14

Spatio-Temporal Changes in Stress Field and Occurrence of the 2003 Tokachi Oki Earthquake in Hokkaido, Northern Japan

Subesh Ghimire and Yuichiro Tanioka
Institute of Seismology and Volcanology, Hokkaido University,Sapporo Japan

1. Introduction

From the historical times, many large subduction earthquakes with magnitude 8 or more have been rupturing different segments of the Kurile and Japan trenches in Hokkaido, northern Japan. The most recent recurrent earthquake in this region is the 2003 Tokachi Oki earthquake with magnitude M=8.0 that ruptured about 100km long fault segment (Yamanaka and Kikuchi, 2003) in the Kurile subduction zone.

As shown in Fig. 1, in this region the Pacific plate subducts beneath the Okhotsk plate along the Kurile and Japan trenches at a rate of 8-10cm per year (DeMets, 1992). The tectonics in this region is complicated by the collision of Kurile and Japan arcs along the Hidaka Collision Zone, HCZ in Fig. 1 (Seno, 1985; Moriya, 1986; Tsumura et al., 1999) where the subducted Pacific slab exhibits bulging or distortion (Kanamori, 1971, Hashimoto, 1984, Moriya, 1986).

Apparent complexity in seismotectonics in Hokkaido region can not be explained by simple models of downdip compression or downdip extension (Isacks and Molnar, 1971, Astiz et al., 1988) based on the relative positions of the P- and T-axes (pressure and tension axes from earthquake focal mechanism solution) with respect to the geometry of subducting slab. The P- and T-axes may not represent the exact direction of the principal stresses because of two reasons: (i) an earthquake might be a result of slip on a preexisting fault plane with frictional strength far below than the intact rock mass, and (ii) even if an earthquake is resulted from the shear failure of intact rock mass, the frictional criteria (Byrlee, 1978; Sibson, 1994) would lead to a deviation up to ±20^{o} of the principal stress directions from the P- and T-axes (McKenzie, 1969).

Christova and Tsapanos (2000) based on inversion of focal mechanism data determined the stress conditions at different depths in Hokkaido region. Ghimire and Kasahara (2009) identified many seismotectonic zones with different stress conditions in this region. Ghimire et al. (2005) explored the temporal variation in this region after the occurrence of the 2003 Tokachi Oki earthquake.

In this paper, we first review the distribution of stress in Hokkaido region both spatially and temporally and then discuss the implications of the stress conditions on ongoing seismic activities.

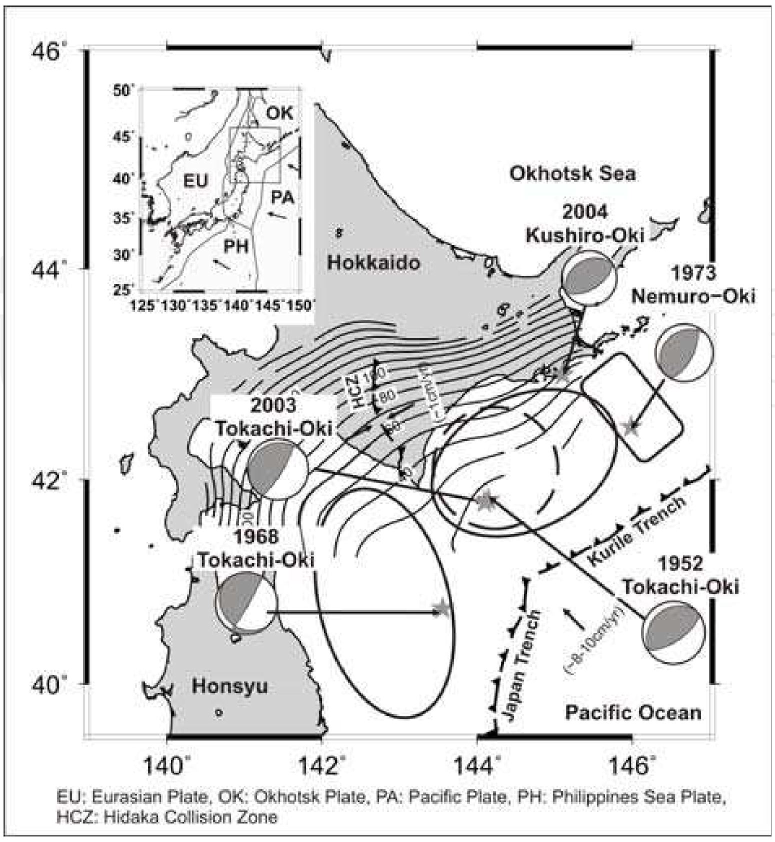


Fig. 1. Seismotectonics in the Hokkaido region. The inset map illustrates the regional tectonics. The beach balls represent the large subduction earthquakes with their rupture areas represented by closed ellipses and rectangles. The rupture area of the 2003 Tokachi Oki earthquake is represented by the dashed ellipse. The labeled contour lines represent depth to the subducted Pacific slab (in km) adopted from Katsumata et al. (2003)

2. Spatial variation in stress conditions

Fig. 2 illustrates different zones in the Hokkaido subduction zone characterized by unique seismotectonics as discussed by Ghimire and Kasahara (2009). In the Hokkaido region the subduction zone can be divided into Kurile and Japan arcs (by line AB in Fig. 2). In Kurile arc, based on the statistical characteristics of the focal mechanism data four seismotectonic zones are identified. Among them zones K1 and K3 spatially covers the rupture areas of the 1973 Nemuro Oki earthquake and the 2003 Tokachi Oki earthquake respectively. Region K4 is associated with the Hidaka collision zone and region K2 covers the shallow part of the subducted Pacific slab (Ghimire and Kasahara, 2009). Similarly, in the Japan arc section regions J2 and J3 covers the rupture area of the 1968 Tokachi Oki earthquake and region J1 covers the shallow part of the subducted Pacific slab adjacent to the Japan trench.

Statistics of P- and T- axes in each zone is illustrated in stereograms of lower hemispheric projection in Fig. 2. In each inset the P- and T- axes are plotted as gray colored solid circles and inverted triangle, the geometry of the subducted Pacific slab is plotted as the thick gray colored great circle, and the mean P- and T- axes are represented by dark solid circle and solid inverted triangle with 95% confidence cone as solid lines. The mean orientation of the P- and T- axes (Table 1) are used as the a-priori maximum and minimum principal stress direction in the initial stage of stress tensor inversion in each seismotectonic zone (Ghimire and Kasahara, 2009).

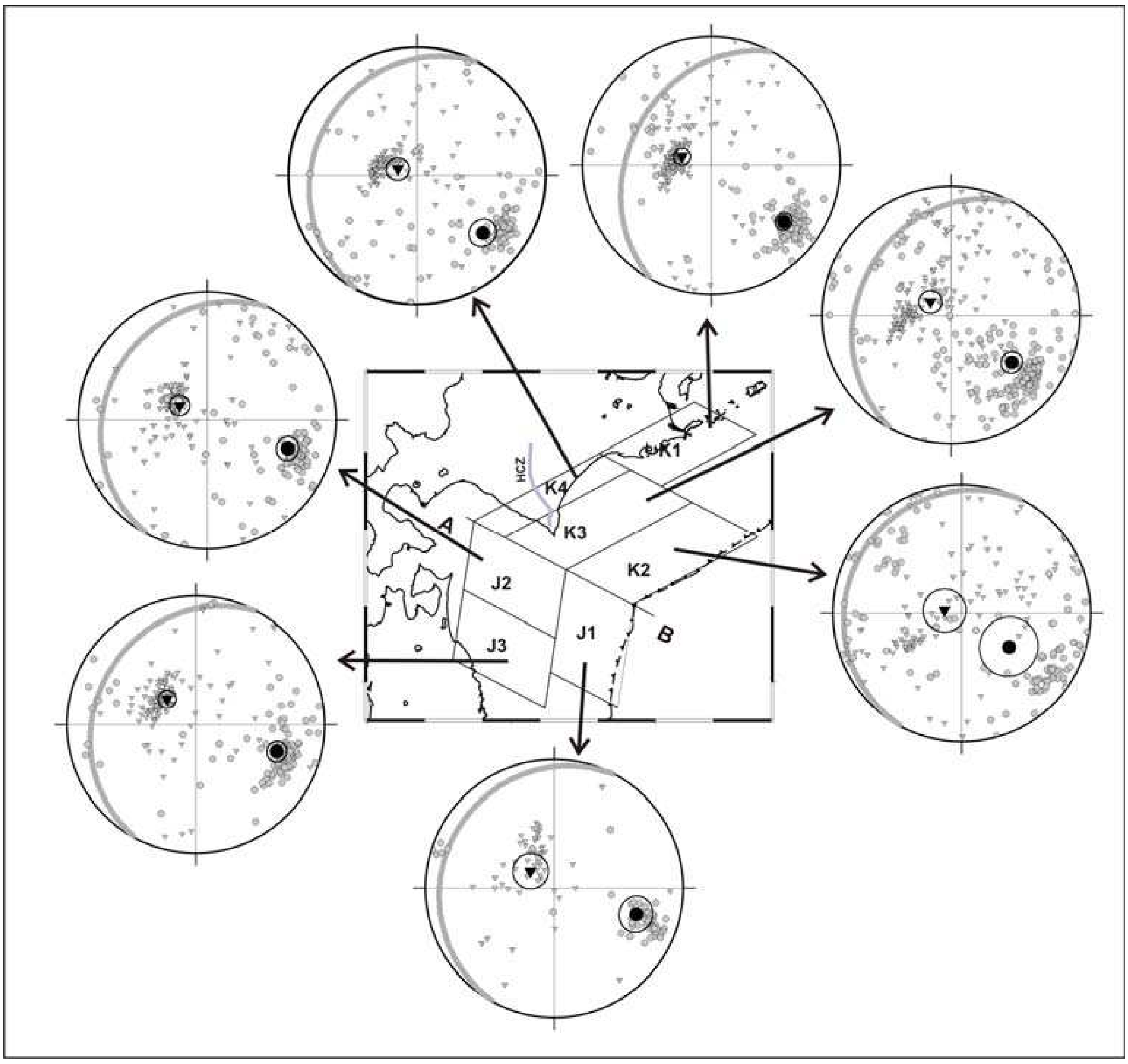


Fig. 2. Statistics of P- and T-axes in different seismotectonic zones

Stress condition in each of these seismotectonic zones is inferred from the focal mechanism data from 1976 to 2007 (Ghimire and Kasahara, 2009). To remove the impact of the 2003 Tokachi Oki earthquake in the stress field, aftershock data were removed from the dataset used in inversion. At the first stage the approximate method of stress tensor inversion (Gephart, 1990) was used with mean orientations of P- and T-axes as the a priori maximum and minimum principal stress direction respectively. After determining consistent stress tensors from the approximate method with a coarse grid search (10^o spacing in stress orientation) the exact method of inversion (Gephart, 1990) was used supplying these results as a priori with a dense grid search (of 5^o) within a narrow zone. The results of stress inversion are shown in Table 2.

The inversion from focal mechanism data estimates four parameters defining the stress conditions of the area: orientations of three principal stress directions s_1, s_2, s_3 (s_1,$\geq s_2 \geq s_3$) and a parameter defining the relative size of the intermediate principal stress with respect to the maximum principal stress and minimum principal stress. This parameter widely denoted by R in literatures is defined as: $R=(s_1-s_2)/(s_1-s_3)$ such that $1 \geq R \geq 0$ (Gephart and Forsyth, 1984). The value of R together with the geometry of the stress tensor (i.e. the orientation of the three principal stress directions) provides important insights on the state of stress in a region of interest (e.g., Ritz and Tabaoda, 1993; Bellier and Zoback, 1995; Bellier et al., 1997) presuming that the stress field in the area is homogenous (McKenzie, 1969; Gephart and Forsyth, 1984).

Seismotectonic Zones	No. of Data	Mean P-axis (Trend/Plunge in degree)	Mean T-axis (Trend/Plunge in degree)
K1	186	129/30	289/72
K2	134	127/51	261/76
K3	349	128/40	297/76
K4	142	129/33	289/78
J1	64	108/34	304/71
J2	167	109/35	292/71
J3	138	109/34	312/66

Table 1. Statistics of P- and T-axis in different seismotectonic zones

In Fig. 3 the geometry of stress tensors in each seismotectonic zones are plotted in stereograms of lower hemispheric projection (left panels in each figure) with the 95% confidence region (areas closed by dotted lines) for each principal stress direction obtained from the inversion. Stress conditions in each zone are shown in terms of Mohr diagram based on the R-values obtained from the inversion (right panels in each figure).

Seismotectonic Zones	A priori values of principal stress axes (trend/plunge in degree) obtained from the approximate method			Final results			
				Principal stress axes (trend/plunge in degree)			R
	s_1	s_3	Variance	s_1	s_2	s_3	
K1	285/25	163/48	10	282/6	14/22	178/67	0.9
K2	175/34	55/67	15	138/13	235/25	23/61	0.4
K3	301/21	43/75	8	275/8	181/25	21/64	0.9
K4	276/33	143/61	10	298/14	29/3	130/75	0.3
J1	287/17	138/71	10	282/12	13/2	111/77	0.7
J2	320/8	70/67	10	320/3	230/26	48/64	0.1
J3	280/12	164/65	10	285/7	16/8	152/79	0.9

Table 2. Result of stress inversion in different seismotectonic zones

In the seismotectonic zone K1, the best fit maximum principal stress direction (S_1), represented by a solid circle in Fig. 3(1), plunges 6^{o} to the northwest (N282^{o}). The intermediate principal stress direction (S_2) represented by a solid triangle square in Fig. 3(a), plunges shallowly along the NE (N14^{o}). The minimum principal stress direction (S_3) represented by a solid triangle in Fig. 3(a), is almost vertical. The geometry of principal stress directions defines a thrust regime in this seismotectonic zone. The R value of 0.9 indicates that the sizes of s_2 and s_3 are nearly the same suggesting uniaxial compression in a thrust regime (Anderson's criteria).

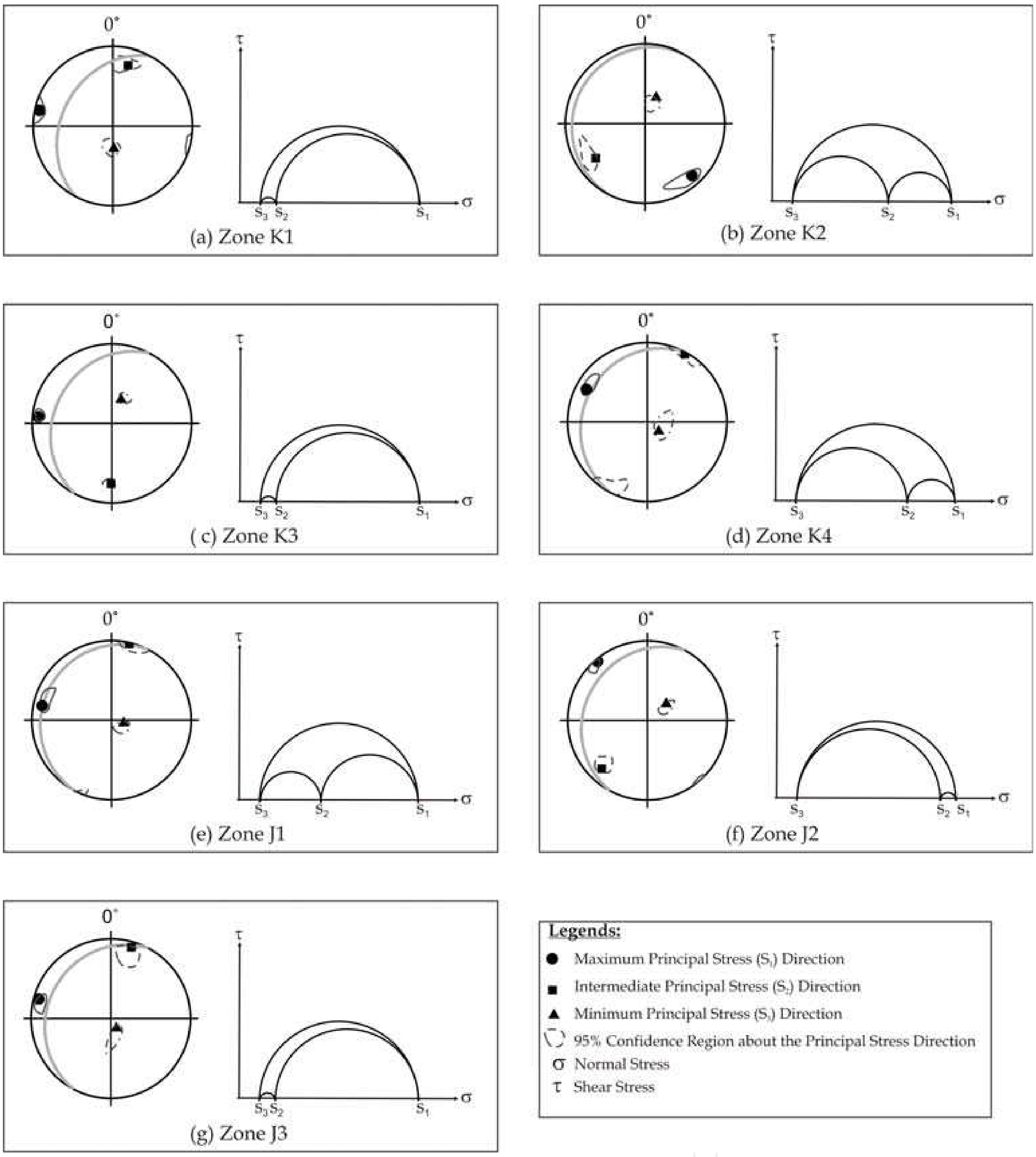


Fig. 3. Stress conditions in different seismotectonic zones. Left panel in each inset illustrates the geometry of the stress tensor in respective seismotectonic zone plotted on a stereogram of lower hemispheric projection, where the thick, gray great circle represents the geometry of the subducted Pacific slab. Right panel illustrates the stress condition in terms of Mohr circles drawn without scale based on R-value

In seismotectonic zone K2 the state of stress is complex (Fig. 3b). However the geometry of the principal stress direction suggests a thrust regime; with steep S_3 and shallow S_1 and S_2, the value of R (=0.4) indicates a transtension in a compression regime (Ritz and Tabaoda, 1993). That is in this zone a significant fraction of seismic deformation should be consumed in strike slip and extensional movements. Ghimire and Kasahare (2009) by statistical analysis of focal mechanism data showed that a significant fraction of earthquake exhibits strike slip, normal and odd events in this seismotectonic zone (Ghimire and Kashara, 2009).

In the seismotectonic zone K3, S_1 and S_2 plunge towards northwest and south respectively with shallow dip angles (Fig. 3c). Steep S_3 and high value of R (=0.9) suggests a uniaxial compression in thrust regime as in the seismotectonic zone K1.

Geometries of the principal stress directions the R-values in the seismotectonic zones K1, and K3 in the Kurile arc relative to the geometry of the subducted Pacific slab indicate a down-dip compression as shown in the steriograms (left panels in Fig. 3a, and c) since the maximum principal stress direction (S_1) is sub-parallel with the dip direction of the subducted pacific slab (thick gray colored great circles in Fig. 3a, and c). The large value of R (=0.9) in these zones further simplify the stress condition to uniaxial compression. However in zone K2 the geometry of principal stress directions relative to the subducted Pacific slab is suggestive of a downdip compression, but the R-value (=0.4) complicates the stress state.

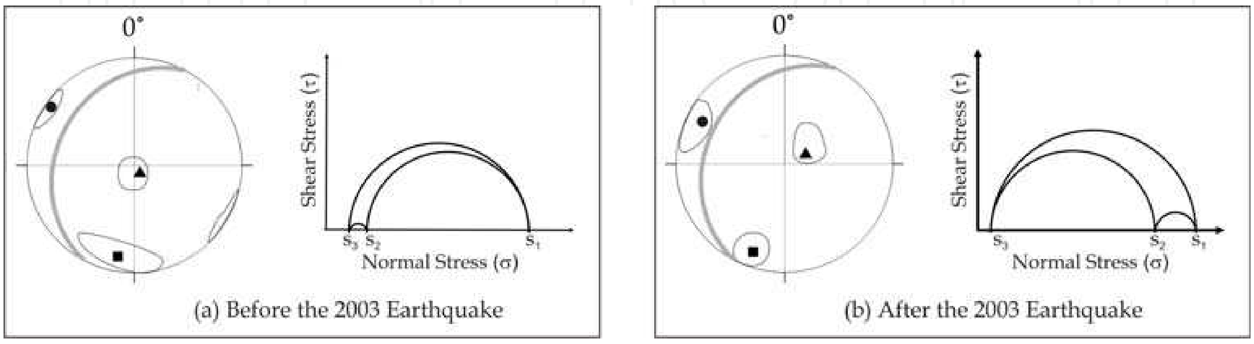
In seismotectonic zone K4 (Fig. 3d), the stress condition is different from the other zones described so far. In this seismotectonic zone, however the geometry of the principal stress directions suggests a thrust regime, comparatively small value of R (=0.3) indicates a transitional stress state going from transpressional to biaxial compression. This seismotectonic zone spatially covers the region of Hidaka collision zone, such that tectonic stress due to the collision of the Kurile and Japan arcs and the subduction of the Pacific slab significantly interact here giving rise to a transition to biaxial compression. As shown in the stereogram in Fig. 3d, the maximum principal stress direction (S_1) is subparallel with the dip direction of the subducting Pacific slab and the intermediate principal stress direction (S_2) is N29^o, nearly parallel to the collision axis indicating that the source of tectonic stresses in this seismotectonic zone is supplied by both the subduction and collision. The R-values in other seismotectonic zones also indicates that the influence of collision decays away from the Hidaka Collision zone.

In the seismotectonic zone J1 covering the shallow part of the subducted Pacific slab in Japan arc, the geometry of the principal stress directions suggest a thrust regime with steep S_3 and shallow S_1 and S_2 (left panel in Fig. 3e). In this seismotectonic zone the R value (=0.7) suggests a transition from a transpressional to a uniaxial compression in a thrust regime.

The geometry of the principal stress directions in seismotectonic zone J2 suggests a thrust regime (Fig. 3f). In this zone the R value is small (0.1) and suggests a biaxial compression. This seismotectonic zone in the Japan arc is in the vicinity of the Hidaka Collision Zone (HCZ, Fig. 2) where the stress condition is complicated by the collision between the Japan and Kurile arc. The intermediate principal stress direction (S_2) in this zone is subparallel to the relative motion of the Japan arc with respect to the Kurile arc indicating that the source of a large S_2 (or radial compression) in this seismotectonic zone is also supplied by the collision. Finally in seismotectonic zone J3, the geometry of the principal stress directions and the R-value (=0.9) together indicates a uniaxial compression in thrust regime like in seismotectonic zones K1 and K3 in Kurile arc. This seismotectonic zone covers major section of the rupture area of the 1968 Tokachi Oki earthquake.

3. Temporal change in stress condition by the 2003 Tokachi Oki earthquake

Occurrence of a large earthquake in an area generally perturbs the stress field in terms of Coulomb stress change (King et al., 1994) enhancing the seismicity. Such a perturbation may include a significant change in the stress state near the earthquake source region. Ghimire (2008) checked such temporal variation in the state of stress in all seismotectonic zones in the study area. For this purpose, the focal mechanism data was split into two time windows in each seismotectonic zone separated by the 2003 Tokachi Oki event. The main shock of the 2003 Tokachi Oki earthquake was not included in the inversion while the aftershock with magnitude between 3.5 and 7.0 were included. Except in the seismotectonic zone K3 in Kurile arc no significant changes in the states of stress are found (Ghimire, 2008). Fig. 4 illustrates the temporal variation in the state of stress in K3.



(a) Before the 2003 Earthquake

(b) After the 2003 Earthquake

Fig. 4. Comparison of stress states in K3 before and after the 2003 Tokachi Oki earthquake

The trends and plunges of the principal stress directions and the R-values before and after the 2003 Tokachi Oki earthquake are shown in Table 3. The orientation of each of the principal stress directions is not changed significantly by the 2003 event and the geometry of the principal stress directions indicate thrust regimes for both time windows. However there is a significant change in the R-value. The R-value before the 2003 event suggests a uniaxial compression which was changed to a transition from transpressional to biaxial compression after the 2003 event (Ritz and Tabaoda, 1993).

	No. of Data	Principal Stress Axes (trend/plunge in degree)			R
		S_1	S_2	S_3	
Before the 2003 Earthquake	239	305/6	183/8	160/81	0.9
After the 2003 Earthquake	183	297/16	199/6	15/76	0.2

Table 4. Stress conditions in seismotectonic zone K3 before and after the 2003 event

Ghimire et al. (2005) estimated similar results while estimating the temporal variation in stress conditions in the aftershock area of the 2003 Tokachi Oki earthquake. They estimated a transition between thrust and reverse fault regime with uniaxial compression before the 2003 event. This stress condition was changed to a radial stress condition in a thrust regime after the 2003 event. They attributed this change in stress condition to the release of fluid trapped in the fault zone. We will discuss on this issue in the next section.

4. Seismotectonic Implication of 2003 Tokachi Oki earthquake

The change in stress conditions in the source region of the 2003 Tokachi Oki earthquake before and after its occurrence may imply the region should undergo a different seismotectonic process in order to compensate this temporal change. In order to find such implication, mechanisms of some significant aftershock that occurred near the interplate boundary are analyzed using waveform inversion of teleseismic P-waves (Kikuchi and Kanamori, 1991) between the period 2003/9/27 and 2004/3/27 with magnitude, M≥ 5.5. The result is shown in Table 5. The focal mechanism of the main shock of the 2003 Tokachi Oki earthquake is also listed (event MS in Table 5) from Yagi (2004). β, in the last column of Table 5 represents the angle (in degrees) made by the fault normal with the maximum principal stress axis in K3 before the 2003 Tokachi Oki earthquake explained in Fig. 5.

Time	Event	Lon (°)	Lat (°)	Depth (km)	Mw	Faulting Mechanism			β(°)
						Strike (°)	Dip (°)	Slip (°)	
2003/09/26	MS	144.2	41.7	22	8.0	250	20	110	78
2003/09/28	E1	144.5	42.0	20	6.2	325	56	160	68
2003/09/29	E2	144.4	42.4	36	6.4	188	28	88	71
2003/10/08	E3	144.6	42.6	36	6.6	176	20	72	77
2003/10/08	E4	144.7	42.2	22	5.8	253	21	146	78
2003/12/03	E5	144.4	41.9	25	5.9	250	22	155	76
2003/12/29	E6	144.7	42.4	26	6.0	233	18	124	78
2004/03/26	E7	144.2	41.9	20	5.9	210	14	90	82

Table 5. Mechanism of some major aftershocks

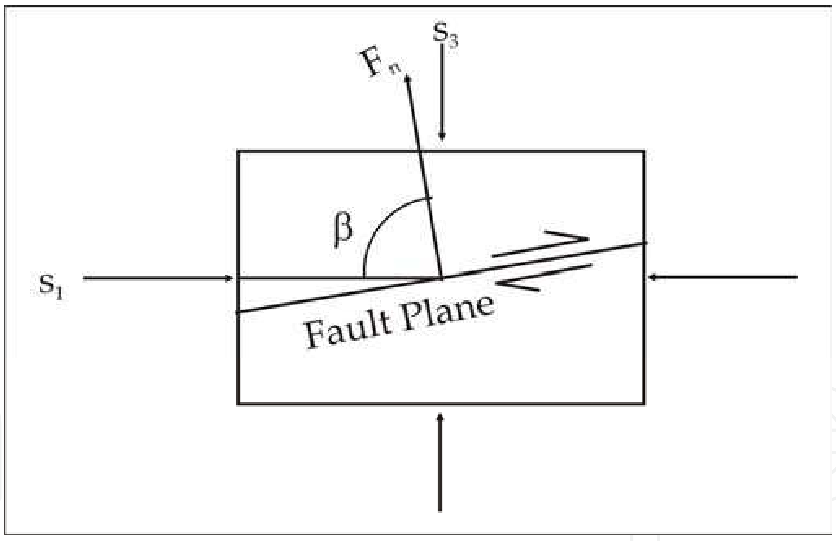


Fig. 5. Schematic diagram illustrating the fault geometry under plain stress condition. S_1 and S_3 are the maximum and minimum principal stresses respectively, F_n is the fault normal and β is the angle between the maximum principal stress direction and the fault normal

Fig. 5 illustrates the geometry of the fault plane with respect to the principal stress directions under a plane stress condition. The shear stress along the fault plane is dependent of the acute angle (β) between the maximum principal stress direction and the fault normal by the following relation (Jaeger and Cook, 1979):

$$\tau = (S_1 - S_3)\sin 2\beta/2 \tag{1}$$

Where, τ, S_1 and S_3 are the shear stress, maximum principal stress and the minimum principal stress respectively. Equation (1) implies that the shear stress along a fault plane will be maximum when the angle β becomes 45^o. For all other values of this angle the shear stress will be small. Table 5 suggests that including the main shock of the 2003 Tokachi Oki earthquake the shear stress along the fault plane was small. That is the aftershock data are suggestive that the earthquakes ruptured mechanically weak faults in the Hokkaido subduction zone.

Fig. 6 illustrates the focal mechanism of the major aftershocks and the main shock. Most of the aftershocks have one of their nodal planes sub-parallel to the main shock fault plane. Only two aftershocks namely, E1 and E5 have their nodal planes inconsistent with the main shock focal mechanism. Fault normal of these fault planes makes steep angles (Table 5) with the maximum principal stress direction (68-82^o) indicating mechanically weak faults. We will discuss this observation in terms of relative weakness of a matured fault (Rice, 1992). Rice (1992) discussed theoretically on the relative and absolute weakness of a matured fault zone in terms of pore fluid pressure.

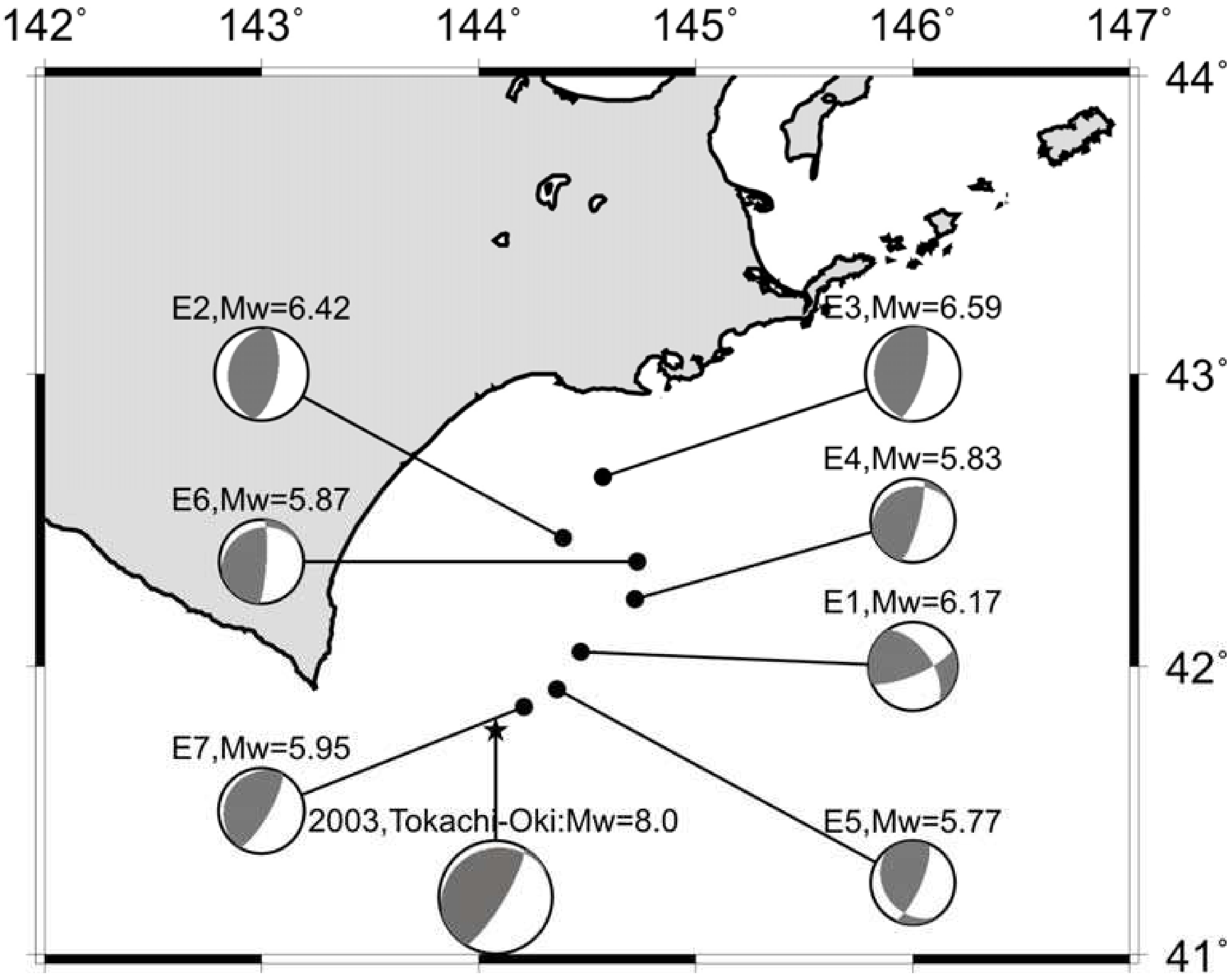


Fig. 6. Map showing the distribution of aftershocks and their mechanism listed in Table 5

In a matured fault zone the rise in pore pressure is not uncommon as suggested by Peacock (1990) and Vroljik (1990) where dehydration of hydrous minerals may supply sufficient amount of pore fluids at seismogenic depths in a subduction zone. On the other hand Moore

(1989) argued on sedimentary origin of fluid due to the compaction of water saturated sediments by tectonic loading. Hyndman and Peacock (2003) discussed on serpentization in the forearc mantle as a result of sinking of geothermal gradient due to the subducted Pacific slab. They further discussed on abundant free fluids to the shallower part of the slab due to dehydration of hydrous phases and compactions of sediments. Iwamori (2007) advocated for the similar conditions of both free fluids in interstitial spaces and hydrous minerals at greater depths in subduction zones in northern Japan and Hokkaido on the basis of seismic tomography result and geochemical simulations.

Hydraulic sealing of fault zones in local or regional scales as advocated by Blanpied et al. (1992), Sleep and Blanpied (1992) and Byerlee (1993) may result in the elevation of pore pressure in the fault zones. Rice (1992) described that pore pressure in a matured fault zone may exceed the hydrostatic conditions (but still smaller than the lithostatic pressure) which further weakens the mechanical strength of the fault zone making a favorable condition for the nucleation of an earthquake without any change in prevailing stress levels. Based on Rice's (1992) theoretical approach, to incorporate the effects of pore pressure on the fault strength and ongoing earthquake phenomenology, a failure model is proposed here.

The shear stress on a fault plane in a prevailing stress environment under plane stress conditions depends on two factors: the strength of the differential stress and the angle between the maximum principal stress axis and the fault normal (Equation 1). Once this shear stress overcomes the frictional strength (Equation 2) the fault will rupture. The frictional strength of faults at seismogenic depths cannot be very small as evidenced by many laboratory derived experiments. Therefore at the seismogenic depths, only a relative weakness of a fault zone can be expected. Such that, a mature fault zone can evolve its own stress condition completely different from the stress conditions in the surrounding regions (Rice, 1993).

This condition i.e. different stress conditions in the surrounding rocks and the matured fault is possible if the levels of pore pressures in the fault zones and the surrounding rocks are different. As discussed so far, the possibility of high pore pressure in a fault zone compared to the surrounding rocks can not be neglected. We show this schematically and qualitatively in Fig. 7 where we propose the failure model for the 2003 Tokachi Oki earthquake.

In Fig. 7, fault normal of each of the fault planes (from focal mechanism data) are fixed in Mohr planes by the angles made by the fault normal with the principal stress axes the Mohr circles being drawn without scale based on the R-value in the seismotectonic zone K3, before the 2003 Tokachi Oki earthquake.

The crosses in Fig. 7 represent the pole to the fault planes of the major aftershocks and the main shock shown in Fig. 6. The Mohr circles are drawn without scale based on the R value obtained from the stress tensor inversion in the seismotectonic zone S3 before the occurrence of the 2003 Tokachi Oki earthquake. From the center of the Mohr circle defining the largest differential stress (S_1- S_3), a dashed line is drawn subscribing an angle 2β, where β (=78^o) is the angle made by the normal to the fault plane of the main shock with S_1. From the point of intersection a failure surface is drawn with a friction coefficient of 0.6 using the Mohr-Coulomb criterion of failure (Jaeger and Cook, 1979):

$$\tau = \mu(\sigma - p) \qquad (2)$$

where, τ, μ, σ and p respectively represents the shear stress, friction coefficient, normal stress and the pore pressure.

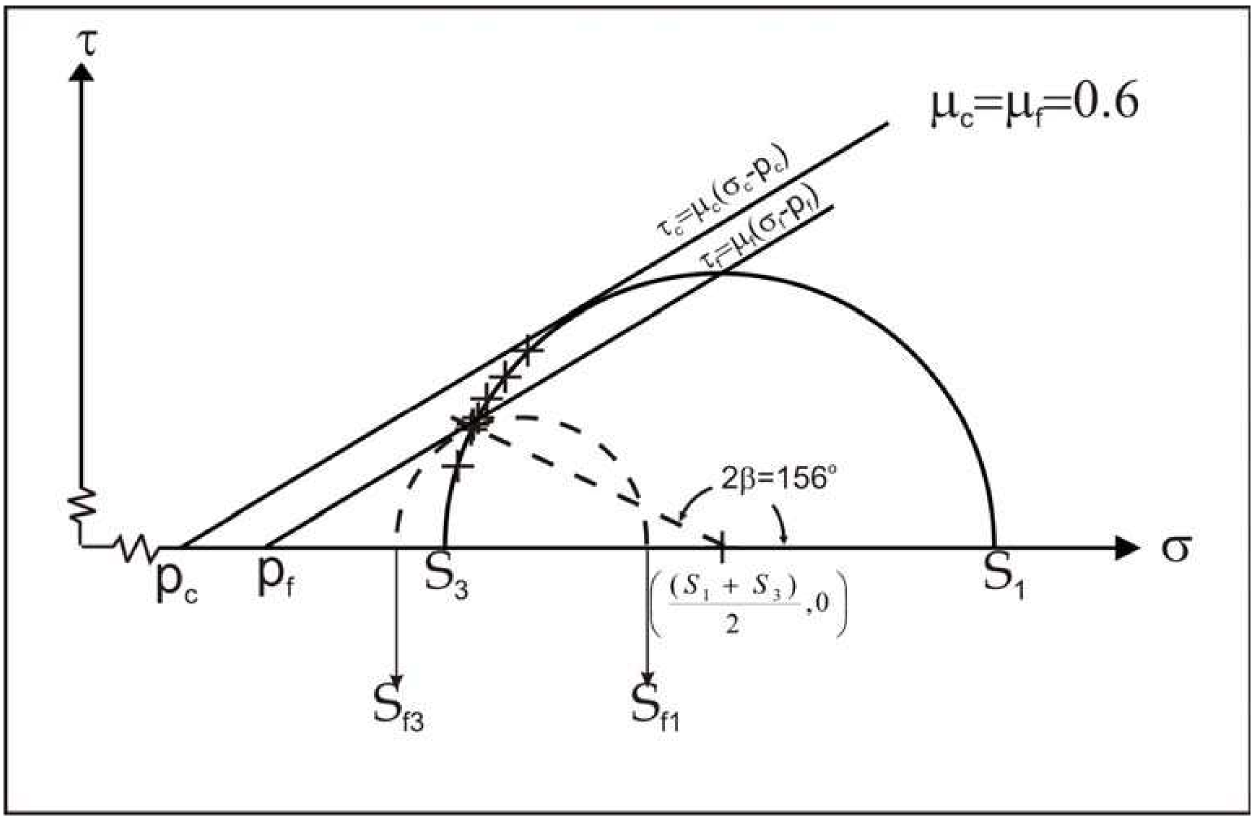


Fig. 7. Failure model describing the stress states in the fault zone and the surrounding crust. The crosses are plotted on the Mohr surface based on the acute angle β made by the fault normal and maximum principal stress direction. At the intersection of the Mohr circle and the fault normal of the mainshock a failure surface for the fault zone is drawn with friction coefficient (μ) of 0.6. A Mohr circle tangent to this failure surface is drawn (dashed circle). Another failure surface is drawn for the surrounding crust with the same friction coefficient and tangent to the main Mohr circle. These failure surfaces cross the horizontal axis (σ, normal stress) at P_c and P_f respectively representing the pore pressures for the surrounding crust and the fault zone. S_{f1} and S_{f3} respectively represent the maximum and minimum principal stress in the fault zone

A Mohr circle tangent to this failure surface is drawn (dashed circle) that represents the failure stress of the fault zone (Fig. 7). Similarly failure surface for the adjacent crust ($\tau=\mu(\sigma_c$-$p_c)$ is drawn assuming the same frictional strength. These two failure surfaces intersect the normal stress axis at the point p_f and p_c, pore pressures in the fault zone and the surrounding crust respectively.

Most of the failure surfaces representing the aftershocks will cut the normal stress axis at locations $p_f \geq p \geq p_c$. This model thus shows that the main shock occurred on a relatively weak fault zone due to the elevation of pore pressure in the fault zone. The stress state in the area after the occurrence of the 2003 event characterized by a radial compression in a thrust regime facilitated the excess pore fluid to squeeze up from the seismogenic depth via seismic pumping during the occurrence of larger aftershocks with similar mechanisms of the main shock.

Thus the phenomenology of the recurrence of large subduction earthquakes in the Hokkaido region can be explained in terms of following physicochemical processes:

I. Locking of fault segment

During an interseismic period the interplate fault undergoes locking as the downgoing slab will be decelerated by the resistance supplied by collision of the Kurile and northern Japan arcs. In this stage the Pacific slab beneath the Hidaka collision zone will undergo a dome-shaped deformation due to strong radial compression. Occurrence of such a dome shaped Pacific slab beneath the Hokkaido has been reported by many previous authors (e.g. Kanamori, 1971, Hashimoto, 1984, Moriya, 1986). This phenomenon will lock the segment of the interplate boundary above the collision zone hosting the asperity for the accumulation of tectonic stress as a site of nucleation of large subduction earthquake in future.

II. Rupture of the asperity

Dehydration and digenetic processes are continuous in an active subduction environment releasing abundant fluids (e.g. Peacock 1990, 1996, Peacock et al., 1994, Hyndman and Peacock, 2003). Locking of the fault will give rise to accumulation of stress within the fault zone and surrounding crust enhancing the sealing of the interconnected fractures (Blanpied et al., 1992) such that the released fluids will be started accumulating within the fault zone. Abundant fluids released by metamorphic and/or digenetic processes will raise the pore-pressure in the fault zone lowering the frictional strength of the fault zone. As discussed in section 5.1b, the increase in pore pressure within the fault zone would lead to its mechanical weakening relative to the preexisting stress conditions in the surrounding crust and the failure may occur nucleating the large subduction earthquake like the 2003 Tokachi Oki earthquake.

5. Conclusions

The seismotectonics in the Hokkaido region is complicated specially by the interaction of two kinds of tectonic activities, the collision between the Japan and Kurile arcs and the subduction of the Pacific slab. As a result, the seismotectonics is spatially variable such that the stress conditions in a particular seismotectonic zone vary from the others.

The occurrence of the 2003 Tokachi Oki earthquake changed the stress conditions in its source region however its impact to the adjacent seismotectonic zones was not significant.

The stress condition in the shear zone of the interplae boundary changes in time as a function of water released in the fault zone such that without any significant change in shear stress the megaquake occurs due elevated water pressure.

Current dataset analyzed in this work includes a single cycle of subduction earthquakes in the Tokachi Oki region. That is the recurrence model proposed here fits well with the occurrence of the 2003 Tokachi Oki earthquake after the occurrence of the 1952 Tokachi Oki earthquake in the same location. The model is to be checked more quantitatively particularly including more detail physicochemical constraints.

6. Acknowledgments

We are thankful to many people in the Institute of Seismology and Volcanology for many fruitful discussions. We thank the Japan Society for Promotion of Science (JSPS) for its support to conduct this research in Japan. We are equally thankful to the Institute of Seismology and Volcanology of Hokkaido University for the research facilities.

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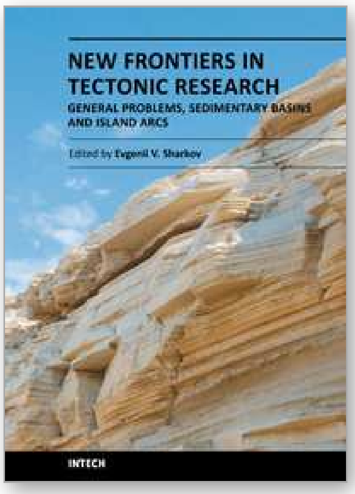

New Frontiers in Tectonic Research - General Problems, Sedimentary Basins and Island Arcs

Edited by Prof. Evgenii Sharkov

ISBN 978-953-307-595-2
Hard cover, 350 pages
Publisher InTech

Published in print edition July, 2011

This book is devoted to different aspects of tectonic research. Syntheses of recent and earlier works, combined with new results and interpretations, are presented in this book for diverse tectonic settings. Most of the chapters include up-to-date material of detailed geological investigations, often combined with geophysical data, which can help understand more clearly the essence of mechanisms of different tectonic processes. Some chapters are dedicated to general problems of tectonics. Another block of chapters is devoted to sedimentary basins and special attention in this book is given to tectonic processes on active plate margins.

Tanioka Yuichiro and Subesh Ghimire (2011). Spatio-temporal Changes in Stress Field and Occurrence of the 2003 Tokachi Oki Earthquake in Hokkaido, Northern Japan, New Frontiers in Tectonic Research - General Problems, Sedimentary Basins and Island Arcs, Prof. Evgenii Sharkov (Ed.), ISBN: 978-953-307-595-2, InTech, Available from: http://www.intechopen.com/books/new-frontiers-in-tectonic-research-general-problems-sedimentary-basins-and-island-arcs/spatio-temporal-changes-in-stress-field-and-occurrence-of-the-2003-tokachi-oki-earthquake-in-hokkaid

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No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821