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Geomorphology surveying and mapping water reservoirs under Global Positioning System

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ABSTRACT

The current geomorphology of the Qinghai-Tibet Plateau area is studied, and the plate movement and future geomorphology of the Qinghai-Tibet Plateau are predicted to further promote the development of geological research in China. Firstly, the wide application of the Global Positioning System (GPS) and its role in geology are explained. Secondly, GPS observations on the Qinghai-Tibet Plateau and its surrounding areas are studied, high-precision GPS observation data are processed, and the observation result data are analyzed and screened. Finally, the qualitative and quantitative research results are obtained for the changes in the Qinghai-Tibet Plateau. The research results show that the use of geomorphological surveying and mapping research based on the GPS can accurately understand the geomorphic features and geomorphic changes of the Qinghai-Tibet Plateau, and accurately understand the horizontal and vertical geomorphic deformations of the Qinghai-Tibet Plateau. The research results show that GPS can effectively survey and map the geomorphology of the Qinghai-Tibet Plateau, which provides new perspectives and new methods for geomorphological surveying and geological research and guarantees China's further research on the influence of plate movement on the terrain and sets an example for future related research.

Keywords: Global Positioning System; Qinghai-Tibet Plateau; Geomorphology surveying and mapping; Uplift and expansion mechanism

1. Introduction

With the continuous acceleration of China's infrastructure construction and the continuous improvement of comprehensive national strength, China's demand for domestic topographic surveying and mapping is increasing. Geomorphology refers to the general term of various landforms on the earth's surface, also known as topography. The shape of the geomorphology is ever-changing, and its causes are diverse and affected by the combined effects of internal and external factors. The internal cause is mainly an endogenous geological process. Due to the rotation and revolution of the earth, the interaction between the earth and the surrounding celestial bodies, and the influence of internal radioactive element decay, the formation of geomorphology is mainly carried out in the crust and mantle, including crustal movement, magmatism, metamorphism and earthquakes. The external causes are mainly internal geological effects, including weathering and erosion of the atmosphere, transportation and accumulation of water, and denudation of organisms, etc., which have formed current various geomorphology [1,2].

Located in the interior of Asia, the Qinghai-Tibet Plateau is the highest plateau in the world. It extends from the southern section of the Himalayas in the South to the Kunlun Mountains, Altun Mountains, and the northern section of the Qilian Mountains in the north, to the Pamirs and Karakoram Mountains in the west. The east and northeast are connected with the western section of the Qinling Mountains and the Loess Plateau. The Qinghai-Tibet Plateau is squeezed by the collision of the Eurasian Plate and the Indian Ocean Plate, and its height is still rising and is

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affected by the southwest monsoon and the Tibetan Plateau monsoon circulation and precipitation, so the unique geomorphology is formed [3,4].

Global Positioning System (GPS) is high-precision radio navigation and positioning system with artificial earth communication satellites as the basic tool. Its scope of use includes any surface area and near-earth space that are not electromagnetically shielded, and can provide users with accurate real-time geographic location, driving speed and time information. After about 10 y of use and testing by China's surveying and mapping departments, GPS has won the trust of China's surveying and mapping personnel and departments with its ancestor features such as all-weather, high precision, automation, and high efficiency. GPS has been used in many fields and has brought a leap forward in surveying and mapping technology. The main components of GPS are divided into three sections: space, ground monitoring, and user terminal [5,6].

Starting from the geographical and geomorphic environment of the Qinghai-Tibet Plateau, the feasibility and necessity of using GPS for geomorphology surveying and mapping are analyzed. Then the GPS is used for actual surveying and mapping to obtain data, and the data are sorted, and finally, the geomorphology change data in the horizontal and vertical directions of the Qinghai-Tibet Plateau are obtained, which lay a solid foundation for future academic research.

2. Formation and development of the Qinghai-Tibet Plateau and surveying and mapping methods

2.1. GPS technology

2.1.1. Principle of GPS in surveying and mapping

GPS technology in topographic surveying and mapping mainly comes from its global coverage satellite system, which continuously collects and sends information on a global scale, uses satellites to achieve uninterrupted observation of the detection target, and then captures the observed information through the GPS system. The received information is preliminarily processed, re-arranged and flowed in, so as to obtain the three-dimensional coordinates of the observed object, and further realize various analysis and calculations for the terrain survey.

2.1.2. Advantages of GPS technology applied to geomorphological surveying and mapping

a) The positioning accuracy of GPS is high.
b) The observation time of GPS is short.
c) There is no need to see between each mobile test station, only the test site conditions are open, which can save a lot of cost.
d) GPS can carry out accurate site three-dimensional coordinate measurement through different measuring stations.
e) The measurement operation of GPS is simple, the degree of automation is higher, and the weight is light.
f) GPS does not necessarily need to be measured on the spot, it can be remotely controlled by automated equipment, and related data can be directly processed on the computer, which helps users to work easily and improve office efficiency [7].

2.1.3. Disadvantages of GPS technology applied to geomorphological surveying and mapping

Due to the current surveying and mapping requirements, most areas have strict requirements for the accuracy of surveying and mapping. Although GPS technology has a strong function of point-to-point communication, it is not perfect and there are many aspects that need to be improved [8,9].

a) Although the measurement range of GPS is very wide, it is not enough for the current demand.
b) The stability of GPS route measurement is difficult to control, so it will affect the result of route measurement.
c) Since there are few measurement points in China, most of them are currently built more than 10 y after the founding of the People's Republic of China. However, after years of wind and sun and ecological destruction, the environment that the current measurement points can provide can no longer guarantee to provide high-quality measurement results.
d) Since the specific requirements of the cross-view are that the control points of the terrain are within 300 m and the natural geographical conditions of China, this condition cannot be met in a considerable range.
e) GPS has high requirements for measurement technology and short operation period. Therefore, it is necessary to complete the detailed division of labor and responsibilities before the operation, and synchronization of various points is required.

2.2. Analysis of the topography of the Qinghai-Tibet Plateau and the uplift and expansion mechanism

2.2.1. Topography analysis of Qinghai-Tibet Plateau

The three-dimensional topographic map of the Qinghai-Tibet Plateau is shown in Fig. 1.

The Qinghai-Tibet Plateau has an average elevation of 4,500 m and an area of more than 2.5 million km^2. The overall landscape is open and flat with a steep and tall periphery. The uplift of the plateau caused by plate movement

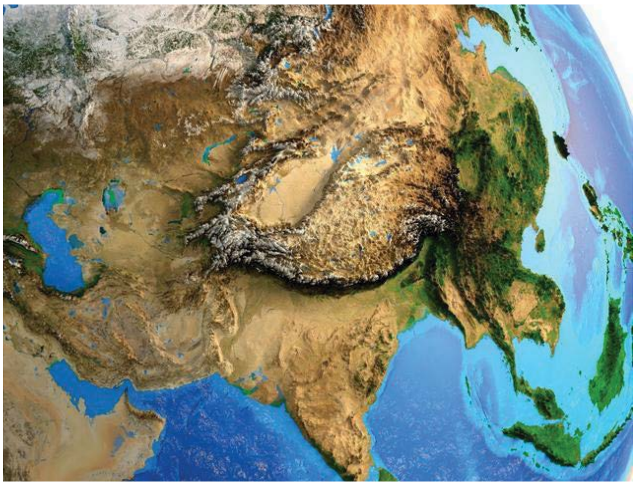

Fig. 1. Three-dimensional map of the Qinghai-Tibet Plateau.

has caused great changes to the geographical conditions here. A series of large east-west rifts develop in and around the Qinghai-Tibet Plateau, which can be used as a natural laboratory to study the structural deformation mode and uplift mechanism of the continental plate collision zone [10].

2.2.2. Uplift and expansion mechanism of the Qinghai-Tibet Plateau

Scientists around the world have produced a variety of different hypotheses and dozens of hypotheses about the formation of the Qinghai-Tibet Plateau, of which five are relatively mature.

a) The double-layer subduction model [11] shown in Fig. 2.

The model believes that during the formation of the Qinghai-Tibet Plateau, the northern Indian Ocean plate in the southern part and the Tarim plate in the northern part both undergo intracontinental subduction, which results in the uplift of the Tibetan Plateau.

b) Fig. 3 shows the lateral crustal compression model [12].

The hypothesis is that the Indian Ocean plate squeezes the lower part of the Himalayan plate, causing the soft material underneath to be crushed and spread everywhere.

c) Continental penetration theory [13]. The model believes that during the downward insertion of the Indian Ocean plate into the Qinghai-Tibet Plateau, the upper mantle of the Indian Ocean plate is subducted under the mantle of the plateau plate due to the action of the viscous lower crust of the Qinghai-Tibet Plateau, which makes the Qinghai-Tibet Plateau uplift.
d) Hypothesis of convective stripping of the mantle lithosphere [14]. The process is shown in Fig. 4.
e) Middle-lower crustal material flow theory [15]. This hypothesis believes that in the process of lateral compression and shortening, the soft material in the lower crust of the Qinghai-Tibet Plateau will disintegrate and separate the upper and lower crusts of the plate, thus causing the formation of ground uplifts. The mountain and the peeling phenomenon have created the current geomorphology.

2.3. GPS observations on the Qinghai-Tibet Plateau

2.3.1. Main errors of GPS geomorphology surveying and mapping and the methods of reducing errors

Table 1 shows the main errors of GPS geomorphology surveying and mapping and the methods of reducing errors.

In the past few decades, China has completed many large-scale GPS observations on the Qinghai-Tibet Plateau. Among them, 1,056 discontinuous GPS observation stations have been established, and most of the main observation points have been observed for 7 periods. Meanwhile, 13 continuous observation networks have been established on the Qinghai-Tibet Plateau.

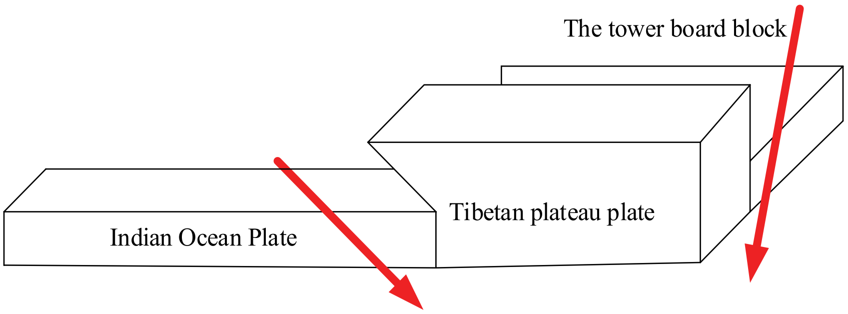

Fig. 2. Schematic diagram of double-layer subduction.

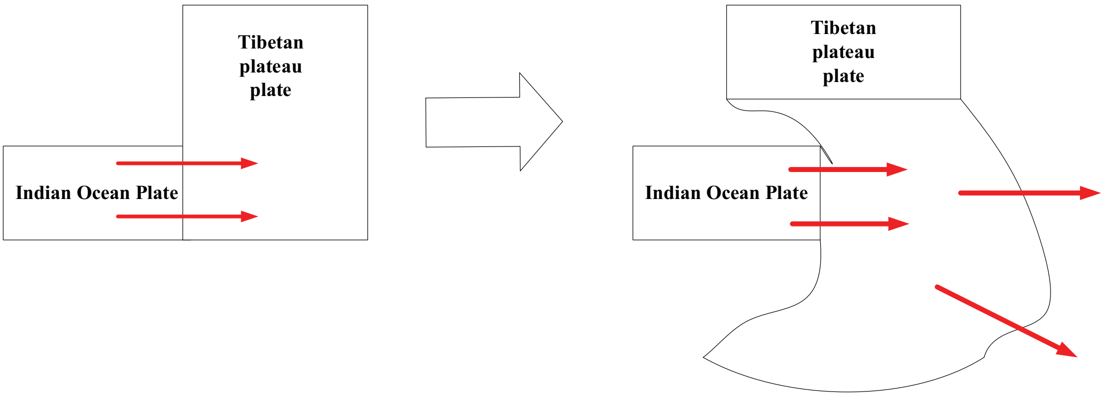

Fig. 3. Schematic diagram of lateral crustal compression.

2.3.2. GPS data processing strategy

Table 2 shows the specific data processing strategy.

After calculation, the parameter transformation is used to convert the single-day solution to the ITRF2008 framework. The 6 h global surface pressure field based on NCEP is set, the spatial resolution is set to 2.5°, and the Farrell function is applied to obtain the atmospheric load shape variable for parameter correction [16].

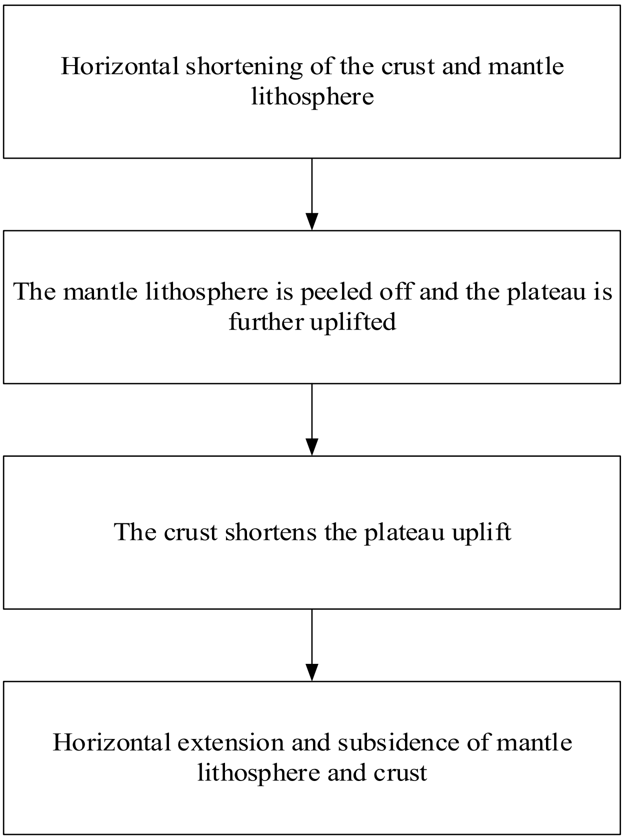

Fig. 4. The process of convection stripping theory.

2.3.3. GPS data processing flow

Although the software developed by various countries is different, the specific processing flow is basically the same. There are several links in Fig. 5.

2.4. GPS data processing method

a) GPS data pre-processing

GIPSY software is a GPS data post-processing software developed by NASA. Its calculation uses root-mean-square information filtering algorithm. The root-mean-square information filtering algorithm is a standard numerical stability optimization algorithm. It has a precise single-point positioning function, so it has high numerical stability, and because of its powerful algorithm, it can eliminate the time difference caused by the satellite, so it is widely used in the GPS data processing process. GPS data processing also includes the following several most commonly used methods. a. No benchmark algorithm. b. Related troposphere. c. Other methods: including tide model, troposphere model, reference time scale, observation interval, antenna phase center correction, satellite cut-off altitude angle, reference frame, gravity field model, and earth orientation parameters.

b) GIPSY data processing flow

The following is the specific process of GPS data processing: a. The existing IGS product parameters are queried. b. 124 core stations with good quality and distribution suitable for expectations are selected as subnets, and the required data of each website are obtained, and the single-day coordinate solution and single-day relaxation constraint solution of each point are calculated through the above model [17].

c) The data are obtained, the single-day slack constraint solution here is calculated, the data of all observing stations in the local network are processed, the single-day coordinates of each station are obtained and merged, and the single-day slack constraint solution here is obtained.

Table 1
The main errors of GPS geomorphology surveying and mapping and the methods of reducing errors

Type of errors	Cause of errors	Methods of reducing errors
Satellite orbit	Celestial gravity	Adjust the difference between stations and the calculation formula
Satellite time	Synchronization rate, theory of relativity	
Tropospheric refraction	Changes in tropospheric temperature and moisture affect electromagnetic wave transmission	Limit the altitude angle, adjust the difference between stations and the calculation formula
Ionospheric refraction	Interaction between the ionosphere and communication electromagnetic waves	Limit the altitude angle, adjust the difference and calculation formula between stations, and multi-satellite observation
Change of antenna position	Antenna geometric centers do not coincide	Calculate the difference between observations
Receiver time	Receiver's built-in clock is not accurate	Calculate the difference between satellites
Observation noise	Background radiation, artificial electromagnetic wave pollution	Choose the right venue

Table 2
Specific data processing strategy

Purpose	Set	Model/software used
Eliminate the linear combination of the plasma effect	Satellite altitude angle: 20° Data sampling rate: 300 s	VMF1
Correction of the impact of ocean tides	Green function online calculation	FES2004
Deviation timing and eliminate antenna position error		Choose a self-consistent model
Increased solution accuracy	Carry out the whole week ambiguity solution using fixed point method	Ambizap

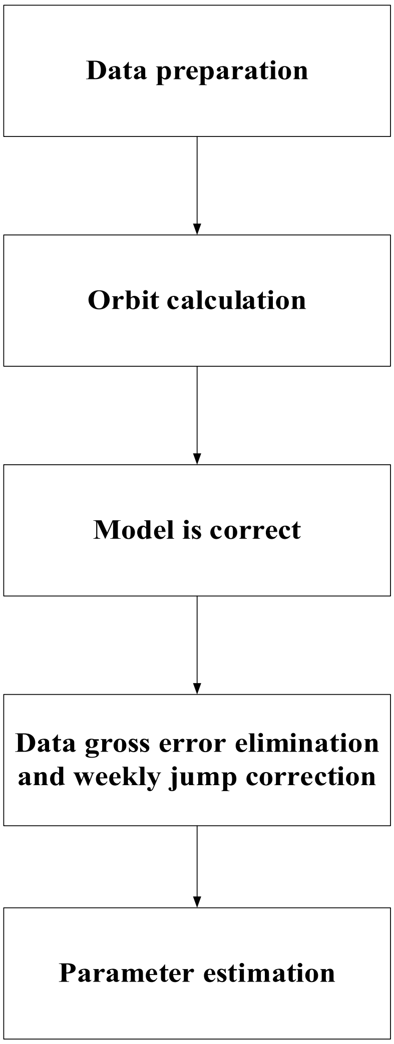

Fig. 5. GPS data processing flowchart.

d) The local phase ambiguity is solved to improve the accuracy of the solution.
e) The local and global single-day slack constraint solutions are merged, the Helmert parameters are converted, and they are merged and added to the ITRF2008 framework, and the baseline distance between any two stations can be calculated.
f) GPS data post-processing

The tool QOCA (quasi-observation combination analysis) software is used to estimate the best observation station coordinates, station speed, coseismic parameters, and gross errors in the observation data are checked and removed, and the station time series are automatically generated. The results obtained by this method need to be naturalized to form common parameters.

The QOCA process is mainly divided into the following steps: (a) The network file is generated. (b) The qob file is generated. (c) The qob files are merged. (d) Other auxiliary documents are prepared. (e) The qob input file is checked [18].

3. Geomorphology surveying and mapping of Qinghai-Tibet Plateau based on GPS

3.1. Horizontal deformation of Qinghai-Tibet Plateau based on GPS

Fig. 6 shows the horizontal rate graph of GPS.

In the collision direction between the Indian Ocean plate and the Eurasian plate, the GPS horizontal velocity from south to north has been decreasing, from 30 to 10 mm/a. The Qinghai-Tibet Plateau is located on the southernmost part of the Eurasian Plate. The velocity vectors on the east and west edges of the plateau are divergent, and the direction is away from the center. In the Pamir Plateau and Tarim Basin to the west, the movement rate drops to 20~25 mm/a, and the horizontal rate of moving northward into the Tianshan Mountains decreases to 10~29 mm/a. The velocity vector in the southeast gradually changes from N60°E to N160°E, and the GPS movement speed in the border zone of the northeastern part of the plateau is about 10 mm/a. The obvious areas of geomorphology deformation in the Qinghai-Tibet Plateau are mainly the following areas: a. For the Himalayas and tectonic structures, the areas where the Indian Ocean plate and the Eurasian plate collide are subject to strong compression and shortening. b. In the central and southern regions of the plateau, in the direction of the collision between the Indo-European plates, the compression shortening effect is significantly reduced, but the lateral stretching effect is significantly enhanced. This change is related to the underground north-south normal fault. c. The eastern part of the plateau is subject to significant north-south lateral stretching. The direction vector at the southeast corner of the plateau is dense and disordered, and the directional velocity is large. Therefore, the east-west diffusion and expansion and the north-south extrusion and compression are significant. d. The directional vector distribution in the northeastern part of the plateau is relatively uniform, so the deformation is relatively uniform [19–21].

3.2. Vertical deformation of the Qinghai-Tibet Plateau based on GPS

Table 3 shows the changes in topographic observations in specific regions.

The mountain range at the southern boundary of the plateau has an extremely significant uplift, and the Longmen Mountain in the east of the plateau has a strong uplift, which exceeds 2.5 mm/a, while the uplift on the other side is relatively small. The movement in the vertical direction of the Gongga Mountain and its nearby areas is strong, while it is weak in the southeastern border zone of the plateau, with a small uplift on the outside, and a small area in the central and southern part of the plateau is significantly affected by subsidence [22–24].

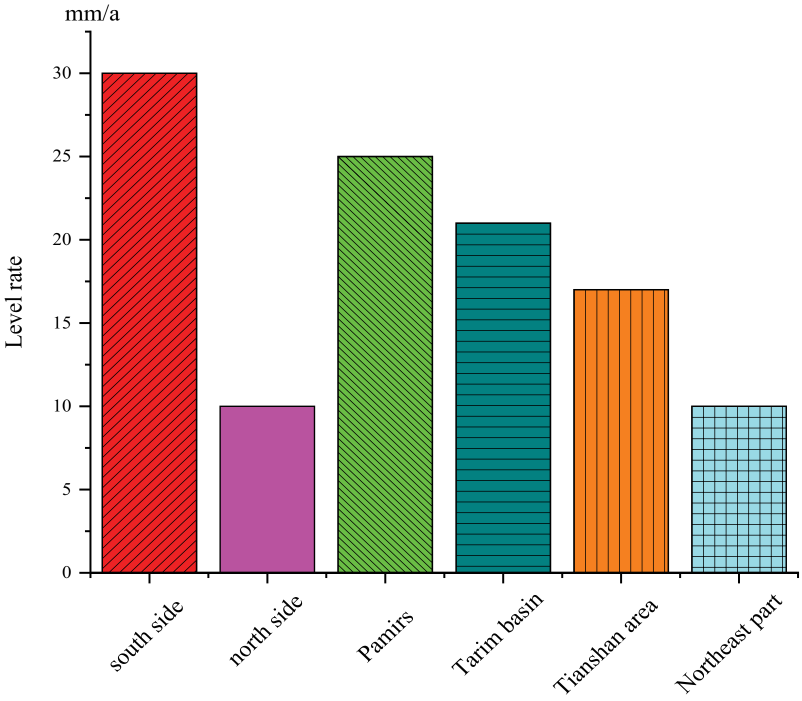

Fig. 6. The horizontal rate graph of GPS.

Table 3
Changes in topographic observations

Area		Observatory	Vertical deformation
East of the Qinghai-Tibet Plateau	Himalaya high altitude area	SRNK, DLPA	Uplift ≥2 mm/a
		CHLM	Uplift ≥3 mm/a
		YARE, J041	The change is not obvious
	From the southern slope of the Himalayas to the Ganges Plain	NPGJ, ODRE	Settlement ≤–3 mm/a
	From the northern slope of the Himalayas to the vicinity of the Yarlung Zangbo River		Uplift or settlement 0~2 mm/a
	Longmenshan area		Uplift ≥2.5 mm/a
	Gongga Mountain and its surrounding area	H066, H078	Uplift 2~3 mm/a
	Southeast edge of Qinghai-Tibet Plateau		Small uplift in the whole, small drop in local
Northeast of Qinghai-Tibet Plateau	Qilian Mountains to Liupanshan Mountains		Uplift significantly
	Ordos, Alxa area		Minor changes
	One side of the Qinghai-Tibet Plateau		2 mm/a
	Haiyuan and Liupanshan faults		Uplift ≥2 mm/a

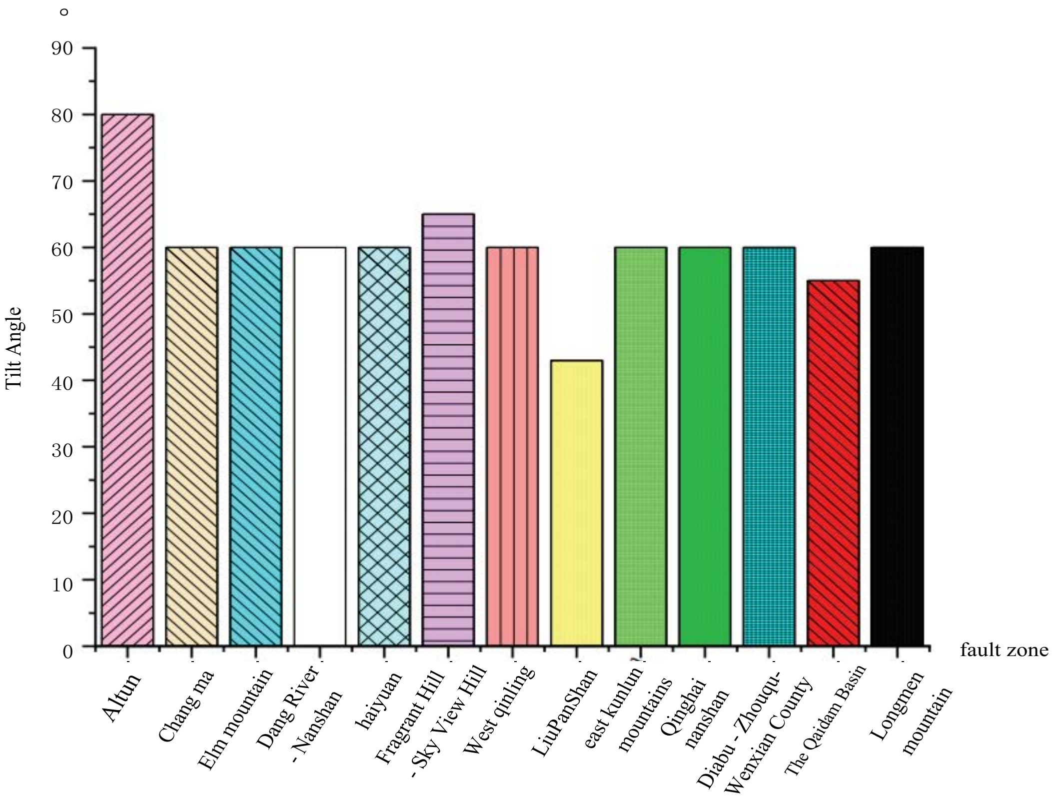

Fig. 7. The inclination angle of the main fault zones in the Qinghai-Tibet Plateau.

3.3. Main active fault zone

Fig. 7 shows the number of inclination angles of the main fault zones on the Qinghai-Tibet Plateau.

The main fault zones in the Qinghai-Tibet Plateau are as follows: (a) Altun fault zone, fault segment 5, incline SE, with an inclination angle of 80°. (b) Chang ma fault zone, fault segment 3, inclined to SSW, with an inclination angle of 60°. (c) Elm Mountain fault zone, fault segment 2, inclined to SSW, with an inclination angle of 60°. (d) Dang River-Nanshan fault zone, fault segment 3, inclined to SSW, with an inclination angle of 60°. (e). Haiyuan fault zone, fault segment 3, inclined to SSW, with an inclination angle of 60°. (f) Fragrant Hill-Sky View Hill fault zone, fault segment 4, incline S, with an inclination angle of 60°~70°. (g) West Qinling fault zone, fault segment 3, inclined to SSW, with an inclination angle of 60°. (h) Liupanshan fault zone, fault segment 3, inclined to SSW, with an inclination angle of 35°–50°. (i) East Kunlun fault zone, fault segment 4, incline S, with an inclination angle of 60°. (j) Diebu-Zhouqu-Wenxian fault zone, fault segment 2, inclined to SSW, with an inclination angle of 60°. (k) Riyueshan fault zone, fault segment 2, inclined to SSW, with an inclination angle of 60°. (l) Fault zone on the northern margin of the Qaidam Basin, fault segment 3, inclined to NNE, with an inclination angle of 60°. (m) Qinghai Nanshan fault zone, fault segment 2, inclined to SSW, with an inclination angle of 60°. (n) Mani-Yushu fault zone, fault segment 3, inclined to SSW, with an inclination angle of 50°–60°. (o) Longmen Mountain fault zone, fault segment 2, inclined to NWW, with an inclination angle of 60°.

The main features of geomorphological changes in the northeastern part of the Qinghai-Tibet Plateau are shortened crustal compression and clockwise rotation in the Haiyuan area, which indicates that the discontinuous fault dislocation deformation mode plays a decisive role in the internal structural deformation of the continent.

4. Conclusion

The geomorphology surveying and mapping of the Qinghai-Tibet Plateau based on the Global Positioning System is analyzed, GPS data of the Qinghai-Tibet Plateau and its surrounding areas are collected and processed, and the crustal deformation characteristics of this area are analyzed. Subsequently, the main fault zones of the Qinghai-Tibet Plateau and the current uplift speed and geomorphology are introduced. The final experiment proves that the geomorphology surveying and mapping of the Qinghai-Tibet Plateau based on the GPS is more effective for the geomorphology surveying and mapping of the Qinghai-Tibet Plateau, the main topography, and the analysis of crustal movement, and finally achieves the purpose of the geomorphology surveying and mapping of the Qinghai-Tibet Plateau.

Although the original expected research goals have been basically achieved, and some more valuable research conclusions have been obtained, due to limited academic literacy, there are still many deficiencies in the research work. The research conclusions may be limited by the following two factors: (1) The geomorphological surveying and mapping stations are limited, and most of them are relatively old. (2) Due to the needs of current social development, there is more interference in surveying and mapping. This also points out the direction for the future research. In the future, the work will mainly focus on the following two aspects: (1) Related departments are further coordinated, relevant research institutions in China and other countries are cooperated, and the number of available surveying and mapping stations is increased. (2) Geomorphology surveying and mapping based on GPS is often conducted on-site inspections and multiple passes, and different combinations of surveying and mapping stations are selected for research.

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