2008 年 8 月
29 卷 4 期:486-494

地 球 学 报
ACTA GEOSCIENTICA SINICA

Aug. 2008
29(4):486-494

震前卫星热红外环形应力场特征

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摘 要 本文包括两部分内容:①描述了 1996 年 2 月 3 日云南丽江 Ms 7.0 级地震,震前几天的卫星热红外图像呈现圆形,它的 NNW、NW、SN、及 NE 向的热旋扭面往 S 收敛。该地震地表破裂由一系列张扭性裂缝组成,呈左旋左列,水平位错不明显,垂直断距数厘米。垂直力对构造变动的作用较为明显;而丽江地震震源机制解破裂面 II 的走向 NNE6°,倾向 W,倾角 44°,P 轴方位为 NNE3°、仰角 75°,近于直立,综合热旋扭面展布、地震地表破裂特征及震源机制解,得出该旋扭椭圆为地幔外侧右旋上涌所造成; ②菲律宾萨马岛 Ms7.0 ~ 7.5 强震群及青海共和 Ms7.0 地震前热应力环椭圆的推进路径。根据这一特征得出交变潮汐力的地球动力学解释。卫星热红外图像震前应力热场的方法是临震预测地震的有效方法,卫星热红外技术辅以震源机制解和地表破裂带力学分析是研究地球动力学有力工具。地球自转速度变化,交变潮汐力和地幔旋扭上涌力是地球动力学的主因。

关键词 环形热应力场; 热旋扭面; 路径; 震前; 卫星热红外
中图分类号: P315 **文献标识码**: A **文章编号**: 1006-3021(2008)04-486-09

The Annular Stress Thermal Field of Satellite Thermal Infrared Prior-earthquakes

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Abstract This paper consists of two parts: in the first part the distribution of the rotation shear circle structure of the Lijiang Ms7.0 earthquake of February 3, 1996. in Yunnan province is presented, combining the mechanics of the surface fracture with earthquake focus moment tensor solution. The Lijiang stress thermal circle can be seen in the satellite infrared images (1995-12-15T19:47, GMT). Its diameter is about 250 km(25.3° ~ 28.3°N, 100.1° ~ 103.2°E). The ground fracture zone from Lijiang earthquake consists of a series of cracks with tension shear character. The cracks are rotated and arranged sinistrally, which did not possess obvious horizontal relative displacement with vertical displacement of centimeters. The vertical stress has the more obvious effect on the structural changes. In the focal mechanism solution, the second fracture plane is in NNE(6°) strike, inclining towards W with obliquity of 44°; Direction of P axis is NNE(3°), its elevation is 75°. The uprush shear force causes the upcover layers above rotated, and the rotation shear force causes the shear

本文由海南省重点科技项目(编号: 06071)资助。
收稿日期:2007-12-07;改回日期:2008-05-16。责任编辑:刘志强。
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rotation in the up-layers and results in en echelon arrangement faults, or annul faults and semi-annul faults. Synthesization of all above data confirms the characteristics of the rotation shear circle structure. We synthetically judge that the circle structure had dextro rotation and uprush movement. This is our first important conclusion.

The second part presents the moving path of the thermal infrared anomaly of the Philippines' Samar island strong Ms7.0~7.5 earthquake swarm and Gonghe M7.0 earthquake in Qinhai province. This is another exemplification on advancement path of the thermal rotational shear ellipse. On April 11 and 12, 1990, the satellite infrared imagery appeared a warming ellipse whose length was 1,500 km, width was 1,000 km, located E 92°~110°, N 36°~44°, temperature was 25~29℃. It was on the south side of the ellipse that Gonghe earthquake with Ms7.0 occurred on April 26. The rotational shear plane in the southeast of the ellipse tends to converge on N and disperses to S, the plane is of pressure shear nature. In the focal mechanism solution of Gonghe earthquake, direction of *P* axis is 45°, strike of the fracture plane is 135°(SE), so that the outboard force of the ellipse was towards left, and the inboard force towards right. 17 days before Gonghe earthquake in Qinghai, at 05:32(GMT) on April 11, 1990, upper part of the satellite image where is 98°~103°E, 39°~43°N (Gansu, Ningxia, Inner Mongolia) appeared as an isolated warming area. Temperature in Gaxun Nur lake and the Bajilin desert (42°N, 100°E) of north Gansu Province was from 25℃ to 29℃. The next day, at 05:32(GMT) on April 12, 1990, the warming area expanded to the south and the west. Coomparing with identical time in different date, the isolated warming area about 100°E, 40°N at 05:32 on April 11 had greatly altered during one day along the way (100°E). The warming area arrived 90°~107°E, 35°~45°N, covering part Xinjiang, Qinghai, Gansu, Inner Mongolia and small part southern Mongolia. The warming area was a huge ring-like ellipse with length of approximate 2,000 km Advancement route of the stress thermal rotational shear ellipse. The pattern of the moving path suggests there are continuingly alternating tidal stresses in the earth. The thermal annulus before Samal Ms7.0~7.5 earthquakes in Philippines is a convictive exemplification. At 06:32(GMT) on April 11, 1995, the satellite infrared imagery revealed a ring-like warming ellipse (pink, 22℃) in NE-trending from the South China Sea to Philippine Luzon. At 05:31(GMT) on April 12, the ellipse migrated to the southeast direction. At 05:31(GMT) on April 13, however, the long ellipse turned its strike from NE to EW, and continually migrated approximately 300 km to south, its south most tip arrived at Samal. By now the ellipse entered the strong seismic zone on Philippines' E side. Then the stress thermal field continually developed. At 05:31(GMT) on April 14 and 15, the warming image deformed from the elliptical annulus to the rectangle block whose length was 2,000 km, width was 1,000 km, and the total warming area reached 2,000,000 km^2. This phenomenon most likely is related to the alternant tidal action. Based on the infrared thermal abnormity characteristics, the strong earthquake swarms with Ms 7.0~7.5 occurred in Philippines' Samal island from April 21 to May 5 in 1995 was successfully forecasted. This phenomenon is connected with the alternant tidal action, and it is of some significance in coming earthquakes.

All theories originate from practice and serve practice. The "Red Swelling" by academician Fu Chengyi on earthquake genesis is presented about 36 years ago. But A new hypothesis "the positive hole charges" was born in 2002 and 2003. The phenomenon of bright temperature increases observed from thermal infrared channels on stationary weather satellites before a strong earthquake has been used as a precursor to earthquake for more than ten years. In 1990's, there were only a few reports in *Science in China* and *Chinese Science Bulletin* and even less reports on its' mechanism. At the beginning of this century, Dr. F. Freund and D. Ouzounov(Professor of physics at San Jose State University and NASA's Ames Research Center) did rock strike experiment on nonconductive igneous rock core samples and observed that "the positive hole charges" becomes active when the samples was stroked, the electro-magnetic emission on infrared band was also recorded. This supports that there are infrared emissions from rocks when rocks are under pressure before earthquakes.

Practice is the standard to prove truth. Satellite thermal infrared technique was put into practice shortly. During the 11 years from 1990 to 2000, we made 119 predictions. of which 58 were valid and 15 were false alarms. 11 earthquake predictions Ms≧7.0 and 28 earthquake predictions Ms≧6.0 are comparatively good. The success rate of those predictions increased from 24% during period of 1990-1995, to 46% in 1996, 53% in 1997, 76% in 1998, and 80% in 1999 and 2000, as summarized by Wang Chunyin in her M A Candidate (2005). The satellite infrared detected thermal stress field is a reflection of the earth's crust stress condition when rock stress increases the spots along the stress produce micro fissures in rock. Therefore, hot planes and lines that are closely related with the stress condition and the rock faulted structure can demonstrate the compression stress direction. The satellite thermal infrared hot stress field's technique was an outstanding example of integrating theory with practice and of making theoretical innovations.

The method of using satellite thermal infrared images combined with pre-earthquake hot stress field analysis to predict impending earthquake is valid. Combining the satellite thermal infrared technology and earthquake focus solution and dy-

namic analysis of surface fracture zones is an innovative and effective method for earth dynamic study. The earth rotation speed rate change, alternative tidal force and rotation shear uprush of mantle are the main earth dynamic sources.

Key words annular hot stress field; the thermal rotation shear plane; advancing route; prior-earthquake; satellite thermal infrared

通过对近几年来实际震例的分析,发现存在震前卫星热红外环形应力场,这对进一步加深对震兆的理解和预测应用有积极意义。

环形热旋扭的力学性质的确定:环形热旋扭面的力学性质受内旋运动方向与撒开或收敛之间的关系而制约。结合震源机制解中的主压应力方向和主破裂面展布及力学性质,决定了热旋面的相对扭动方向,有时辅以地表破裂力学性质,则更加科学和全面可靠。

1 云南丽江 Ms7.0 地震(27.2°N, 100.3°E; 1996 年 2 月 3 日)

从卫星热红外图片(图版 I-1)上可以见到丽江环,直径约 250 km(25.3° ~ 28.3°N, 100.1° ~ 103.2°E),分布在大理、丽江到盐源、西昌一带。从图 1 中得知 10 ~ 20°C 温度区主要分布在丽江以南广大地区,5 ~ 7°C 温度区在图的中部分布,而 0 ~ 4°C区在图的北部。在环的东南部旋扭结构面上,NNW、NW、SN、及NE向的旋扭面往南收敛。热旋

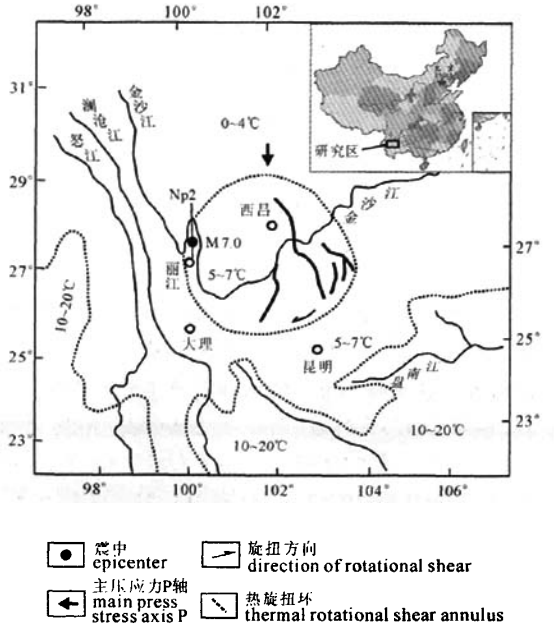

图 1 云南丽江热旋扭椭圆

Fig. 1 The Lijiang thermal rotational shear ellips structure in Yunnan province

扭面环的力学性质受内旋运动方向与撒开或收敛之间的关系而决定(李四光,1966,1973;马宗晋等,1995;李东旭,2003)。

丽江地震破裂带由一系列张扭性裂缝组成,呈左旋左列,水平位错不明显,垂直断距数厘米。垂直力较为显著(图 2)。张建国、周光全(陈琪福,2002)描述的丽江地震破裂带上,垂直力较为明显(云南省地震局, 1998)。

再结合丽江地震震源机制解,破裂面 II 的走向 NNE6°,倾向 W,倾角 44°,P 轴方位为 NNE3°、仰角 75°,近于直立。判定为外侧右旋上涌(强祖基等,1990,1995,1998)。上涌旋转力带动"围岩"及上覆岩层扭

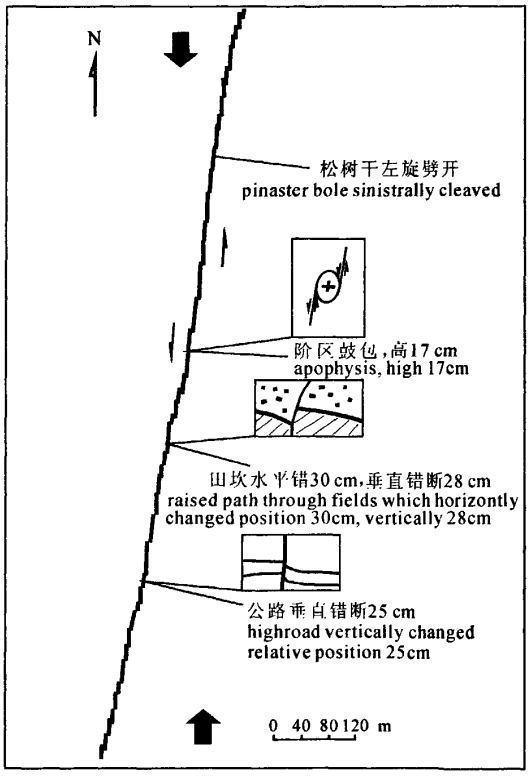

图 2 1996 年 2 月 3 日云南丽江 7.0 级地震地表破裂实测图(据云南省地震局,1998 修改)

Fig. 2 Ground fracture distribution of Lijiang earthquake with M_S 7.0 in 1996 (modified from Earthquake Bureau in Yunnan Province, 1998)

转,形成扭转力偶,使水平岩层或近水平地块产生差异旋转剪切,形成弧形雁行断裂、或环状、半环状断裂。

考虑到梅世蓉等(1996)利用了中国几千年地震历史记载研究了距今千年历史上16次大巨震的前数十年或上百年的4~5级地震环形分布,此环形展布的规模达几百千米或上千千米。如公元1556年华县8.3级地震、1668年山东郯城8.5级地震及1695年山西临汾地震7.8级地震,它们都处于中国东部,呈椭圆形,长轴北东向。公元1920年宁夏海原8.5级地震、1931年新疆富蕴8.0级及1950年西藏察隅8.6级地震,与东部地震震前中等地震的环形分布不一样,呈北西向展布。并且提出地震这种环形展布具有地幔物质上隆的可能性。

综合上述,地震地表破裂带、震源机制解、热环旋扭面力学性质及展布,认为丽江外侧右旋地幔上涌的可能性更大。

2　热旋扭椭圆环的推进路径

2.1　菲律宾萨马岛M7.0~7.5地震热应力椭圆环

1995年4月11日06:32(GMT)的卫星热红外图像上显露出由中国南海到菲律宾吕宋岛的NE向的椭圆环增温(粉红色22℃)(图版I-2)。4月12日06:32(GMT)NE向椭圆向东南方向迁移(图版I-3)。但是到了第三天即4月13日06:32(GMT),图像中的NE向长椭圆变成EW向,继续又向南迁移,移距约300 km,它的最南端到达萨马岛(图版I-4)。这时已进入菲律宾东侧强震带(图3)。继续向前发展到了第四、五天即4月14日05:31(GMT)、15日05:31(GMT),增温图像由椭圆环形变成长方块形,边长2000 km,上下宽1300 km,增温总面积达260万km^2(8°~21°N,108°~128°E)(Qiang et al.,1997)。这时已进入菲律宾E侧强震带(图3)。此现象与交变的潮汐作用很可能有关。1995年4月21日到5月5日发生在菲律宾萨马岛的7.0~7.5级强震群事先做了成功预报(Qiang et al.,1997,2001;强祖基等,2001)。梅世蓉等(1996,1995)研究了距今千年历史上16次大巨震的环形分布,震前中等地震的时空变化特征与卫星热红外热旋扭椭圆环推进路径非常相像。以郯城巨震为例,相当于"坚固体孕震模式"的3个阶段,第一阶段公元1568~1606年,第二阶段公元1607~1656年,第三阶段公元1657~1668-07-25。这3个阶段持续近百年的地震时空演化与卫星热红外几天的变化相当。1995年4月11日到12日,环形增温椭圆的推进路径类似坚固体孕震模式的第一阶段,中等地震呈环形分布;4月13日环形增温椭圆推进路径由NE向改为近EW向,两个不同大小的圆一并向未来震中推进靠拢为第二阶段;4月14、15日环形增温椭圆发生根本性改变,成长方块形,边长约2000 km,上下宽1300 km,增温面积达260万km^2(图版I-5,6)(Qiang et al.,1997)。这时深部物质渗入到震源体下部,出现大量微裂隙,很少有地震发生。相当于坚固体孕震模式的第三阶段,构成大震未到之前的空区。

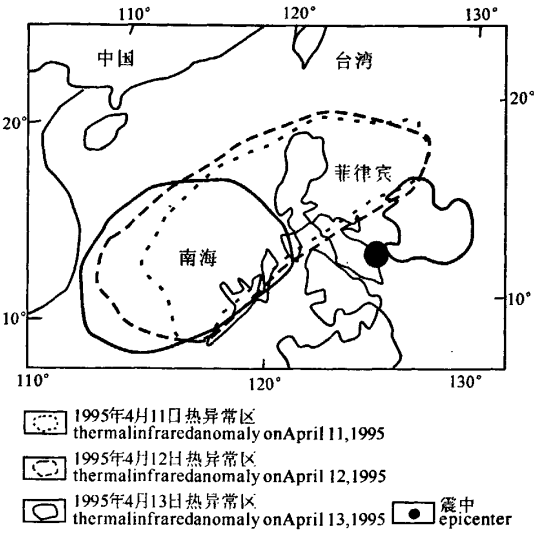

图3　菲律宾萨马岛卫星热红外升温椭圆环推进路径

Fig. 3　The moving path of the Samal warming ellipse in Philippines

2.2　青海共和Ms7.0地震(36.1°N,100.3°E;1990年4月26日)

青海共和旋扭椭圆:1990年4月11、12日卫星红外图像上显示了长1500 km、宽1000 km的增温椭圆,位于92°~110°E,36°~44°N,温度25~29℃,而地震发生在其南侧的青海共和境内。旋转椭圆的东南部旋扭面向N呈收敛趋势,而向S撒开,属压扭性。结合震源机制解中的主压应力方向和主破裂面展布和力学性质也可决定热旋面的相对扭动方向。共和地震震源机制解为P轴45°,破裂面走向135°(SE)(张肇诚,2000),共和椭圆外旋力向左,而内旋力向右(王绳祖,1998)。

青海共和地震前17d,1990年4月11日05:32(GMT)在98°~103°E,39°~43°N(甘肃、宁夏、内蒙),图像的北部出现孤立增温区,位于甘肃省北部

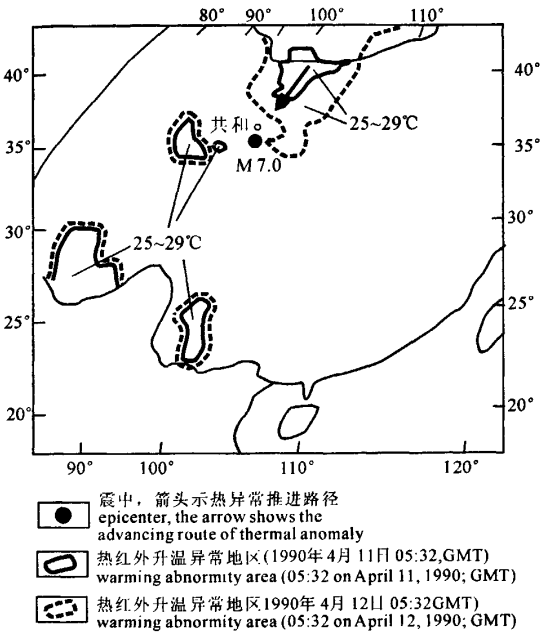

图4 青海共和卫星热红外升温异常推进路径

Fig. 4 The advancing route of warming abnormity in Gonghe, Qinghai

嘎顺诺尔湖及巴吉林沙漠(42°N,100°E)处(粉红,25℃;红色,29℃)(图版I-7)。翌日,1990年4月12日05:32(GMT)增温区向南、向西扩大了,采用同一时间不同日对比,说明前一天(4月11日05:32)在100°E,40°N附近的孤立增温区(粉红,25℃;红色,29℃)经过一天已经产生了巨大的改变。增温区由北向南推进。它的范围达到90°~107°E,35°~45°N,涵盖新疆、青海、甘肃、内蒙部份地区及蒙古南部一小部分。增温为一巨大环形椭圆,东西长近2000 km,而南北长约1000 km(图版I-8)。另外还可观察到增温沿着一定的路径(100°E)往南推进,推距300 km左右(图4)。此现象与交变的潮汐作用有关。热物质迁移路径由地幔顶部(甘肃北部)向低处(青藏高原)迁移是热物质上涌的一种形式。对这次地震,强祖基等进行了第一次尝试性预测,从地震预测三要素来检查,时间、震级都正确,地点差300 km。由此可以看到地震到来之前是有前兆的,地震不是不可预测的。

再论梅世蓉等(1995, 1996)以中国悠久的含4、5级历史地震记录及其分布,研究其巨震发展规律,初始阶段,向未来震中迁移及坚硬体形成阶段,在坚固体边缘处为未来强震震中。这3个阶段是由于地下深处岩层的温度压力变化所致。其时间尺度可延续上百年到几百年,并且做了以断层为背景的数学模拟试验。这些规律性认识一方面为了揭露地下深处岩层的力学性质及其变化而另一方面为地震临震预测指明道路,但是事与愿违,在实际地震监测中往往见不到地震蕴育的三个阶段,究其原因,乃是软流层或上地幔热物质上涌所造成。菲律宾萨马岛强震群的应力热环演变历史,从初期阶段到强固体阶段的形成只用了几天时间。其相应于卫星热红外图像的发展时间段分别是:1995年4月11日~12日;4月13日;4月14~15日。强固体理论在实际预测应用上遇到困难。力图通过孕震区地震介质参数:Q值、b值、波速比值及应力降等出现。实事上很难搞清强震区所处的阶段性。

卫星红外孤立增温现象作为地震的前兆有以下特征:①震前升温其初始点往往远离未来震中几百或上千千米;②孤立升温范围往往呈环形、不轨则椭圆或圆形;③地震的震级受增温面积制约,增温范围大震级大;④孤立增温跨越不同构造单元,显然与表层地质构造关系不明显,而是与地幔上层的热物质上涌、迁移运动有关(周玖等,1980)。

所有理论研究都要为实际应用服务,震前卫星热应力场提供了解决地震临震预测的判定。自1990年至2000年10月开展试验性预测预报取得著有成效的结果。1994年曾获得国家地震局地震预测表扬奖(国家地震局震发科(1995)002号),国家科委国家遥感中心正式批准为国际卫星观测委员会卫星资料成功应用提供"地震预测在中国"(CEOS et al.,1995; NRSCC, 1996)。

台湾国立台湾大学地理系硕士研究生王纯莹(2005)就此写出了硕士论文"利用时空内插及资料正规化辅助地震前热异常现象之侦测"。她通过我们的合作伙伴(航天部卫星信息工程研究所)获得了全部(1990~2000年)大于或等于5.0级地震预报卡片(119次)并做了检验(表1)。这里包括自1990年至1995年在中国地震局地质研究所的地震预报卡与以后两家合作预报的卡(1996~2000年)共119次一并交给了国立台湾大学。她对我们十余年的预测试验工作给予肯定和高度评价。实际预测较好的含7级及7级以上地震有10次。她的研究肯定台湾5.9级地震(1999~2002年)以上共13次每次地震都有升温,排除暖气团和暖流(黑潮)的可能。

因此,卫星热红外图像的预测地震试验方法已取得明显进展,若再辅以潮夕力谐震共振波(HRT)等方法,则将能更加提高预测未来地震三要素的精

表1　热红外异常预报地震成果统计(据王纯莹,2005)

Table 1　Statistics of Prediction Results with Thermal Infrared Anomaly Precursor (from Wang, 2005)

时间	预报次数	预报成绩				成功率
		70分以上	60~70分	60分以下	虚报	
1990~1995年	50		12	33	5	24%
1996年	13	3	3	6	1	46%
1997年	15	7	1	3	4	53%
1998年	21	11	5	3	2	76%
1999年	15	11	1	1	2	80%
2000年	5	4	0	0	1	80%

注:未含漏报及5级以下地震。

度。达到减轻地震灾害的目地。

3　地球动力学浅析

用沉积地层法、地貌法来研究地壳振荡运动的有别洛乌索夫(1980)、黄汲清(1957)、任纪舜等(2004)、Nikolayev(1961)等。马杏垣等(1984)也强调垂直运动。地球的海陆、地槽、地台、盆地及山岭演化历史告诉我们壳内软流层和上地幔物质的水平迁移和旋涌运动的存在(王绳祖,1998;杜乐天,2000;池顺良等,2002)。20世纪90年代徐常芳等(1994,1996)、刘国栋等(1984)、赵文津(Zhao,1997,2001)等指出地震区,如:河西走廊、西藏羊八井、渭河盆地华阴、唐山、山东郯城地区地壳深处有低速高导层存在或上地幔拱起。刘福田等(1989)、孙若昧(1991)及梅世蓉等(1996)在地震层析结构分析上做了大量工作,在壳下400 km深处的速度图像表明,102.5°E附近有约200 km宽的条带存在,地下400 km层析结构说明以100°~105°E为中国大陆东西部深部构造差异的分界。地质力学(Li,1929;李四光,1973)与板块构造学强调地块水平应力为主(Tapponnier et al.,1981;Zoback,1992;Wang et al.,2001;谢富仁等,2004;许绍燮,2006)。日月交变潮汐应力(池顺良等,2002)与地球深部流体的上涌则可能为垂直运动提供了力源。卫星热红外提供了许多水平应力热场的例子,如:单臂式、串珠状、X形剪、多字型、山字型应力场等(Qiang et al.,1997;强祖基等,1990,1992a,1992b,1995,1998,2001);也有垂直应力热场的例子如:丽江热旋扭椭圆、美国奥林匹亚蜗牛状应力热场、菲律宾萨马尔旋转推进应力热椭圆环等(Qiang et al.,1997;强祖基等,1998);刘善军等,2007)。有时以水平应力为主,有时以垂直应力为主,有时两者共同作用。因此,我们应该把水平运动和垂直运动结合起来,从地球的整体行为来研究现今构造运动和地震成因。

现今增温异常移动路径为地球动力学提供了线索。萨马尔热旋椭圆推移路径图像揭示,南海热椭圆源于南海盆地,地幔隆起区的热物质从顶部向低处运移,由西向东移动,向菲律宾岛链推移。青海共和热旋椭圆环推移路径图像又显示,应力热场由甘肃嘎顺诺湖和巴丹吉林沙漠向青藏高原移动;从深部来说,地幔隆起区的热物质向南,向地幔低处推移。正如池顺良、骆鸣津共同指出的:地球内部存在交变潮汐应力的长期作用,地球横向不均匀,交变的潮汐作用可能引起热物质的定向运动。地球自转速度变换、交变潮汐力和热物质旋扭上涌是地球动力学重要力源。建议卫星热红外图像技术辅以地震震源机制解和地震地表破裂带力学分析为研究现今应力场的有效方法。

最后,笔者以沉重悲痛心情向5.12四川汶川大地震死难同胞致哀,向受伤的兄弟姊妹致以亲切慰问。我们将以顽强的意志战胜一切险阻,为攻克地震临震预报这一世界难题而奋斗。

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图版说明

图版 I　Plate I

1. 1995-12-15T19:22, GMT。绿色 green、黄色 yellow 0 ~ 7℃;红色 red 9℃。
2. 1995-04-11T06:32, GMT。咖啡色 sienna 19℃;粉红色 pink 22℃;红色 red 25℃。
3. 1995-04-12T06:32, GMT。咖啡色 sienna 19℃;粉红色 pink 22℃;红色 red 25℃。
4. 1995-04-13T06:32, GMT。咖啡色 sienna 19℃;粉红色 pink 22℃;红色 red 25℃。
5. 1995-04-14T05:31, GMT。咖啡色 sienna 19℃;粉红色 pink 22℃;红色 red 25℃。
6. 1995-04-15T05:32, GMT。咖啡色 sienna 19℃;粉红色 pink 22℃;红色 red 25℃。
7. 1990-04-11T05:32, GMT。黄 yellow,棕色 brown 19 ~ 24℃;粉 pink,红色 red 25 ~ 29℃。
8. 1990-04-12T05:32, GMT。黄 yellow,棕色 brown 19 ~ 24℃;粉 pink,红色 red 25 ~ 29℃。

图版 I Plate I