition easier. Initially, the network consisted of 14 control points, starting the first campaign in April 2017 and subsequently conducting data surveys every 6 months. For the third campaign, 4 more points were added to the monitoring network, thus obtaining a total of 18 control points throughout the study area. The points were strategically distributed along regional and local fault structures that affect the Acoculco and Los Humeros boilers, the structures have NW-SE, NE-SW and WSW-ENE orientations.

2.3. EQUIPMENT USED

The equipment used for the surveys of the control points were four high precision geodetic GPS, LEICA brand, GPS System 500 model, with NAVSTAR-GPS signal (NAVigation System Time and Ranking-Global Position System) of twelve channels and two bands (L1 and L2) of reception. The GPS consists of the following components:

- AT502 dual-frequency antenna: Receives and amplifies the signal received from satellites.
- SR 520 Receiver: Computer that decodes the signal received by the antenna and records the observations.
- TR 500 Terminal: It is a user interface that allows to know the reception status, calculation process, and to carry out the edition of the receiver data.

Figure 2: Components of the Leica SR530 geodetic GPS.

The Standard Static observation method was used to collect or obtain data in the field, which is used to measure long baselines, greater than 20 km. For each control point data were taken for 6 hours, because the baselines exceed 30 km (Table 1), thus ensuring a better correction of the coordinates and a lower margin of error, according to the Guide to Static and Fast Static Measurements by Leica, Geosystems.

Obs. Method	No. sats. GDOP ≤ 8	Baseline Length	Approximate observation time	
			By day	*By night*
Rapid Static	4 or more 4 or more 5 or more	Up to 5 km 5 to 10 km 10 to 15 km	5 to 10 mins 10 to 20 mins Over 20 mins	5 mins 5 to 10 mins 5 to 20 mins
Static	4 or more 4 or more	15 to 30 km Over 30 km	1 to 2 hours 2 to 3 hours	1 hour 2 hours

Table 1: Approximate guide to baseline lengths and observation times for mean latitudes below current levels of ionospheric activity when using a dual-frequency sensor. Taken from Geosystems, Leica. (2003).

2.4. POST-PROCESSING

Once the data collection campaign was completed, a post-processing of the data was performed, using Leica Geosystems SKI Pro Version 3.0 software. To process the data, the coordinates (figure 3) of the base stations of the network that was installed for monitoring were corrected, using the DGPS technique using as reference the ICEP station of the Active National Geodetic Network (RGNA), installed by INEGI (National Institute of Statistics and Geography) located in the state of Puebla, Mexico. For the correction of the coordinates of the mobile stations of the monitoring network, the DGPS technique was once again applied, but now the base points of the network, which were already corrected, served as a reference to make the correction of each mobile station of the entire study area. The correction was made separately for each area of interest.

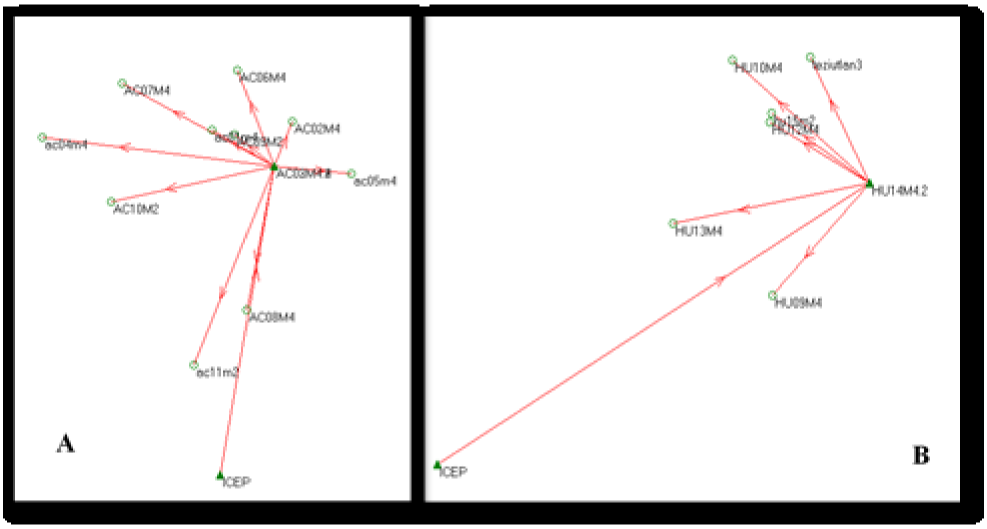

Figure 3: A) Correction of coordinates of the Acoculco area. B) Correction of coordinates of the Humeros area.

Once the results were obtained we proceeded to elaborate in a map that showed structural guidelines, the horizontal displacement, obtained from the comparison between the campaigns of monitoring and graphing by means of vectors. To the map was added georeferenced information of wells and hydrothermal manifestations of different consulted bibliographic sources, to know if there is some relation between these data, the structures and the field of stress.

3. Results

As a result, maps are being obtained that show the current regional and local stress field of the geothermal zones of Acocuclco and Los Humeros, by comparing the movements that are occurring over time and that have been registered by geodetic GPS in each of the monitoring campaigns that have been done. The stress field can be observed by the horizontal displacement vectors, having displacements from 2 mm to 50 mm, plus the trend of the vectors shows that the current stress field has a NW-SE orientation (figures 4, 5 and 6). In the maps we can also see that the fluids (hydrothermal manifestations) circulate to the surface through or near the geological structures, which are responding to the current stress field.

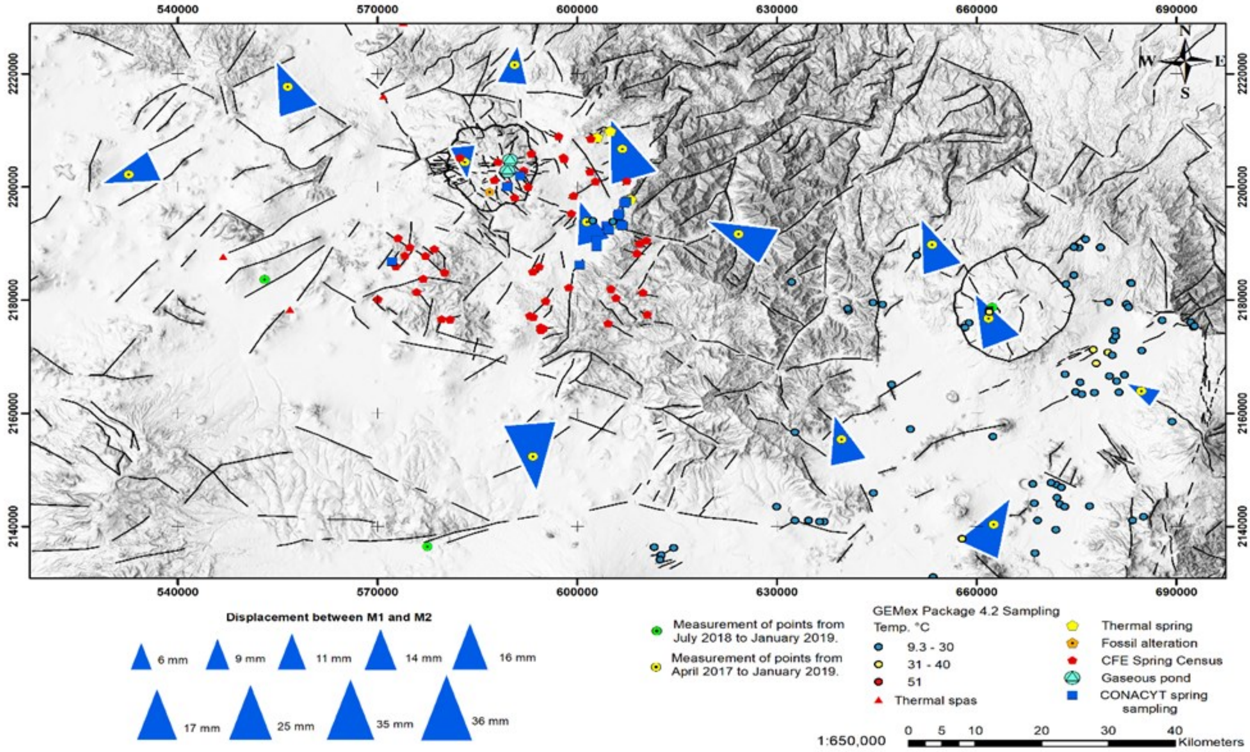

Figure 4: Map of comparison between M1 and M2 monitoring, in which it can be observed that most horizontal displacement vectors have a preferential movement to the NW, with half-yearly rates ranging from 6mm to 36mm.

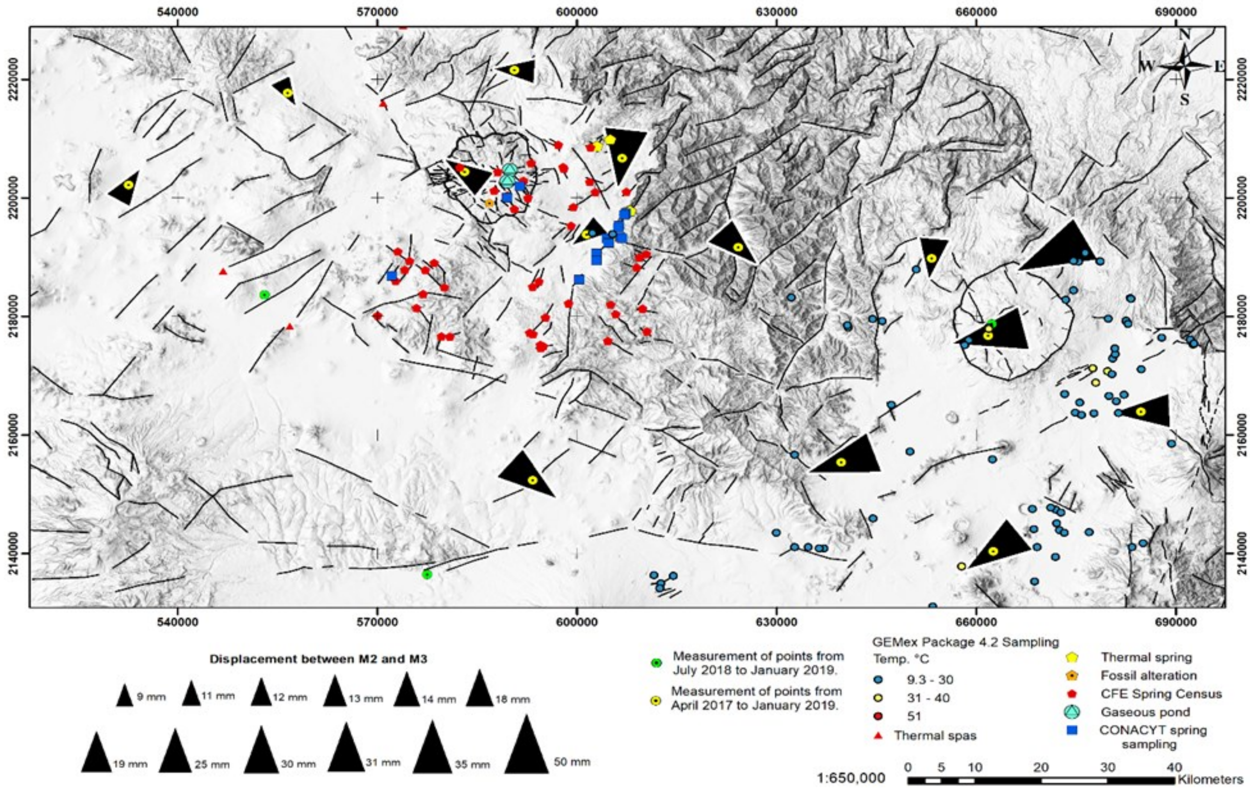

Figure 5: Map of comparison between M2 and M3 monitoring. It is important to mention that one day before the second monitoring (19/09/2017) there was a great earthquake that affected the study area, which may have affected the movement of some structures and resulting in a difference in the orientation of some vectors of M2 and M3 monitoring compared to the vectors obtained from M1 and M2 monitoring. Displacement rates possibly increased with the earthquake and range from 9 mm to 50 mm.

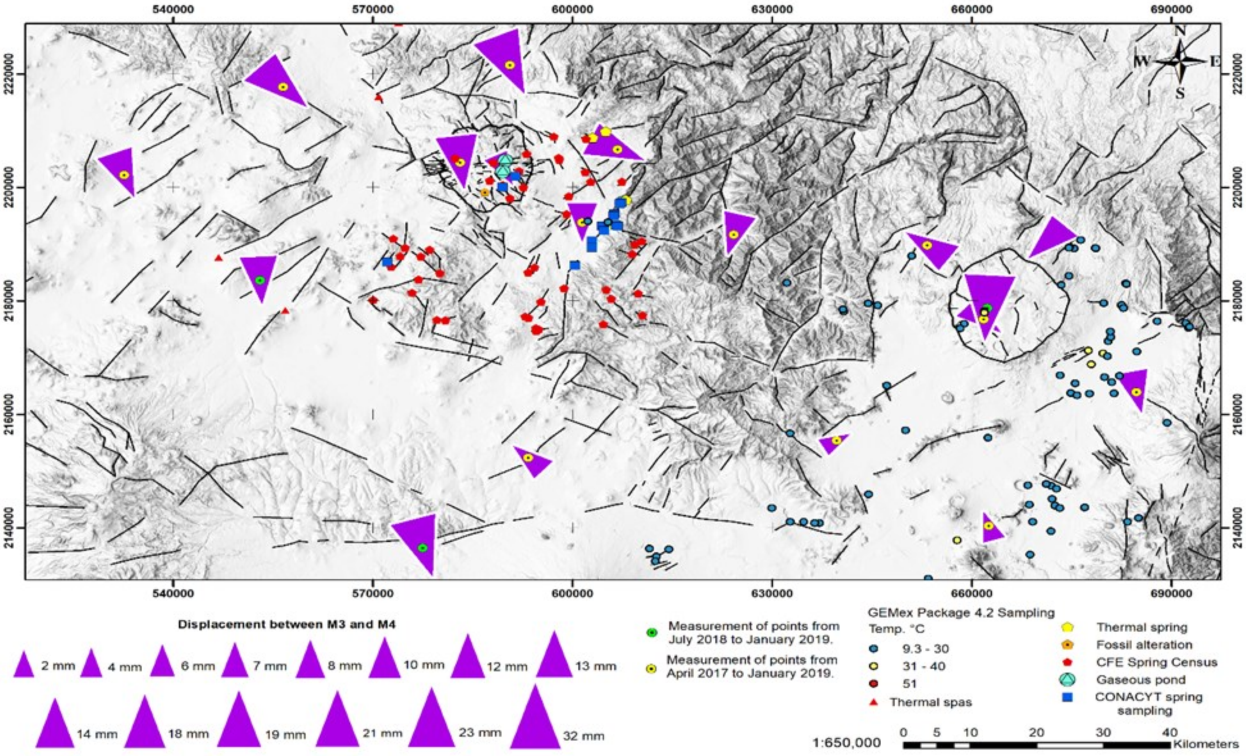

Figure 6: Comparison between M2 and M4 monitoring, in which it is observed that most of the vectors adopt a preferential SE orientation, with displacement rates from 2 mm to 32 mm.

4. DISCUSSION

According to Suter et al (1991), the eastern part of the TMVB is being affected by a stress field and active extensional deformation, with a preferential orientation of σ3 NW-SE (figure 7), due to the superposition of two sources of stresses. The first, due to the local intraplate stress related to the high elevation of the TMVB, causes normal faults, which collide parallel to the axis of the volcanic arc. On the other hand, the observed left strike-slip component can be explained by a distant stress field, caused by the loads applied at the boundary between the Cocos and North American plates. In the maps, most horizontal displacement vectors show that the current stress field in the study area has a preferential extension orientation NW-SE (σ3), just as Suter et al. reported (1991). The structures present (NE-SW, NW-SE and WSW-ENE) in the eastern zone of the FVTM, may be responding to the current extensional stress field, thus favoring the circulation of hydrothermal fluids as shown in the maps.

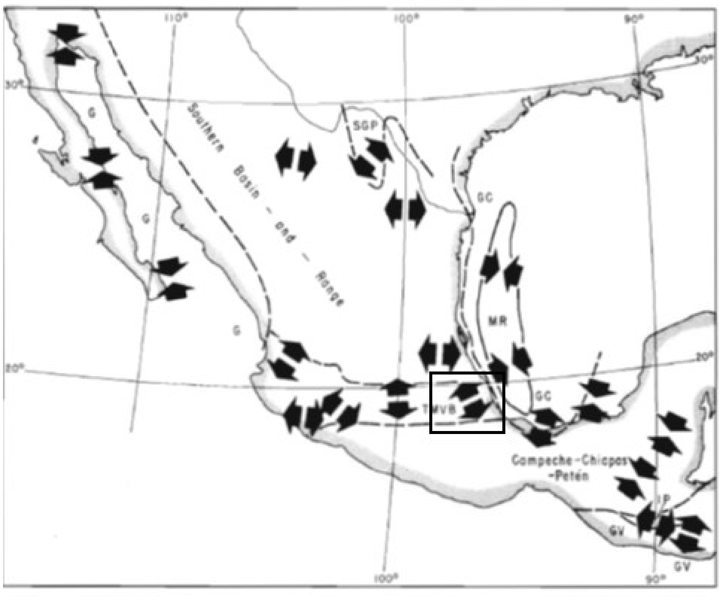

Figure 7. Stress provinces defined for México. The black box shows the study area and the NW-SE extension, which affects the eastern part of the transmexican volcanic belt. Taken and modified from Suter (1991).

The reason that some of the horizontal displacement vectors change their direction from NW to SE, is due to the fact that the FVTM presents a very complex tectonic and to the presence of normal faults with NW-SE, NE-SW and WSW-ENE orientations, the plane of rupture of these structures is not infinite, that is to say that there is a horizontal limit between each structure and between these limits transfer zones are generated. If the GPS control point is located in a transfer zone it will have displacements that sometimes will have different directions, in this case from NW to SE, but the current field of efforts will maintain the same NW-SE orientation.

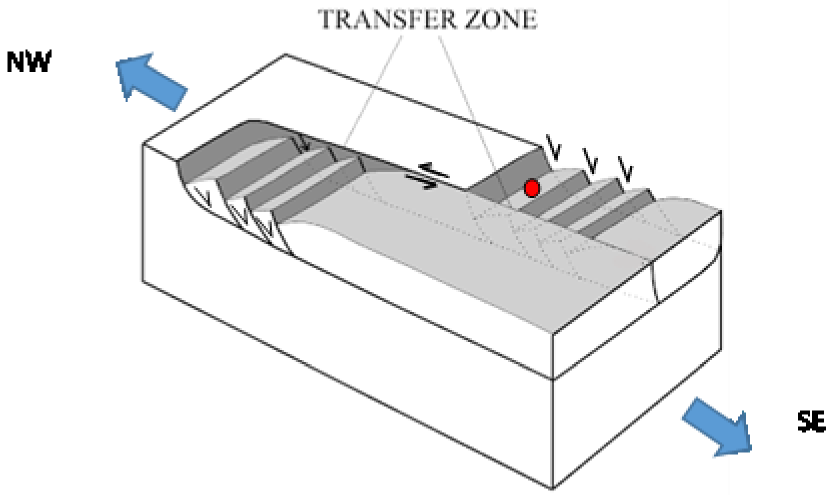

Figure 8: Normal faults separated by the transfer zone, which is generated between the boundaries of the rupture planes of each fault. The red dot symbolizes the GPS control point, which will register the horizontal movement of the block of the normal falling fault, or the inverse horizontal movement of the whole block where the normal faults are housed. Although these movements are inverse, the same orientation of extension of the field of stress will always be maintained. Taken and modified Faulds, J. E. (1998).

5. CONCLUSIONS

The horizontal displacement vectors of each map show that the current stress field has a NW-SE orientation.

The Acoculco geothermal deposit and the Humeros geothermal field are located in the eastern part of the FVTM in the state of Puebla, the area has an active extensional tectonics with a NW-SE orientation according to Suter et al., (1991).

The NE-SW, NW-SE and WSW-ENE structures may be responding to the current extensional stress field, thus favoring the circulation of hydrothermal fluids, which flow to the surface through or near geological faults.

The extensional active tectonics of the eastern sector of the VTMF can generate normal faults, which host within their limits transfer zones, causing that sometimes the horizontal displacement vectors present different directions, NW to SE, but even so the orientation of the stress field remains NW-SE.

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