2020 年度陈嘉庚科学奖专辑

陈嘉庚科学奖——地球科学奖

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获奖项目名称

华北克拉通破坏

获奖项目介绍

克拉通是地球上最古老的大陆, 通常表现为缺乏明显的岩浆活动和地壳变形, 因此传统上认为克拉通是稳定的。但华北克拉通在中生代发生了大规模的岩浆活动和陆内造山, 这些地质现象成为困扰地球科学家近百年的难题。针对这一问题, 朱日祥及其团队对华北克拉通开展了地质、地球物理和地球化学多学科综合研究。发现了华北克拉通岩石圈减薄、大规模岩浆活动和构造变形只是克拉通演化过程中的表现形式, 其实质是岩石圈地幔物质组成与属性发生了根本转变, 导致克拉通固有稳定性的破坏, 改变了人们对古老克拉通“一成不变”的传统认识。确定了华北克拉通破坏主要发生在东部陆块, 破坏峰期为早白垩世。华北克拉通西部陆块仍保持稳定属性, 中部陆块表现为部分被改造的特征。发现了早白垩世西太平洋板块俯冲作用是导致华北克拉通破坏的一级驱动力, 俯冲板片在地幔过渡带的滞留脱水使上覆地幔发生熔融和非稳态流动, 是导致克拉通破坏的主要途径。论证了洋-陆相互作用导致克拉通破坏与大陆增生是全球大陆演化的普遍规律, 这些发现和认知为陆内造山与成矿提供了全新的研究思路, 拓展了板块构造及成矿理论。

华北克拉通破坏对地表地质与陆地生物的影响

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摘要 晚中生代古太平洋板块俯冲导致东亚古大地幔楔形成和华北克拉通破坏, 该动力过程引发华北克拉通发生强烈伸展和岩浆活动, 广泛形成裂谷盆地和变质核杂岩, 并造成燕辽和热河生物群的繁盛与消亡. 古太平洋板块俯冲角度的变化导致东亚大陆经历了三次短暂挤压事件和两次强烈伸展构造. 多学科综合研究进一步揭示, 晚中生代燕辽和热河生物群的演化与华北克拉通的破坏强度、岩浆活动强弱以及盆地发展存在明显的时空相关性. 上述现象表明地球深部动力过程不仅控制了克拉通破坏和地壳构造演化, 而且也极大地影响了地表环境的变迁和陆地生态系统的演变. 因此, 地球生命是与环境协同演化, 并且共同受地球深部过程的控制.

关键词 华北克拉通, 燕山运动, 裂谷盆地, 火山活动, 燕辽和热河生物群

华北克拉通是中国大陆一个重要的古老地质单元, 在中元古代-古生代时期经历了长期缓慢垂向升降和发育广阔的陆表海沉积^[1,2]. 早中生代华北克拉通虽受周缘地块汇聚和碰撞的影响, 但其依然保持了整体稳定性^[3]. 晚中生代华北克拉通构造演化发生了根本性变化: 发生大规模岩浆活动^[4,5]、形成伸展盆地和变质核杂岩^[6-10], 以及岩石圈厚度明显减薄^[11-14]. 华北克拉通岩石圈地幔由典型的大陆型转变为似大洋型^[15,16]. 地质、地球物理和地球化学多学科综合研究表明, 华北克拉通破坏的实质是岩石圈地幔物质组成与物理化学性质发生了根本转变, 而大规模岩浆活动、强烈构造变形和巨量岩石圈减薄仅是克拉通破坏过程的表现^[15,16]. 这一科学发现揭示了克拉通稳定性丧失的根本原因和科学内涵, 改变了古老克拉通“一成不变”的传统观念, 对建立大陆演化新理论具有非常重要的

意义.

华北克拉通破坏深部动力过程也造成陆地生物发生重大变化. 中-晚侏罗世燕辽生物群和早白垩世热河生物群化石保存完整, 记录了它们出现-繁盛-消亡的全过程以及生物地理变迁的信息, 为解决一系列重大生物演化问题提供了关键证据, 如现代陆地生态系统如何从中生代陆地生态系统演化而来? 被子植物、鸟类和哺乳动物等主要生物类群如何起源和如何演化分异? 特异埋藏和完美保存的燕辽、热河生物群无疑是探索上述重大科学问题的重要窗口. 深入探索华北克拉通破坏与燕辽、热河生物群演化的相关性, 也为深入开展“地球动力过程与陆地生物演化”这一交叉学科前沿研究提供了难得的机遇. 深入分析华北克拉通破坏对地表地质和陆地生物演化的控制, 对探究地球不同圈层之间相互作用和认识宜居地球过去、现在与未

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来皆具有重要意义。

1 克拉通破坏与浅部地质响应

晚中生代华北克拉通构造环境发生了重大变化,经历了多期伸展和挤压构造变形(图1)。晚古生代古亚洲洋俯冲消减,最终导致华北克拉通与阿穆尔地体在晚二叠世拼合^[17~19]。扬子地块与华北克拉通在早-中三叠世发生斜向碰撞拼合^[20~22],但汇聚作用主要影响华北克拉通南缘,未对克拉通稳定性和岩石圈地幔属性造成重大影响^[3]。华北克拉通北缘中生代层序存在3个区域性角度不整合面,分别记录了3次挤压构造变形幕(图1)^[23~28]。上侏罗统与下伏地层之间的不整合面(不整合A)记录了燕山运动A幕事件(图1),是华北克拉通北缘和西缘在晚中生代经历的第一次强烈挤压构造变形^[3,29~34]。值得注意的是,华北克拉通内部侏罗系并未发生挤压变形,仅局部出现宽缓褶皱^[35,36]。这一现象指示引发燕山运动A幕的动力过程并未造成华北克拉通

的整体破坏。

燕山运动B幕发生在早白垩世初(约145~140 Ma),比A幕影响地域更加广泛,导致华北克拉通周缘白垩纪之前地层发生强烈褶皱和逆冲推覆^[37,38]。在燕山构造带下白垩统张家口组角度不整合于上侏罗统之上^[39];在合肥盆地地下白垩统毛坦厂组角度不整合于侏罗系之上^[40];在二连盆地和海拉尔盆地地下白垩统普遍角度不整合于侏罗系和其他老地层之上^[8,41~43];在鄂尔多斯西部下白垩统志丹群不整合于上侏罗统芬芳河组之上^[44]。燕山运动B幕在华北克拉通北缘形成一系列大型逆冲断裂带,如阴山构造带内的色尔腾山和大青山逆冲断裂带^[45,46]、燕山构造带内的丰宁-隆化断裂带、承德县逆冲断裂带、古北口-平泉断裂带等^[38,47]。鄂尔多斯盆地西缘逆冲断裂体系也主要形成于燕山运动B幕阶段^[34,48]。燕山运动B幕还形成许多韧性剪切带,如云蒙山北缘四合堂逆冲剪切带^[9,49~51]。华北克拉通东部普遍缺失上侏罗统,下白垩统平行不整合或低角度不整

图1 华北克拉通北缘晚中生代地层、盆地和构造演化以及与古太平洋板块俯冲的关系。冀北早白垩世大北沟组与花吉营组是区域上的同物异名,角度不整合将中生界分为3个火山-沉积序列,分别记录了燕山运动A、B、C幕短期挤压事件。3个火山-沉积序列形成于裂谷盆地,燕山运动导致一些裂谷盆地反转和抬升。晚中生代伸展和挤压构造环境的交替与古太平洋板块俯冲角度变化有关。早白垩世华北克拉通破坏是古太平洋板块高角度俯冲与回转、海沟回撤、俯冲板片在地幔过渡带滞留等构造过程共同作用的结果。燕山运动B幕引起的地层缺失由东向西逐渐减弱,说明太平洋板块俯冲是控制燕山运动的主因

Figure 1 Diagram showing late Mesozoic stratigraphic, basin and tectonic development in the northern North China Craton and their relationships with the paleo-Pacific plate subduction. Angular unconformities divide Mesozoic successions into three volcano-sedimentary sequences, recording three compressional events termed as Phases A, B and C of the Yanshanian Orogeny, respectively. All the three sequences formed in rift basins and were deformed and uplifted in response to the multiple phases of the Yanshanian Orogeny. Late Mesozoic alternation of extensional and compressional tectonic settings was due to the change of subduction angle of the paleo-Pacific plate. Note that Early Cretaceous destruction of the North China Craton is ascribed to a combined effect of high-angle subduction and slab rollback of the paleo-Pacific plate, trench retreat, and slab stagnation in the mantle transition zone. The degree of the lateral stratigraphic hiatus resulted from Phase B of the Yanshanian Orogeny decreased from east to west, suggesting that subduction of the paleo-Pacific plate played a dominant role in triggering the Yanshanian Orogeny

合于下伏地层之上^[36]。上述地质观察反映燕山运动B幕仍主要影响华北克拉通边缘区域,未对其整体稳定性产生显著影响。最近,不同学者对华南地块晚中生代构造开展了深入研究,提出在约153~140 Ma期间华南地块经历了一次强烈挤压变形,并将其归因于古太平洋板块低角度俯冲^[52,53]。因此,华南大陆这次挤压事件与华北克拉通燕山运动B幕应该都是由西太平洋板块低角度俯冲所导致。我们认为,这次挤压变形在华南地块与华北克拉通起始时间的差异有两种可能:其一是古太平洋板块向东亚大陆边缘穿时性低角度俯冲的结果,即晚侏罗世古太平洋板块首先在华南地块边缘发生低角度俯冲,尔后向北穿时传播;其二是定年技术与方法的不同以及实验误差所致,甚至是两种因素叠加所致。显然,我们需要更多地地质事实和实验数据来对晚侏罗世-早白垩世初中国大陆东部挤压变形过程的时空变化进行限定,从而进一步理解晚中生代古太平洋板块的俯冲历史。

与燕山运动A、B幕相比,燕山运动C幕挤压强度较弱,并且主要影响华北克拉通东缘地带。上、下白垩统之间的角度不整合记录了这期构造变形,如合肥盆地上白垩统张桥组与下白垩统响导铺组之间的角度不整合^[10,54]以及沂沭盆地上白垩统王氏组与下白垩统大盛组之间的角度不整合^[55]。与燕山运动C幕相关的构造变形包括辽宁北票南天门逆冲断裂^[56,57]和郯庐断裂压扭性左旋走滑^[58,59]。上白垩统在华北克拉通其他区域大多缺失^[60]或与下白垩统呈平行不整合接触^[8]。我们推测燕山运动C幕也可能与古太平洋板块低角度俯冲相关^[61,62],并且这一认识得到动力学数值模拟的支持^[63]。

尽管华北克拉通晚中生代构造环境演变受到周缘不同构造体系的影响,但我们认为导致构造环境不断转换的主因是古太平洋板块俯冲角度的不断变化^[61,62]。板块高角度俯冲与回转可引发上覆板块伸展变形,而低角度俯冲则使上覆板块挤压缩短。因此,古太平洋板块俯冲角度的交替变化导致了华北克拉通东部和邻区构造环境的相应变换;燕山运动A、B、C幕挤压变形对应于古太平洋板块的低角度俯冲过程,而晚侏罗世和早白垩世强烈伸展变形则是古太平洋板块高角度俯冲的结果(图1)。燕山运动A幕形成一系列褶皱和逆冲推覆构造^[38,61,62],但变形强度在空间上展现出明显的变化。野外地质观察揭示,燕山运动A幕变形强度由东南向西北方向逐渐减弱。另外,中、上侏罗统之间的不整

合面在燕山构造带为角度不整合,但在北部的二连盆地转变为平行不整合^[41]。这些地质记录反映,导致燕山运动A幕挤压变形的动力应来自东南,即与古太平洋板块向西北方向低角度俯冲相关。蒙古-鄂霍茨克洋闭合主要造成缝合带附近和阿穆尔地体的缩短变形。

晚侏罗世古太平洋板块高角度俯冲导致华北克拉通周缘发生强烈伸展和岩浆活动(图1)。在克拉通北缘和东缘发育一系列晚侏罗世伸展盆地^[19,64,65]以及变质核杂岩和伸展穹隆,如医巫闾山变质核杂岩^[66]、喀喇沁变质核杂岩^[67]和玲珑伸展穹隆^[68,69]。晚侏罗世岩浆岩地球化学特征也进一步指示它们形成于伸展构造背景^[67,70~74]。早白垩世整个华北克拉通东部和周缘皆发生强烈伸展和岩浆活动,克拉通稳定性完全丧失^[16]。

华北克拉通晚中生代地质演化的另一重要现象是广泛发育伸展盆地。晚侏罗世伸展盆地主要形成于华北克拉通北缘,而早白垩世伸展盆地则遍布于整个华北克拉通东部和北部阿穆尔地体(图2)。两期伸展盆地皆以发育火山-沉积充填层序为特征,表现出主动裂谷型盆地特征(图1)^[19,65,75,76]。晚中生代挤压构造事件(燕山运动A、B、C幕)持续时间短,主要造成早期裂谷盆地反转,并未形成挤压型盆地(图1)。一些研究者认为,华北克拉通北缘晚侏罗世盆地构造沉降和沉积过程主要受逆冲推覆构造控制^[77,78]。然而,中-上侏罗统发育厚达4000 m的九龙山组-髫髻山组火山岩(163~152 Ma)^[79,80],晚侏罗世变质核杂岩的出现(157~147 Ma)^[67,81,82],部分晚侏罗世盆地仍保存早期边界正断层^[64],以及二连盆地晚侏罗世受伸展构造控制^[8,41],这些地质现象明显指示上侏罗统火山-沉积序列是裂谷盆地演化的结果。我们认为华北克拉通北缘晚侏罗世盆地边缘逆断层是后期挤压过程的结果,它们造成晚侏罗世裂谷盆地反转,而非控制盆地沉降-沉积过程。对遍布整个华北克拉通东部和边缘的早白垩世裂谷盆地已开展了大量研究(图2),如阿穆尔地体内的宽裂谷体系以及华北克拉通内部和边缘众多的小型裂谷盆地^[8,36,83~85],本文不再赘述。

对华北克拉通破坏机制已开展了大量综合性研究,结果表明古太平洋板块向东亚大陆高角度俯冲、俯冲板片回转、海沟回撤以及俯冲板片在地幔过渡带的滞留等过程是导致华北克拉通破坏的主要动力学因素^[15,62]。这一地球深部动力过程还促使晚中生代东亚大地幔楔的形成^[62]。与新生代东亚大地幔楔类似,晚中生代东亚大地幔楔与滞留在地幔过渡带的俯冲板片和

图2 华北克拉通早白垩世裂谷盆地和岩浆岩分布。早白垩世裂谷盆地遍布整个华北克拉通东部和周缘, 大规模岩浆活动和变质核杂岩与裂谷盆地发展相伴生; NE-SW走向盆缘正断层指示区域伸展应力方向为NW-SE。华北克拉通西部仍为一个大型拗陷

Figure 2 Distribution of Early Cretaceous rift basins and magmatic rocks in and around the North China Craton. Large-scale magmatism and metamorphic core complexes occurred synchronously with rift basins. The NE-SW-trending bounding normal faults indicate regional NW-SE stretching. The western North China Craton still behaved as a large sag basin

下地幔共同构成了一个独特的“三明治”式地幔结构^[86]。由于地幔过渡带滞留板片的存在, 晚中生代中国东部幔源岩浆的源区不可能来自下地幔。地幔过渡带的主要成分是瓦兹利石和尖晶橄榄石(或称林伍德石), 它们都具有1 wt%~3 wt%的含水能力, 比上、下地幔高1~2个量级^[87]。因此, 当大洋俯冲板片滞留在地幔过渡带, 就很容易发生脱水 and 脱碳过程, 并在地幔过渡带上、下部位发生熔融和交代作用。这个过程既是华北克拉通岩石圈地幔属性发生根本改变的驱动力, 也为地表大规模岩浆活动提供了物源。岩石-地球化学研究表明, 早白垩世华北克拉通东部岩石圈地幔源区含水量大于1000 ppm(1 ppm=1 μg/g)^[88], 远高于MORB(mid-ocean ridge basalts)源区(50~200 ppm)^[89]和长期稳定的南非克拉通(~120 ppm)^[90]。地球化学研究还进一步揭示, 早白垩世华北克拉通岩浆源区含有来自地幔过渡带滞留板片再循环的沉积碳酸盐组分^[91]。东亚古大地幔楔不仅在地壳浅部留下了诸多地质记录, 如强烈构造变形、大规模岩浆活动以及广泛分布的裂谷盆地与变质核杂岩^[15,92~94], 还对地表生态环境和陆地生物群演化造成

巨大影响。

2 克拉通破坏与燕辽、热河生物群演化

燕辽生物群与热河生物群是华北克拉通中生代两个特异埋藏的陆生生物群, 因保存大量完整的脊椎动物、昆虫以及伴随的软组织等化石而著称。近年来, 精确的地层定年为准确厘定这两个生物群的时代及其演化过程奠定了良好的基础。中-晚侏罗世燕辽生物群包括带羽毛的恐龙、哺乳类、翼龙、两栖类与昆虫等。最新定义的燕辽生物群可分为两个演化阶段, 即早期道虎沟生物群(海房沟组, 165~163 Ma)和晚期玲珑塔生物群(髫髻山组, 161~159 Ma)^[95,96], 繁盛期约在160 Ma。燕辽生物群缺少真正的鸟类、真骨鱼类和被子植物化石。

早白垩世热河生物群包括带羽毛的恐龙、鸟类、哺乳类、翼龙、蜥蜴、离龙类、两栖类、鱼类、昆虫以及被子植物等。最新定义的热河生物群分为3个演化阶段, 含化石层位分别以冀北花吉营组、辽西义县组和九佛堂组为代表^[97,98], 延续时代约为135~120

Ma^[98-100], 最繁盛期约在125 Ma. 热河生物群演化伴随生物多样性的增加, 其分布范围及含化石层位表现出由西向东的发展趋势。

目前, 对燕辽生物群和热河生物群的研究都强调火山活动的影响, 揭示化石组合的特异埋藏多与火山灰沉降和湖泊沉积密切相关. 热河生物群无论在生物多样性还是分布范围上都超过燕辽生物群^[101,102]. 值得注意的是, 这两个生物群之间有超过两千万年的时间间隔, 这一时期主要对应化石十分稀少的土城子组沉积, 目前对两个生物群之间的联系还知之甚少。

东亚古大地幔楔如何影响燕辽和热河生物群的发生、发展、繁盛和消亡是近年来地球科学领域关注的前沿科学问题. 中-晚侏罗世燕辽生物群和早白垩世热河生物群在空间上位于华北克拉通东部破坏区域, 在时间上与华北克拉通破坏的启动和峰期时代一致^[61]. 值得注意的是, 地质历史时期重大地质事件常导致生物演化发生剧烈变化. 譬如, 古元古代早期陆壳快速增生和大氧化事件促使真核生物的出现; 新元古代早-中期, 罗迪尼亚超大陆裂解、冈瓦纳大陆重组以及雪球地球形成及融化, 造成埃迪卡拉纪地球环境的巨大变革和多细胞生物的起源及寒武纪生命大爆发; 显生宙发生了5次生物大灭绝事件, 其中4次与大规模火山喷发相伴发生. 上述事实说明地球各圈层之间存在密不可分的内在联系和相互作用. 燕辽和热河生物群演化

及生物地理变迁与华北克拉通破坏强度、岩浆活动强弱以及沉积盆地发展等存在明显的时空相关性, 表明克拉通破坏与陆地生物演化之间存在内在联系. 因此, 地球深部动力过程不仅控制了克拉通破坏与浅部大地构造演化, 而且也引发了地表古环境变迁和陆地生态系统的演变^[62,98]. 传统生物演化研究通常将环境因素作为生物演化的背景来考虑. 然而, 越来越多的证据显示生物演化不仅是地球环境演变的一部分, 而且在不同程度上也在改造地球环境, 而不是简单地适应地球环境的演变. 地球生命与环境的协同演化从根本上来讲是受地球深部动力学过程所控制(图3), 没有内部动力引擎的星球肯定不会有像地球一样高度文明的生物, 也就是说地球内部动力过程控制了地球的宜居性, 这是宜居星球最显著的特征。

华北克拉通晚中生代大规模岩浆活动以及盆-岭地貌可对陆地生物演变产生重要影响. 频繁岩浆活动造成的环境变化可导致地区性生态系统发生崩溃, 使自然选择压力明显增大, 从而加速生物演化进程. 众多独立小型盆地的形成则有利于新物种的产生和生物多样性的增加. 因此, 晚中生代小型裂谷盆地群和火山活动应是控制燕辽和热河生物群形成和演化的重要因素. 火山喷发产生的火山灰不仅为湖泊和森林生态系统提供了丰富的营养物质, 而且也是燕辽和热河生物群得以完好保存的重要因素之一. 初步研究结果揭示, 中侏

图3 地球深部过程对地表系统控制过程示意图

Figure 3 Diagram showing controls of deep dynamic processes of the Earth on paleogeography and terrestrial ecosystems

图4 华北克拉通北部构造环境变化与燕辽和热河生物群演化。繁盛于中-晚侏罗世的燕辽生物群与裂谷盆地和九龙山组-髫髻山组火山活动同期, 燕山运动B幕导致盆地反转和燕辽生物群消亡; 繁盛于早白垩世的热河生物群与裂谷盆地和义县组火山活动同期, 燕山运动C幕导致盆地反转抬升和热河生物群消亡

Figure 4 Temporal relationships of tectonic settings and evolution of the Yanliao and Jehol biotas in the northern North China Craton. The Yanliao Biota was flourishing in Late Jurassic and synchronous with rift basin development and intense volcanism recorded by the Jiulongshan and Tiaojishan volcanics. The second-phase Yanshanian Orogeny resulted in inversion of Late Jurassic basins and possibly the vanishing of the Yanliao Biota. Flourishing of the Jehol Biota was coeval with Early Cretaceous rift basins and volcanic activities recorded by the Yixian Formation. The third-phase Yanshanian Orogeny then led to inversion and uplift of Early Cretaceous basins and disappearance of the Jehol Biota

罗世晚期太平洋板块低角度俯冲使中国东部大陆处于挤压构造环境, 导致华北克拉通北部地壳挤压和抬升;

致谢 感谢中国科学院地质与地球物理研究所邓成龙和杨进辉研究员、中国科学院古脊椎动物与古人类研究所邓涛研究员在论文撰写过程中提出的建议和认真修改。

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晚侏罗世晚期太平洋板块高角度俯冲促使华北克拉通东部岩石圈强烈伸展, 引发岩浆活动和形成裂谷盆地^[62]. 早白垩世初华北克拉通经历第2次强烈挤压变形, 造成晚侏罗世裂谷盆地反转和抬升. 早白垩世强烈伸展形成广泛分布的裂谷盆地和引发大规模火山活动, 但自早白垩世末开始裂谷盆地和火山活动又逐渐消失. 图4显示了华北克拉通北部晚中生代构造环境演变与燕辽和热河生物群演化在时空上的密切关系.

3 结论

综合地质、地球物理和地球化学研究结果, 我们认为, 如果没有古太平洋板块俯冲带回撤、俯冲板片回转与在地幔过渡带滞留, 就不会产生东亚古大地幔楔; 而没有东亚古大地幔楔的形成, 也不会导致华北克拉通破坏和燕辽、热河生物群的繁盛与消亡.

对华北克拉通破坏、浅部地质响应及其陆地生物演化的综合研究揭示, 华北克拉通在中侏罗世晚期、早白垩世初和早白垩世末经历了3次地壳挤压事件, 而中-晚侏罗世和早白垩世主要为强烈伸展构造阶段. 挤压和伸展环境以及岩浆活动在时间上交替发生, 反映它们都受深部动力过程和地壳应力场的控制. 3次挤压事件分别对应古太平洋板块3次低角度俯冲过程, 而晚侏罗世和早白垩世两次伸展变形和火山活动则与古太平洋板块高角度俯冲、俯冲板片回转以及俯冲带回撤相关. 燕辽和热河生物群形成、繁盛和消亡在很大程度上也受深部动力过程和裂谷盆地演化的控制. 展望未来, 以剖析东亚古大地幔楔对华北克拉通破坏、浅部地质过程和陆地生态系统演化的控制机理为切入点, 通过多学科交叉与整合研究, 探索地球深部动力过程与生物圈协同演化机制是未来值得深入研究的前沿科学问题.

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Summary for “华北克拉通破坏对地表地质与陆地生物的影响”

Destruction of the North China Craton and its influence on surface geology and terrestrial biotas

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The North China Craton (NCC), a major geological element of East Asia, had behaved as a stable craton until late Mesozoic. The NCC experienced multiple contraction and extension in late Mesozoic, evidenced by three phases of shortening and two phases of stretching. The three shortening phases occurred in the late Middle Jurassic, earliest Early Cretaceous, and latest Early Cretaceous, respectively. Crustal stretching happened in Late Jurassic and Early Cretaceous times, and was marked by large-scale magmatism and development of rift basins and metamorphic core complexes. Widespread vigorous magmatism and extensive rifting indicate the loss of the NCC stability in the Early Cretaceous. Alternating crustal contraction and extension of the NCC are attributed to the change in subduction angles of the paleo-Pacific plate, with low-angle subduction resulting in shortening and high-angle subduction leading to stretching. However, magmatism, deformation and lithospheric thinning are merely the various expressions of the NCC destruction. It is shown that deep thermal processes must have strongly altered the properties of overlying lithosphere, resulting in a change from the continental into oceanic mantle. It was the transformation of physico-chemical properties of the lithospheric mantle that destabilized the NCC. Also noticeable are occurrences of the Yanliao and Jehol biotas that evolved in the Middle-Late Jurassic and Early Cretaceous, respectively, and just coincided with the initial and peak stages of the NCC destruction. Flourishing and vanishing of the biotas appeared closely related to volcanic intensity and rift basin development in space and time, implicating a profound control of deep dynamic processes on surface paleogeography and ecosystems. Implicitly, life should have been evolving in accord with surrounding environments. Volcanism might have exerted a strong influence on prosperity and disappearance of the Yanliao and Jehol biotas, with ash fallout leading to perfect preservation of a variety of precious fossils. Also noteworthy is that biotas thrived in the period when rift basins were developing, whereas biotas died out when basins were inverted. It is still a challenge to explore the linkage of terrestrial life evolution and tectonic processes. Recent developments in geodynamic studies reveal that subduction of the western paleo-Pacific plate might have produced a unique mantle profile in late Mesozoic, with the stagnant plates in mantle transition zone being sandwiched between the lower mantle and the big mantle wedge. Extensive dehydration and decarbonization of the stagnant plates resulted in melting and metasomatism of the upper and lower parts of mantle transition zone. These processes should have played a crucial role in altering the nature of lithospheric mantle and in triggering large-scale magmatism in the crust. A big mantle wedge is thought to have developed beneath the East Asia continent during the Early Cretaceous as a result of the slab rollback and the stagnation in the mantle transition zone. The combined tectonic processes must have exerted a profound influence on both the NCC destruction and Yanliao/Jehol biotal evolution. Interdisciplinary researches will help us understand the complicated interaction of deep and surface processes and comprehend the past, present and future of our habitable planet.

North China Craton, Yanshan orogeny, rift basin, volcanic activity, Yanliao and Jehol biotas

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