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THE SEISMOTECTONIC STRESS FIELD IN THE CHINESE CRATON

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Abstract

The seismotectonic conditions in China are determined by the fact that the Eurasian, the Indian, the Philippine and the pacific tectonic plates extend into its vicinity. The Pacific plate pushes from the NE, the Philippine plate from the SE and the Indian plate from the S into the Eurasian plate. The intraplate stresses in China are the continuation of the indicated rim stresses. Evidence for their orientation is based on the statistical assessment of in-situ measurements, earthquake fault plane solutions, valley trends and joint orientations. Inasmuch as the direction of the rim stresses is different in various sectors, their continuation into the plate interior must eventually lead to a stress discontinuity: This is the band of the N-S seismic zone at roughly 104°E longitude. Thus, the latter is seen to be a direct consequence of the plate tectonic conditions prevailing in the vicinity of China.

1. Introduction

Earthquakes are the result of the release of stresses in the lithosphere. Thus, seismic events are a direct response to the comportment of the neotectonic stress field. The present paper has as its aim the determination of this neotectonic stress field in the Chinese craton.

The present writers have previously collected available evidence in various partial regions of the Chinese craton regarding the orientation of the tectonic stresses therein. This was mostly done by perusing data available in the literature on in-situ measurements, on geodetic strain measurements and on fault plane solutions of earthquakes. In addition, the orientation structure of the drainage nets in various parts of China has been interpreted in terms of neotectonic stresses according to a method proposed by Scheidegger (1979a). Meanwhile, it has become possible to collect additional evidence in the field, which is based upon the interpretation of the orientations of joints in recent rock outcrops. This new evidence will be presented in this paper.

If all the evidence is taken together, a geotectonic model of the Chinese craton is indicated, in which it is supposed that the intraplate stresses in China are the continuation of the rim stresses caused by the collision of the Eurasian, the Philippine, the Pacific and the Indian lithospheric plates. The continuation of the rim stresses into the plate interior must of necessity lead to a stress-discontinuity. This is the well-known N-S seismic zone at 104°E longitude. Thus, the latter is seen to be a consequence of the plate-tectonic conditions prevailing in the vicinity of the Chinese craton.

2. General tectonic conditions

Up until recently, the tectonic pattern of the Chinese craton has generally been interpreted in terms of blockfaulting (cf., e.g. Chang, 1961). Thus, depressed and elevated areas, separated by deep-seated fault zones, have been delineated. A typical example of this type of tectonic interpretation is shown in Fig. 1; its style corresponds very much to the view of geotectonics propagated by Belousov (1980).

One of the most prominent "deep seated faults" shown in Figure 1 is represented by the zone formed by the mountain chains of the Hengduan Shan, Longmen Shan, Liupan Shan and Helan Shan. This zone is characterized by a pronounced seismicity. Thus, it is in this zone that the severe earthquakes e.g. of 16 December 1920 near Jingtai (M=8.5), of 25 August 1933 near Diexi (M=7.5), of 5 January 1970 near Tunghai (M=7.7) and of 6 March 1973 near Luhuo (M=7.9) occurred. Inasmuch as this zone straddles more or less the 104°E-meridian, it has become known as the "140°N-S seismic zone of China" (Wang et al., 1976).

However, the interpretation of geotectonics in terms of block movments separated by deep-seated faults has recently fallen out of favor. It is much more likely that the tectonic features are the results of the movements of lithospheric plates. It is commonly assumed that four "plates" collide in the vicinity of the Chinese craton: The Eurasian plate to the north, the Indian plate to the SSW, the Philippine plate to the ESE and the Pacific plate to the ENE (Ai and Scheidegger, 1983). In such a scheme, the 104°-seismic zone would represent a geometrically necessary discontinuity in the neotectonic stress field (Fig. 2).

In the present paper, we shall adduce further evidence corroborating the model proposed in Fig. 2.

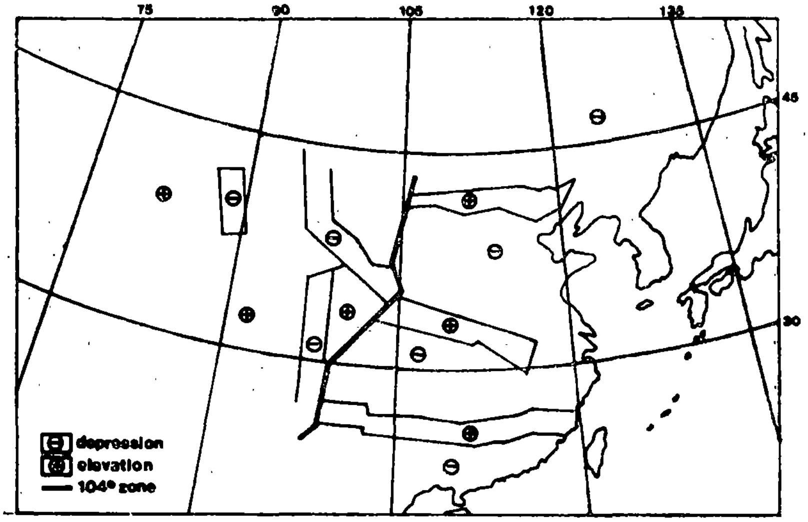


Fig. 1 Interpretation of the tectonics of the Chinese craton in terms of block faulting (schematically after Chang, 1961).

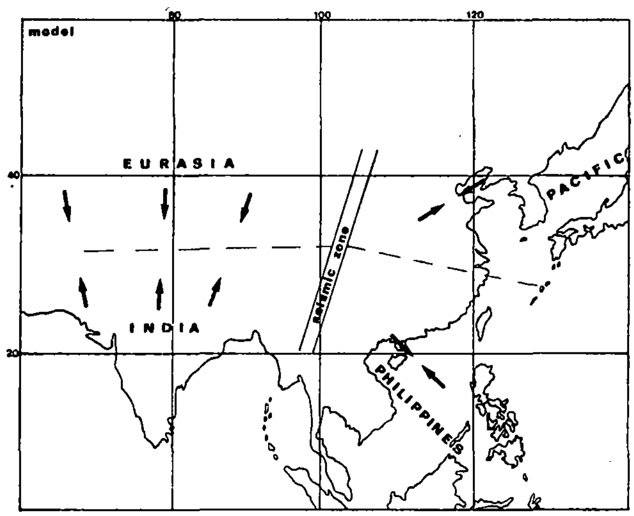


Fig. 2 Plate-tectonic model of the Chinese craton.

3.Summary of previous data

Data for the corroboration of the stress model outlined in Fig. 2 have been collected previously by the writers. These will now be reviewed briefly.

The available data that can be used for the indicated purpose stem

(I) from fault plane solutions of earthquakes, (II) from in-situ stress measurements, (III) from the analysis of the orientation structure of hydrographic nets and (IV) from geodetic strain measurements. Individual studies have been made by the present writers for various partial areas of the Chinese craton, such as for Tibet (Ai and Scheidegger, 1981), Shanxi, Gansu, Ningxia and Qinghai (Ai et al. 1981), South-East China (Ai et al. 1982) and North China (Ai and Scheidegger, 1983). The areas covered in the individual papers straddle the "natural" regions implied in the scheme presented in Fig. 2. Thus, results pertinent e.g. to the 104°-seismic zone are contained in different papers (Ai et al., 1981, 1982).

We have collected the numerical results from the papers mentioned above once more and have listed them in Table 1. These values are averages for the azimuth of the maximum-compression direction obtained by the methods outlined above. In Fig. 3, these directions have been plotted on a geographic map.

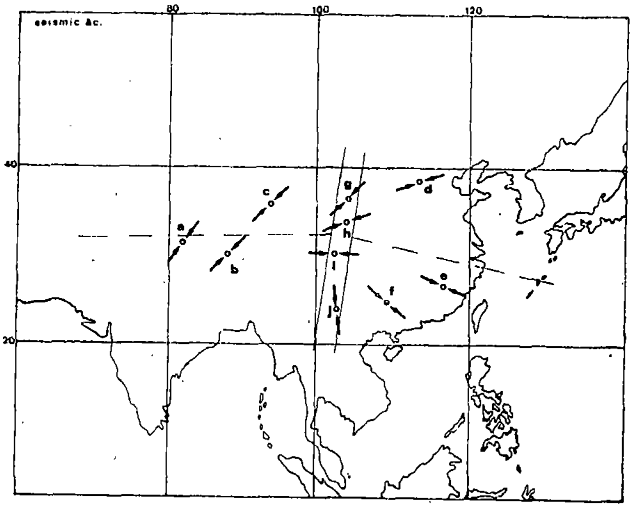


Fig. 3 Direction of maximum compression in various parts of the Chinese craton as determined from seismic, geodetic, geomorphic and in-situ data. The letters refer to the regions indicated in Table 1.

In order to arrive at a useful plate-tectonic interpretation, the above values have been grouped into "natural" groups as they pertain to the influence regions of the four colliding plates. The resulting averages have also been listed in Table 1; the corresponding directions have been plotted in Fig. 4. It is seen that the basic tectonic model proposed in Fig. 2 is corroborated by these results.

Table. 1

Azimuths of maximum-compression directions in various regions of the Chinese craton, as determined previously from seismic, geodetic, geomorphic and in-situ data.

Region	P-azimuth	Group	Av. P-azimuth
a. West Tibet	33		
b. East Tibet	42	A	40
c. Qinghai	45		
d. North China	71	B	71
e. South-East (E)	111	C	121
f. South-East (W)	131		
g. 104°-zone (N)	45		
h. do. (middle-N)	71	D	indef.
i. do. (middle-S)	93		
j. do. (South)	175		

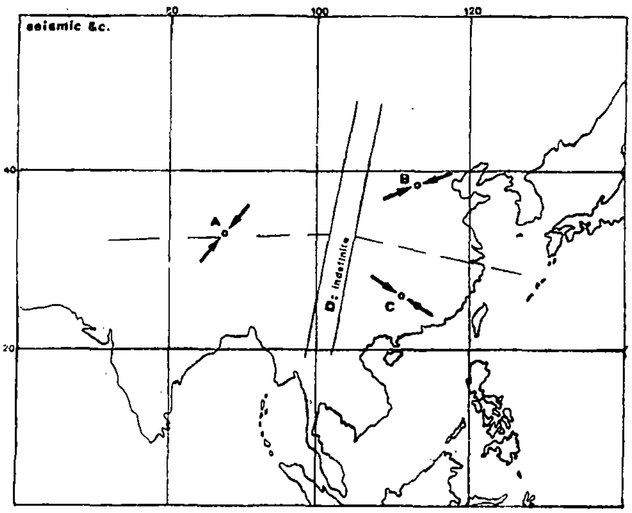
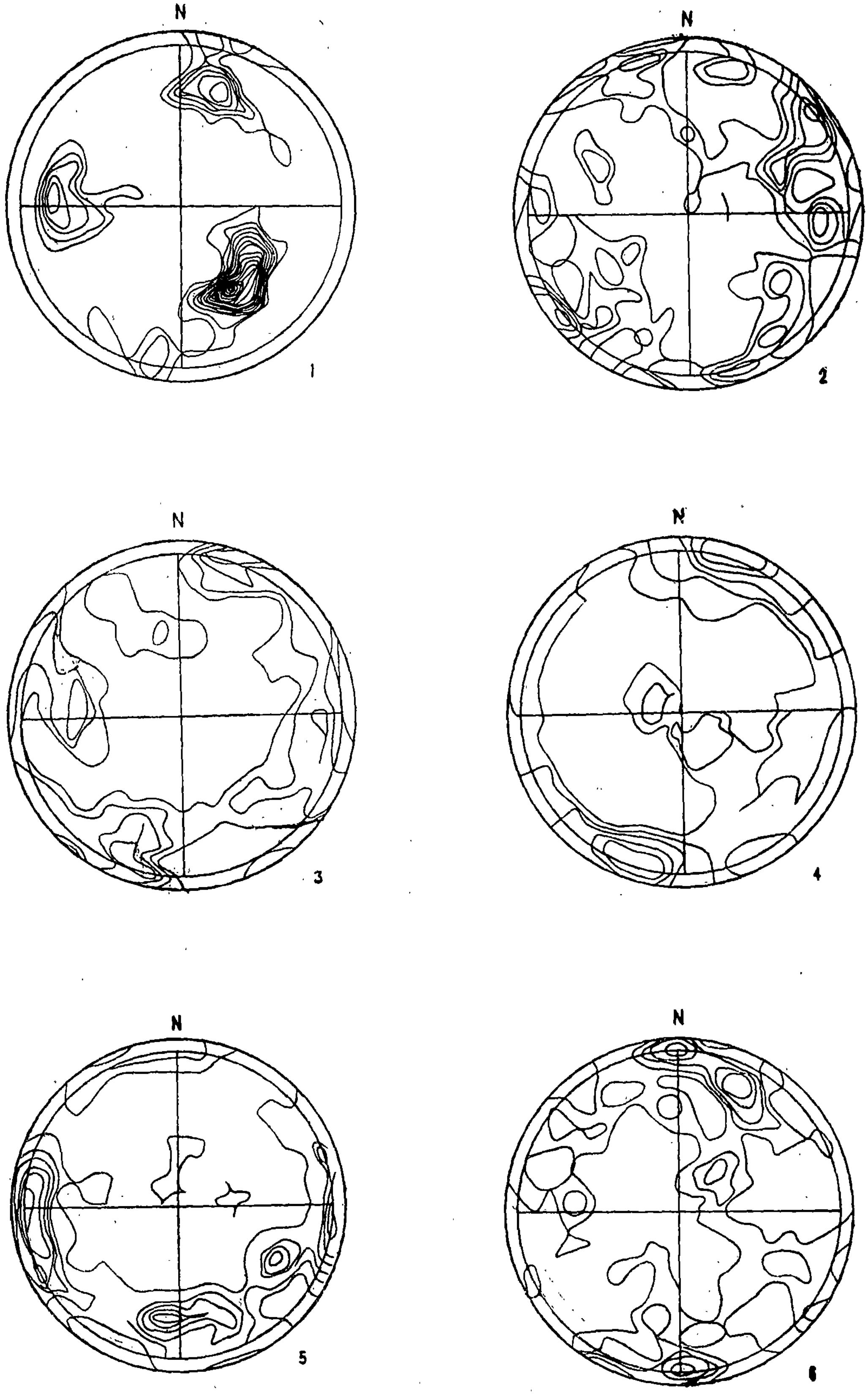


Fig. 4 Direction of maximum compression as determined from seismic, geodetic, geomorphic and in-situ data in the "natural" regions of the Chinese craton. The letters refer to the regions indicated in Table. 1.

Table. 2 Joints in the Chinese Craton

Location	Group	№.	Max. 1	Max. 2	Angle	P	T
1. Source Urumchi River	W	120	198±14/72±14	94±10/61±09	87	329/35	234/07
2. Dunhuang	W	126	156±13/84±14	245±18/79±18	88	111/03	20/12
3. Tacheng, Xinjang	W	28	26±25/81±23	106±40/89±33	80	156/6	246/7
4. Hetian-Yecheng, Xinjang	W	24	indef.				
5. Jiuqan, Gansu	W	52	277±19/86±18	358±16/65±13	81	231/16	138/18
6. Chaidamu	W	58	182±22/82±20	indef.			
7. Long Yang Xia Pass	104	27	235±25/51±20	45±10/54±09	75	154/84	50/02
8. Jingtai	104	118	186±16/78±15	110±16/89±12	76	59/09	328/08
9. Lanzhou	104	210	273±14/90±10	350±13/77±11	76	222/10	131/08
10. Min Jiang Valley	104	44	127±11/86±09	42±32/85±24	84	174/00	264/06
11. Kangding-Gongga Shan	104	76	indef.				
12. Daocheng	104	25	173±09/37±12	15±21/36±13	72	184/01	278/82
13. Haiyuan	104	89	indef.				
14. Tongxin, Ninxia	104	15	277±18/86±14	indef.			
15. Peking	N	113	0±14/82±11	92±09/89±07	88	226/06	136/05
16. Nanjing	S	24	274±24/80±23	191±16/63±15	79	319/13	55/24
17. Hong Kong-Macao	S	78	261±13/84±11	169±10/87±09	88	35/07	125/03
18. Chongqing	S	42	85±19/84±16	170±14/88±12	84	217/3	308/5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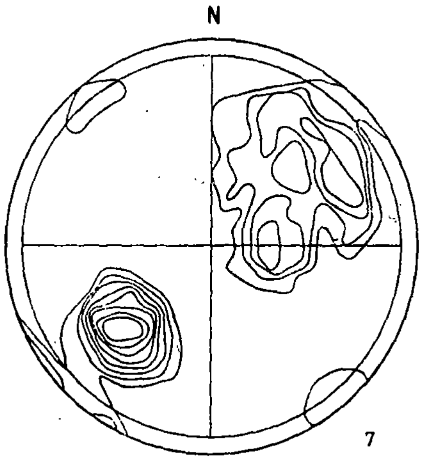

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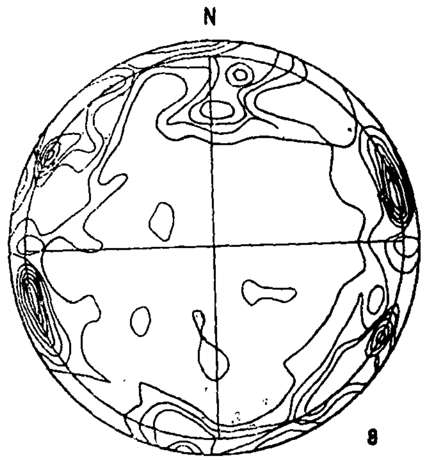

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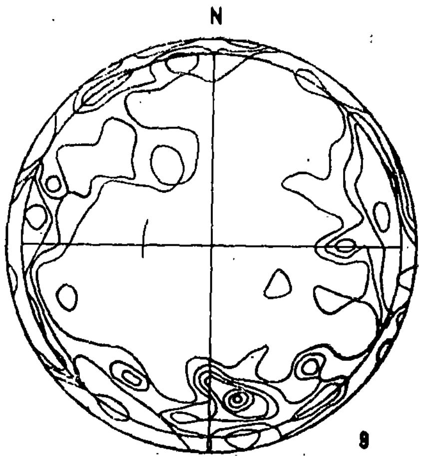

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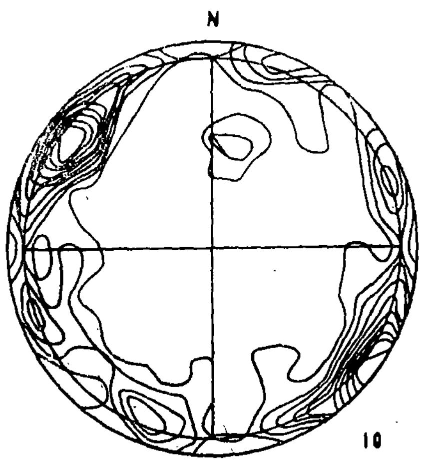

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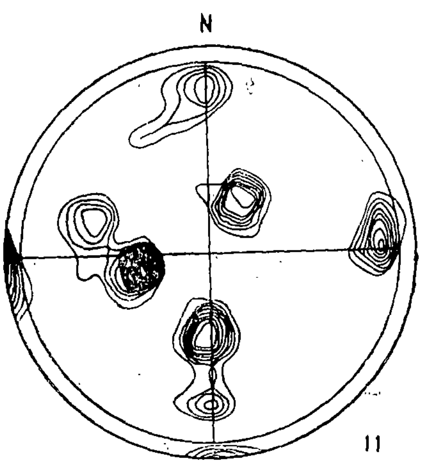

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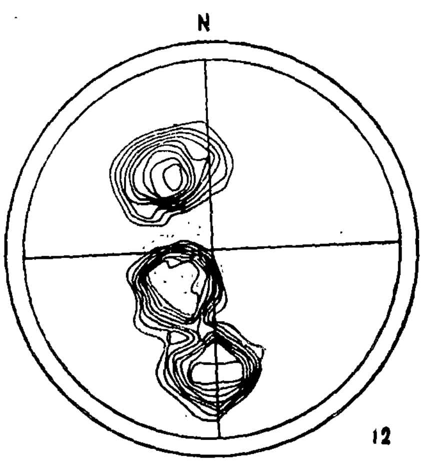

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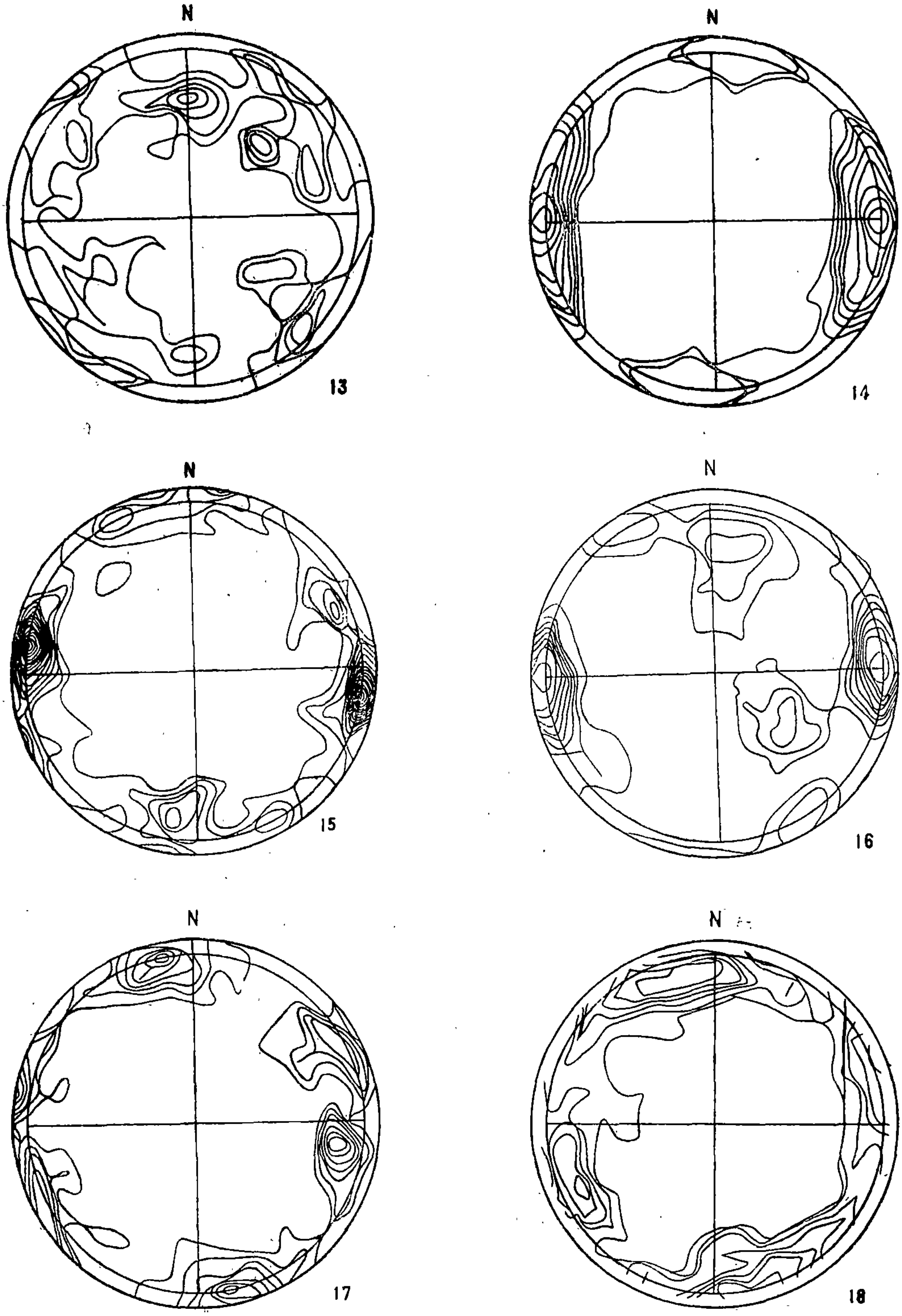

Fig. 5 Pole density diagrams for 18 regions of the Chinese craton. The numerals on the individual diagrams correspond to those in the descriptions of the locations in the text and to those in Table 2 and Figure 6.

4.Joint orientations

a.General Remarks

The orientation of joints visible everywhere in rock outcrops has been generally taken as representing a response to the orientation of the principal neotectonic stress directions: Joints appear to be shearing-phenomena of some sort; they occur in steeply dipping conjugate sets (in addition to a more or less horizontal set which is obviously lithologically conditioned) so that the maximum compression bisects the smaller quadrant(Scheidegger, 1979). Upon this basis, it is possible to deduce the neotectonic stress directions from measurements of joint-orientations.In order to do this, a statistical procedure has to be applied because, naturally, individual joint orientations scatter considerably in an outcrop.Thus,the preferred orientations are found by fitting two theoretical distributions of Dimroth-Watson type to the field data and determining the "best" parameters hereof by a function-minimization procedure.The algorithm has been described by Kohlbeck and Scheidegger (1977).In carrying out the procedure, it is often found that the angle between "preferred" joint-sets at an outcrop (a group of outcrops) is close to 90°, so that the smaller quadrant cannot always be identified with certainty. This can leave an ambiguity as to which of the two principal stress directions found is that of the maximum and which that of the minimum compression.

For the presentation of the results, joints are generally defined by giving their dip direction (azimuth N-E) and dip angle (angle with the horizontal).In drawings, joints are represented by plotting their poles on a unit sphere, the latter being represented in an equal area projection, so that poledensity lines can be constructed.The visualization is enhanced if a 10°-overlap of the lower half of the unit sphere is shown.In the tables which present the results of the statistical evaluations, we list the location of the measurements, the two best-fitting joint-sets with errors(90%-confidence intervals), the angle between them, and the direction of the maximum (P, $\sigma 1$) and minimum (T, $\sigma 3$) compression (azimuth N-E of downward plunge and plunge angle with the horizontal).

The data used in this paper have been collected all over China by the writers as well as by many of their collegues.A summary of the statistical evaluations,perusing the above indicated scheme as presentation, is given in Table 2.The poledensity diagramms are given in Fig. 5.

b.Individual Regions

(1) Source of Urumchi River

In this remots region of Xinjiang (Sinkjiang) province, some 120 joint orientations were measured.

(2) Dunhuang

Measurements of 126 joint orientations were taken in the Cave country of Gansu.

(3) Tacheng, Xinjiang

In this area, 28 joint measurements were supplied.

(4) Hetian-Yecheng, Xinjiang.

In this area, 24 joint measurements were supplied.

(5) Jiuqaun, Gansu

In this area at the Province of Gansu, 52 joint orientations were available.

(6) Chaidamu

A further set of 58 joint orientation measurements was available from Chaidamu in the center of Qinghai.

(7) Long Yang Xia Pass

Here, near a power development in Qinghai, 27 joint orientations were measured.The joints show the unusual feature that the two preferred conjugate sets have almost the same strike bus dip in opposite directions.

(8) Jingtai

During an inspection trip of the damage still visible caused by the 1920-earthquake, 118 joint orientations were measured.

(9) Lanzhou region

In this area, two sets of joint-orientation measurements were taken. The first was near Yuzhong, the second during an outing to the Liu Jia Xia power station.At the latter, the rocks were mainly precambrian granites

(10) Min Jiang Valley

Two outcrops in the Min Jiang valley were visited during a study tour in September 1982 undertaken to view the effects of the 1933 Diexi earthquake.The rocks were Paleozoic metamorphic schists.

(11) Kangding-Gongga Shan

Further to the West in Sichuan, joint measurements were supplied to us from the limestone region of Kangding and the granite of the Gongga Shan.The joint-orientations turned out to be nearly random; no preferred orientation-sets could be discerned.

(12) Daocheng

Further to the South, another set of orientation was abtained from metagranites near Daocheng.The two definable preferred joint sets do not dip steeply, but have a strike in the same direction with opposite intermediate dips.

(13) Haiyuan

Passing now to the East of the 140°-seismic zone, we note the 99 joint orientations near Haiyuan in the Ningxia Autonomous Region. There exist no preferred joint-orientations.

(14) Tongxin, Ningxia

A small number of joint orientation measurements (15) was also available from this area.

(15) Peking (Beijing)

In this region, three sets of outcrops were visited: near Tahuichang on the Babao Shan fault, near Peking Man's cave and in Xiang Shan Park. The rocks ranged from Ordovician to Jurassic limestone.

(16) Nanjing (Nanking)

A few joints were also measured near the city of Nanjing.

(17) Hong Kong and Macao

Finally, joints were also measured in the Jurassic volcanic and granitic rocks around Hong Kong and Macao, during a sojourn there.

(18) Chongqing

Finally 42 joint measurements were available from Chonqing.

c. Interpretation

In order to assess the significance of the joint orientation measurements, we have plotted the preferred strike directions for the individual locations mentioned above at their respective positions on a map (Fig. 6).

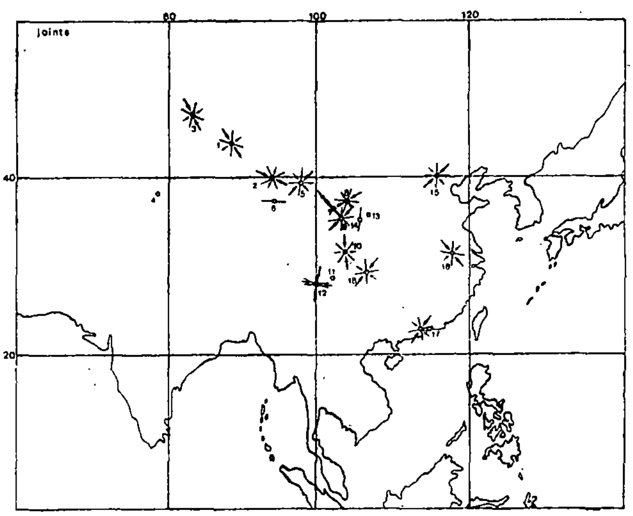

Fig. 6 Preferred joint strikes and principal stress directions deduced therefrom for 18 locations on the Chinese craton. The numbers on the map correspond to those of the descriptions given in the text.

The corresponding principal stress directions are also shown (arrows), as they were calculated by the computer-routine of Kohlbeck and Scheidegger (1977). The maximum-pressure direction (variously denoted by P or σ_1) is defined as that principal stress direction which is contained in the smaller quadrant. However, as noted above, this quadrant often cannot be reliably identified so that the identification of P (σ_1) and T (σ_3) is often also not certain.

In connection with the view that four litospheric plates are involved in the tectonics of the Chinese craton, it would appear as meaningful to group the areas, in which joint orientations were measured, into corresponding regions. As such regions, one preferably chooses the same ones as those used previously in Sec. 3 when the plate tectonics of the Chinese craton was discussed, viz.:

(A) The area West of the 104°-zone where one would expect a NNE--SSW compression. The area comprises the regions 1—6 above.

(B) The northeastern part of China (region 15 above) which is under the influence of the Pacific plate and thus subject to a NE-SW compression.

(C) The southeastern part of the Chinese craton (regions 16—18) which is under the influence of the Philippine plate and thus subject to a SE-NW compression.

(D) The 104°E N-S seismic zone (regions 7—14), which represents a singular region.

An inspection of the map in Fig. 6 and of the results in Table 2 shows indeed that the preferred orientations of the joints in the areas 1—18 are in conformity with the stress pattern expected in the various areas. The plate tectonic model implied in Fig. 2 is, thus, supported by the orientation of joints observed in the field. One can test this statement further by calculating the preferred orientations for all the joints measured in the groups of regions designated above by A, B, C and D. The results of such a calculation are given in Table 3; they have been plotted on a geographic map in Fig. 7. The corresponcing poledensity diagrams are shown in Fig. 8.

Table. 3 Joints in Groups of Regions

Group	№.	Max. 1	Max. 2	Angle	P	T
A. West China (1—6)	408	220±29/88±15	317±08/53±06	86	83/28	185/22
B. North China (15)	113	92± 9/89±07	000±14/82±11	88	226/6	136/5
C. South China (16—17—18)	144	264±10/86±9	170± 9/86±8	86	37/06	127/00
D. 104°-Zone (7—14)	614	352±21/90±12	94±16/89±9	78	223/1	313/1

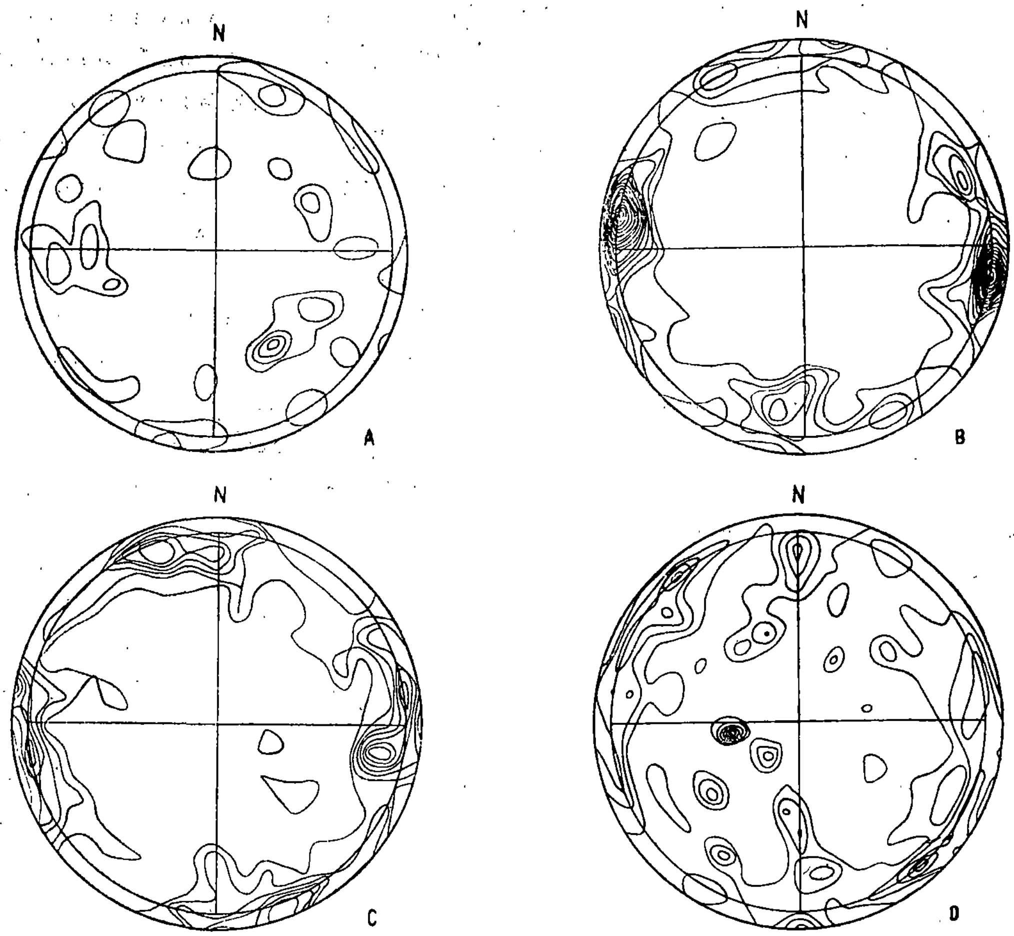

Fig. 7 Preferred joint strikes and principal stress directions deduced therefrom for the four regional groups of locations. The letters refer to the groups listed in Table 3 and in the text.

5. Discussion

An inspection of the maps given in the Figures 2, 4 and 7 shows the general correspondence of the field results with the proposed plate-tectonic model of the Chinese craton.

The results obtained from an interpretation of joint orientations agree with those obtained from the other sources indicated (earthquakes, geodesy etc.). True, formally the computer gives the result that the principal stress direction in the South (Region C) with an azimuth of N 127°E is the minimum rather than the maximum compression, but it should be noted that the angle between conjugate joint sets is 87°. Since the error is given as ±10° for each set, the smaller quadrant (which defines the compression) cannot be reliably identified. The interpretation of the 127°-direction as the actual compression, as indicated by the seismic etc. results, is therefore certainly permissible.

With the above proviso, the new results from the field observations of joint orientations are completely in agreement with the plate tectonic model shown in Fig. 2. In the 140°-seismic zone, the stress directions are not defined from the joint orientations, which confirms the supposition that this seismic zone is a singular region caused by the continuation of the rim stresses into the craton.

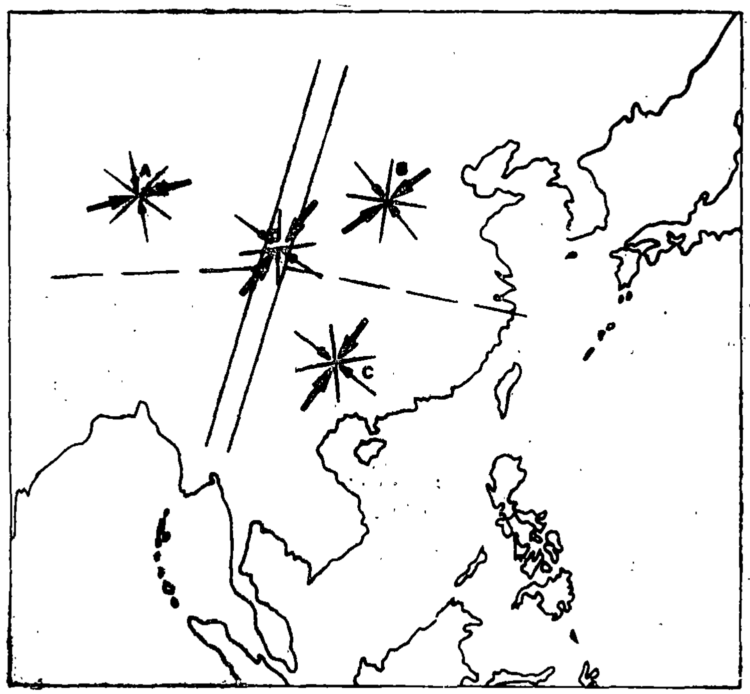

Fig. 8 Pole density diagrams for the joints belonging to the regional groups mentioned in the text. The letters on each diagram refer to the individual groups.

Acknowledgments

It is a pleasant duty for the writers to thank the many colleagues and friends who have supplied them with measurements of joint-orientations from all over China. Additional measurements were taken during a stay of A.E.S. in China under the auspices of the Austrian-Chinese cultural treaty, during which also the lay-out of the paper could be planned. The calculations were performed at the Computing Center of the Technical University of Vienna whose support is gratefully acknowledged.

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中国地块的地震应力场

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摘　　要

印度板块往北，菲律宾板块往北西，太平洋板块往南西与欧亚板块碰撞的格局是中国地震构造的决定性因素。根据实地应力测量、地震断层面解、河谷走向和节理产状等不同资料，计算出了由于板块相互作用所形成应力场的方向。计算结果表明：上述板块的碰撞形成了中国境内板内的三大地震构造区，即西部区、华北区、东南区。区内应力是连续的。由于不同区内应力方向有显著不同，这种应力的连续性就必然导致了在其结合部出现应力的不连续，这就是大致沿N40°E的南北地震带。所以南北地震带的出现可能是中国及邻近地区诸板块相互作用的结果。