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中国西北地区中—新生代构造与气候格局演化

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摘要:研究我国西北干旱区形成演化过程对认识我国现今构造—环境格局形成及演变具有重要意义。通过我国西北地区中—新生代重要的构造和环境事件的梳理,显示我国西北地区中生代以来经历了印支、早燕山、晚燕山和喜马拉雅个构造旋回,气候在三叠纪—始新世以干热为主,渐新世以来冷干。古亚洲洋闭合及羌塘、拉萨、印度板块渐次与亚洲南部碰撞使西北地区越来越远离海洋水汽。西北地区气候演化经历了三叠纪—中侏罗世、晚侏罗世—始新世和渐新世—第四纪 3 个阶段,并存在晚三叠世—中侏罗世温湿、晚侏罗世—白垩纪干热及渐新世—第四纪冷干 3 个气候转型阶段,分别由 5 次湿热、5 次干热和 5 次冷干气候波动事件组成。同时,发现在晚三叠世—侏罗纪以古天山—古祁连山为界,构造与气候格局存在南北差异,构造活动南弱北强、气候北干南湿。而在白垩纪,西北地区构造活动西强东弱,气候南干北湿。我国西北干旱区的形成既是对全球变化的响应,也是区域构造活动叠加的结果,构造活动先于全球变化影响我国西北地区的气候环境变化。渐新世以来两极冰盖出现、青藏高原整体快速隆升和副特提斯海退出塔里木是现今西北干旱区形成的主要原因。

关键词:演化;构造格局;气候格局;西北干旱区;中—新生代

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我国西北干旱区是中东亚内陆干旱区的重要组成部分,西、北部以国界为限,东达黄土高原,南至昆仑山一线,面积 200 多万 km^2,位于中高纬西风环流和低纬亚洲季风环流的交互地区,区内高大山系和巨型盆地相间展布,沙漠广布,气候干旱,生态环境脆弱,已成为全球变化研究的重点地区之一[1]。但目前对它形成的时间、过程和机制还存在着争论。现有的研究认为,西北干旱区的形成主要与青藏高原隆升[2-7]和副特提斯海退出[6,8]或北极冰盖形成[9-10]关系密切,大多数人认为它起源于中新世[3-5,7],但也有人认为在渐新世[11-12]或晚侏罗世初期[13]已有萌发。造成争论的主要原因是对这一干旱区形成的构造—环境背景不清楚。本文通过对我国西北地区中—新生代以来重要的构造和环境事件的梳理,总结了西北地区中生代以来的构造和环境演变过程及其对西北干旱区形成的控制作用,对认识西北干旱区形成演化具有重要意义。

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1　构造事件与构造格局演变

1.1　中—新生代构造事件

我国西北地区中—新生代构造活动以板内变形为主,表现为盆地发育和山脉隆升,岩浆活动较弱。中—新生代构造演化过程主要与古亚洲洋的闭合,基梅里大陆(裂解为羌塘地块、拉萨地块)、印度板块与亚洲板块的碰撞有关[13-15]。按照盆地地层沉积与构造变形特征,结合区域大地构造演化,本文以区域性地层角度不整合为依据,划分出印支(T_1)、早燕山(T_2)、晚燕山(T_3)和喜马拉雅(T_4)4 个构造旋回;以局地性(平行)不整合及岩相变化为依据,划分出 19 次构造事件(图 1、图 2)。

1.1.1　印支构造旋回(T_1)　二叠纪末—三叠纪初,随着古亚洲洋的闭合,我国西北大部分地区进入陆内造山与成盆阶段[28]。受南部昆仑洋闭合和北部阿尔泰山隆升的影响,准噶尔、塔里木、河西走廊、银根-额济纳旗(银-额)及陇中等山间盆地开始发育(图 1、图 2),沉积了 400～2 600 m 厚的山前洪积—河湖相碎屑岩,底部多为粗碎屑岩为代表的磨拉石沉积,这次构造事件($T_{1\text{-}1}$)在区域上表现为三叠系角度不整合覆盖在前三叠系之上。同时,沉积物在西部盆地厚,东部盆地薄,说明这次构造事件在西部

强烈,东部鄂尔多斯一带较弱。这次构造活动还导致阿尔金断裂开始走滑活动[29]。中三叠世晚期开始(构造事件 T_{1-2}),柴达木盆地、银-额盆地及六盘山盆地开始发育。柴达木盆地以大规模的火山喷发为特征,形成巨厚的中酸性火山岩,银-额盆地沉积了上三叠统陆相粗碎屑堆积建造,而河西走廊盆地则抬升遭受剥蚀。

1.1.2 早燕山构造旋回(T_2) 晚三叠世至早侏罗世,古特提斯洋东段闭合,羌塘地块与亚洲大陆南缘拼贴,前人称为印支运动,这次构造运动对我国西北地区影响强烈,表现为三叠纪末廻返(柴达木、陇中、鄂尔多斯)或萎缩(塔里木、准噶尔、吐鲁番)的盆地再次活动,盆地以稳定下凹为主,沉积了大规模的河湖—沼泽相含煤岩系(图 1、图 2)。早侏罗世初(构造事件 T_{2-1}),下侏罗统与上三叠统呈角度/平行不整合接触,天山开始隆升[30-32]。这次构造运动的影

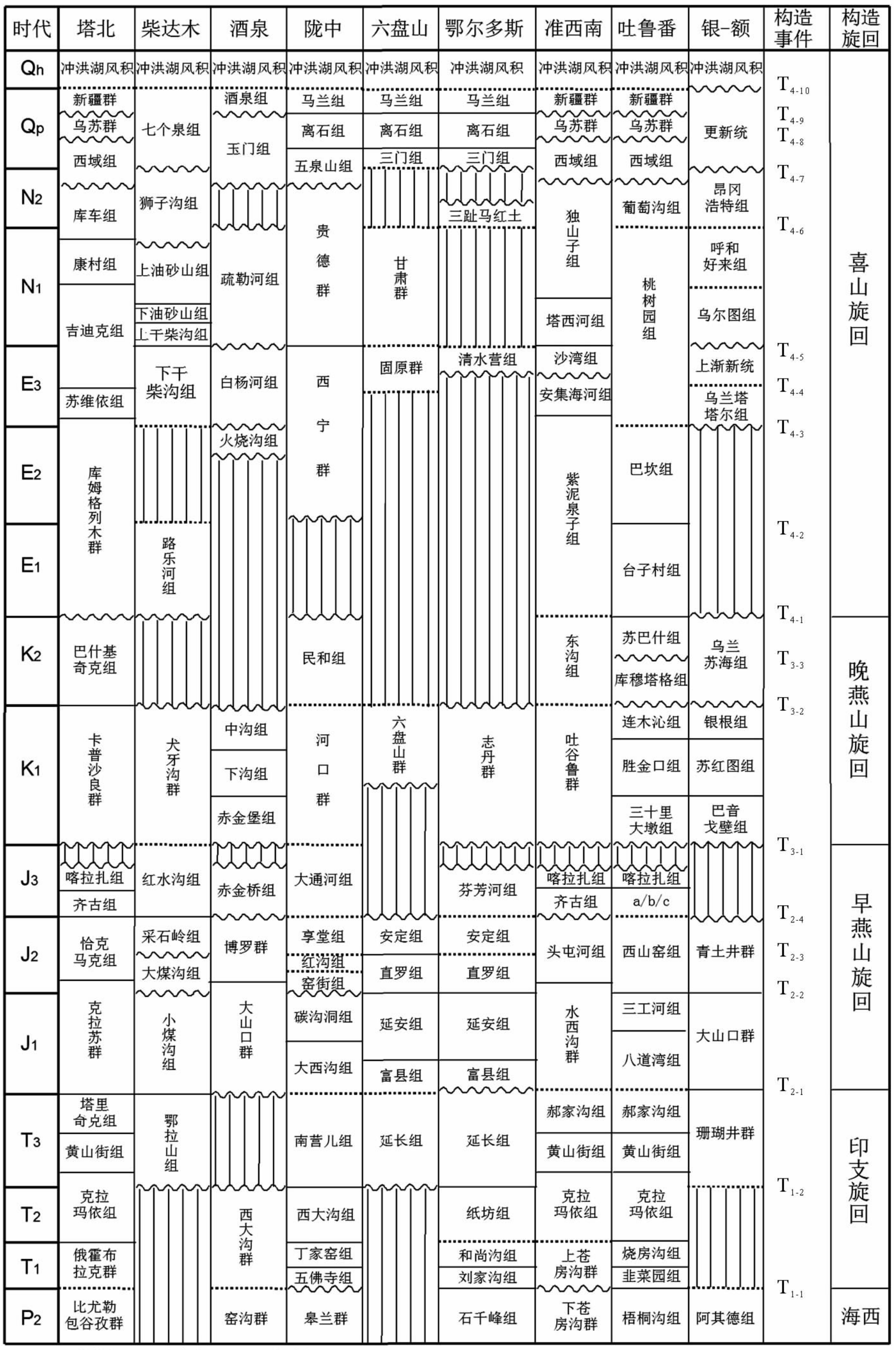

图 1 我国西北地区中—新生代地层与构造活动框架(据文献[16-27]编)

Fig. 1 the Mesozoic-Cenozoic stratigraphic system and tectonic movement pattern in NW China

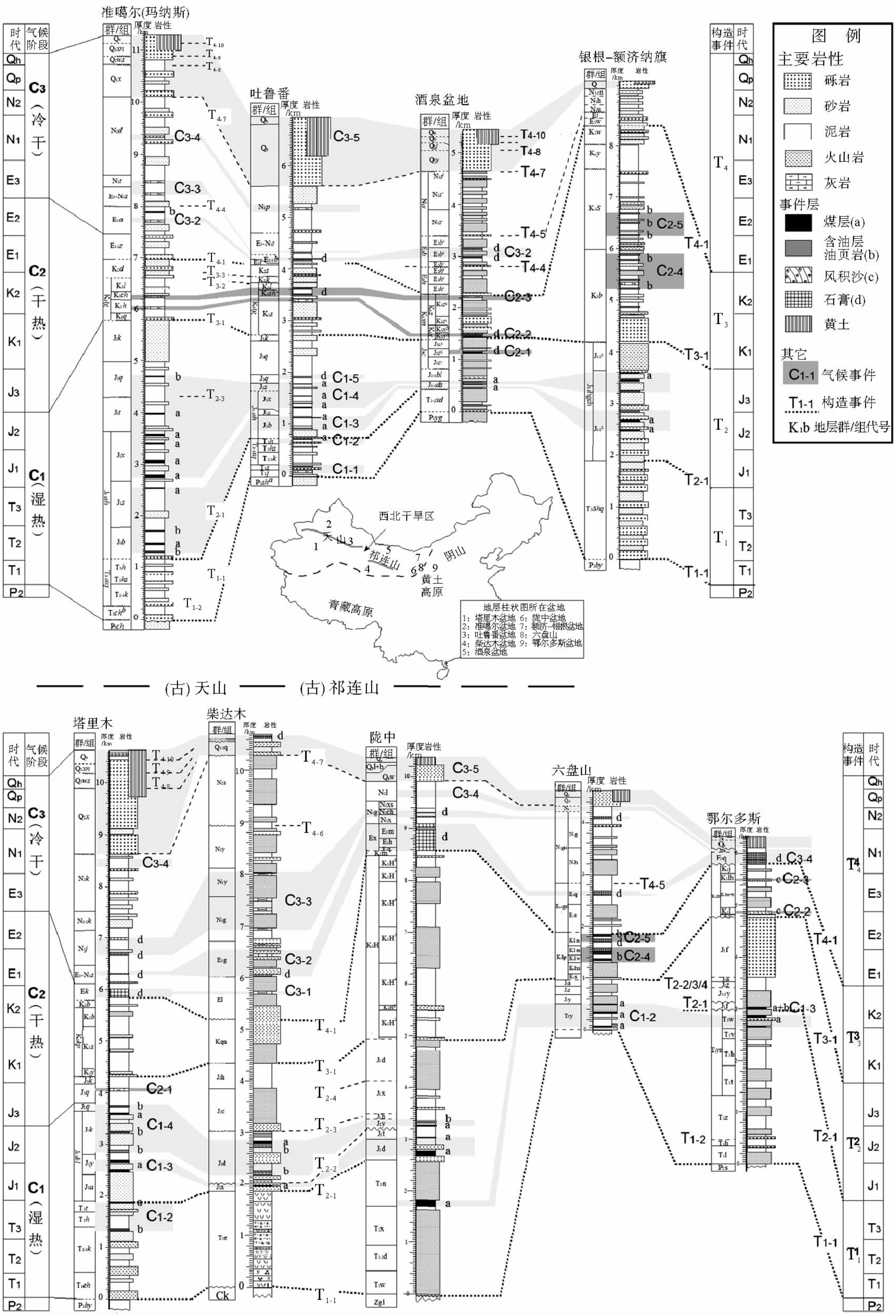

图 2　我国西北地区中—新生代岩石地层与构造—气候事件

Fig. 2　the Mesozoic-Cenozoic lithostratigraphy, and tectonic and climate events in NW China

响一直持续到侏罗纪末，期间最少发生了 3 次规模比较大的构造运动（T_{2-2}、T_{2-3}、T_{2-4}），分别是早侏罗世末—中侏罗世初，柴达木盆地和陇中盆地发生角度不整合（T_{2-2}），而在银-额盆地有中基性火山岩喷发活动；中侏罗世中期（T_{2-3}），准噶尔、柴达木、银—额盆地发育角度不整合，而在吐鲁番、陇中、鄂尔多

斯盆地可见平行不整合。中侏罗世末—晚侏罗世初(T_{2-4}),现今西北干旱区的北部、东部地区如准噶尔、吐鲁番、酒泉、银-额、六盘山盆地发育不整合构造界面,在陇中、鄂尔多斯盆地则表现为平行不整合。这次构造事件可能与阿尔金断裂再次强烈活动[29,33]及东部西伯利亚板块与华北-蒙古地块碰撞[34]有关,并使得准噶尔、吐鲁番、银-额、六盘山盆地持续抬升剥蚀,缺失上侏罗统,直至早白垩世才开始接受沉积。

1.1.3 晚燕山构造旋回(T_3) 晚侏罗世末到早白垩世初,班公湖—怒江洋盆(中特提斯洋)闭合,拉萨地块与亚洲大陆南缘碰撞,这一构造运动同样波及到我国西北地区。同时,我国西北地区还可能受华北岩石圈拆沉作用[35]的影响。前述各大型盆地再次复活(T_{3-1}),以断陷作用为主,沉积了巨厚的冲积扇—河湖相沉积(图 1、图 2),并在酒泉盆地[36]、银—额盆地[37]有拉张环境的中基性火山熔岩产出。早白垩世末至晚白垩世(T_{3-2}),除西北部准噶尔、塔里木等盆地外,东部地区总体处于抬升剥蚀时期,酒泉、鄂尔多斯、六盘山盆地普遍缺失上白垩统地层。

1.1.4 喜马拉雅构造旋回(T_4) 白垩纪末—古近纪初,印度板块与亚洲大陆碰撞,新特提斯洋闭合[38],这次构造运动(T_{4-1})对我国西部地区影响深远,导致一系列高大山脉如天山、祁连山强烈隆升。山前盆地充填了上万米的碎屑沉积(图 1、图 2)。通过对这些盆地构造—沉积过程研究,结合磁性地层和热年代学结果,目前基本确立了青藏高原北部及天山地区构造隆升过程[17-27,39-41]:即距今约 55 Ma(T_{4-2})、40 Ma(T_{4-3})、33 Ma(T_{4-4})、22 Ma(T_{4-5})、8 Ma(T_{4-6},青藏运动序幕)、3.6 Ma(T_{4-7},青藏运动 A 幕,西域砾岩、玉门砾岩等磨拉石建造形成)、1.2 Ma(T_{4-8})、0.14 Ma(T_{4-9},共和运动)等 9 次构造事件。其中前几次构造隆升的幅度都不大,结合模拟结果,大致在晚渐新世—中新世到达足以导致西北地区干旱化强烈的高度[3,4,7]。

1.2 构造格局演变

构造格局涉及大地构造和古地理两方面的内容。二叠纪末,随着古亚洲洋闭合,中国西北地区处于欧亚板块腹地,中—新生代以板内变形为显著特征,表现为一系列大型山脉如天山、阿尔金和祁连等山系隆升,塔里木、准噶尔、柴达木等大型内陆盆地的形成。总体上,受南部地块(基梅里大陆、印度板块)与亚洲大陆碰撞作用,该区处于挤压环境,盆地类型西部以大型坳陷及前陆盆地为主,东部银—额、鄂尔多斯盆地以断陷为主。

关于我国西北地区中—新生代以来的古地理位置即古纬度变化,前人利用古地磁获得了很多数据,总体上反映柴达木自二叠纪在北纬 10 度左右持续向北漂移。而塔里木和准噶尔则自二叠纪在约北纬 30°～35°,新近纪以来才到达现今的位置,即大致向北移动 5°～10°,期间在侏罗纪还有块体的南向漂移[42-44]。由于以前的研究精度及采样位置等限制,或可能的重磁化作用影响,由这些数据获得的地块古纬度的变化还存在着不确定性。

西北地区三叠纪以来的古地理环境总体上表现为山盆相间,仅在塔里木西南有间歇性的海侵[45-46],同时,地势逐渐从东高西低变为西高东低(图 3)。三叠纪至早白垩世,我国东部地势高,西部地势低。大致以古天山—古祁连山—古秦岭为界,北部为准噶尔、河西走廊—银额及鄂尔多斯等大型内陆盆地,而南部则多发育山间盆地(图 3a、3b、3c)。三叠纪塔里木、柴达木大部为低缓的丘陵地带,并与松潘—甘孜海槽相接(图 3a)。侏罗纪随着古昆仑山—古巴颜喀拉山的隆起和阿尔金断裂活动增强,塔里木东南、柴达木及银—额盆地开始发育,是区域隆升向区域沉降的转换界面。此时河道、湖沼密布,森林植被发育,为成煤提供了良好的条件。在各大山体内部也见有同时期的含煤岩系分布,表明三叠系出现的山体均已被剥蚀夷平,不再具有分隔作用。塔里木西南到东北还有一次明显的海侵过程,塔里木盆地沉积范围扩大(图 3b)。至早白垩世,西北地区总体保持了晚侏罗世的古地理特征,盆地扩展,塔里木西南遭受新特提斯洋海侵,地表相对高差进一步加大(图 3c)。而晚白垩世西北地区中部处于抬升剥蚀阶段,普遍缺失上白垩统,西部准噶尔、塔里木及北部银—额盆地下陷接受沉积。

晚白垩世末期至古近纪初,太平洋板块与亚洲东部碰撞[48],东部处于拉张断陷环境;同时,印度—欧亚板块碰撞[38,49]导致天山、昆仑山和祁连山等山系开始强烈隆升,地势变为西高东低。西北地区山前盆地强烈坳陷,盆地沉积范围进一步扩大,堆积了巨厚的沉积物。在塔里木盆地,特提斯海从西南侵入形成浅海(图 3d)。新近纪印度板块持续向北推挤,青藏高原快速隆升,天山、祁连山、昆仑山和喀喇昆仑山等已经形成,副特提斯海退出塔里木盆地(图 3e)。第四纪随着青藏高原和天山脉动式隆升(图 1,图 2),西北地区多表现为河流—湖泊地貌单元的频繁转换,西部山前冲积扇发育,形成一系列大型山前冲积平原,奠定了山前绿洲的雏形,东部黄土高原

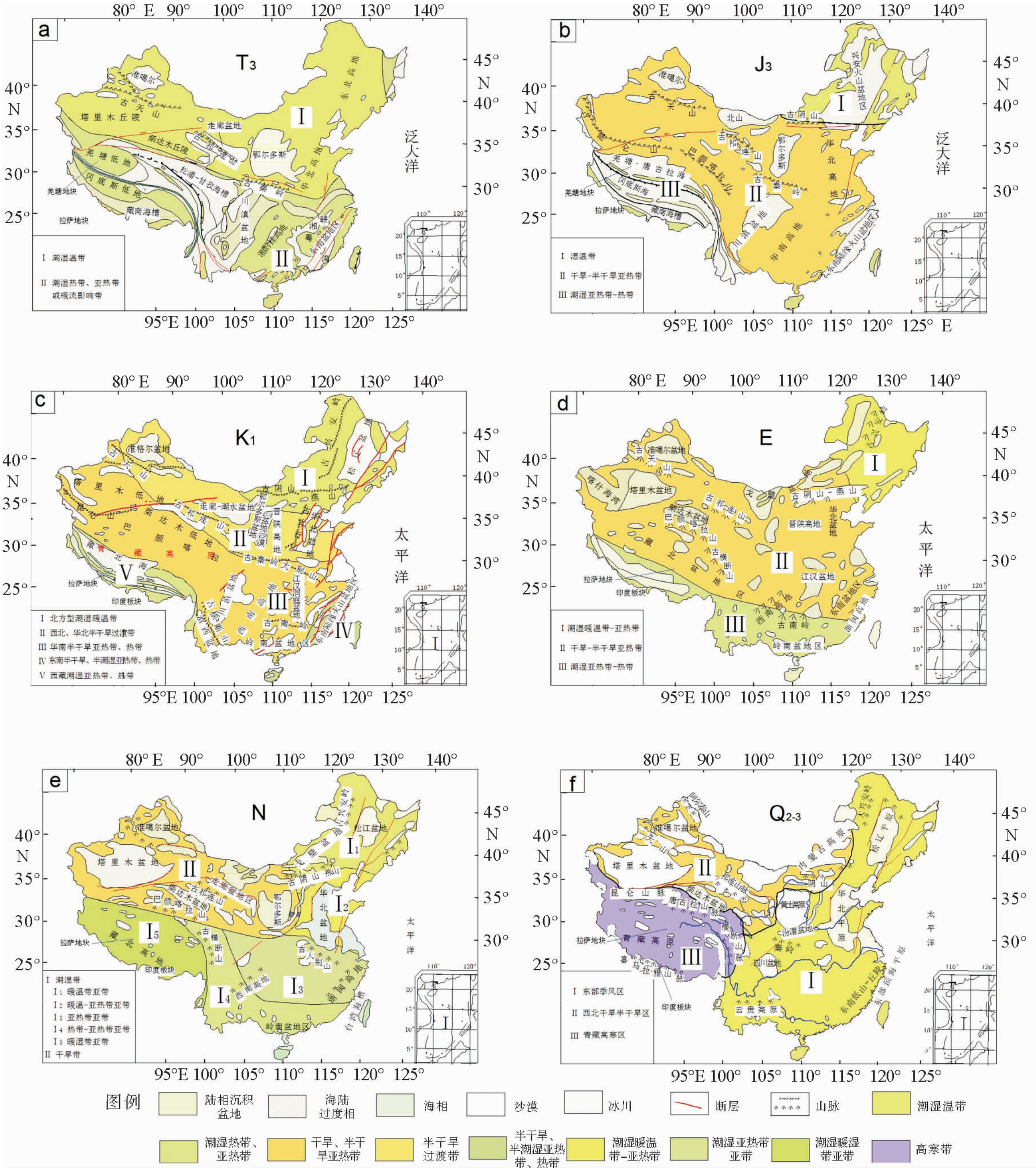

图 3　中国三叠纪以来岩相古地理及气候区带

Fig. 3　the paleography and paleoclimatic zone of China since Triasssic

形成[50]、黄河贯通[51]；我国各大沙漠形成[52]（图 3f）。

2　气候环境事件及演变

我国西北地区中—新生代以来沉积了巨厚的沉积物，以碎屑岩为主夹灰岩、油页岩、煤层及膏盐层等，颜色以红色为主夹灰—灰绿色，总体反映气候比较干热，而页岩、煤层等特征夹层反映了气候的温湿波动，这些特征沉积物夹层可能反映了下列古气候环境信息：含煤层、油页岩层段指示温湿环境，风积砂指示干旱（沙漠）环境，而膏盐岩、灰岩沉积指示半干旱—干旱环境。这些沉积层在不同盆地均有出现，即区域上具有可对比性，因而把这些特征沉积层定义为气候事件。根据这些气候波动事件的时空分布特征，西北地区气候在三叠纪—始新世总体干热、渐新世以来冷干。期间存在晚三叠世—中侏罗世温湿（C1）、晚侏罗世—白垩纪干热（C2）和渐新世—第四纪干冷（C3）3 个气候转型阶段（图 2，图 3）。

早—中三叠世沉积以厚层红色碎屑岩为主，孢

粉组合中裸子植物花粉含量远超蕨类孢子含量[53-55]反映了干旱炎热气候特征，在吐鲁番盆地发育有灰岩夹层，指示了相对干旱的气候事件(C_{1-1})(图 2)。中三叠世沉积物以灰色色调为主，红色岩系不发育；孢粉植物群中裸子植物更加茂盛，晚期松科植物繁殖，指示中三叠早期的气候可能在一定程度上有所继承早三叠世干旱的特征，晚期气候有所改善。晚三叠世，在古天山—古祁连山以南塔里木、柴达木、鄂尔多斯等地，普遍发育煤层，喜湿热环境的蕨类植物[54,56-57]和喜水环境的昆虫群[58]丰富，指示气候显著湿润(C_{1-2})(图 2)。而以北的准噶尔、银—额盆地没有发现煤层，表明此时气候存在南湿北干的差异(图 2、图 3a)。

早侏罗世山体夷平作用明显，各盆地普遍出现含煤层，多呈两套煤系夹一套非煤系的“三明治”式结构，局部地区甚至夹杂色层或红层出现，大型湖泊则发育了暗色湖相泥岩[59]，喜湿热型蕨类植物显著增多[60]，盆地呈现最大湖泛面，气候明显温暖湿润(C_{1-3})。早侏罗世晚期煤层沉积结束，气候干热，喜干热的 *classopollis* 分子大量出现[60-62]。中侏罗世是西北陆相煤层和油页岩最为重要的成藏阶段[63](见图 2)，各大盆地再次出现最大湖泛面，喜湿热环境的蕨类植物爆发[62]，陆生动物群明显发生多样化，这些沉积、生物特征表明这一时期温度适宜，降水丰富，气候处于极适宜阶段(C_{1-4})。中侏罗世晚期各大盆地内煤、油页岩沉积结束，吐鲁番盆地出现大套含石膏质、钙质的红色碎屑沉积，表明气候明显变干(C_{1-5})。

晚侏罗世早期吐鲁番，陇中盆地见有少量油页岩，可能指示了短暂气候湿润，说明气候在短时期内的波动非常强烈。晚侏罗世中晚期，陆相红层大规模发育，陆生动植物稀少，喜干热环境的掌鳞杉科花粉占绝对含量(平均 80%～90%)[61,64-65]气候变得极为干燥(C_{2-1})，是西北地区从湿热向干热变化的转折时期。进入白垩纪，气候总体干热，但也存在几次温湿波动，但由于高大山体的影响，气候南北差异性显著增大，北部公婆泉至银—额盆地一带出现煤线及油页岩沉积，南部诸多盆地发育厚层红色碎屑岩或风成砂岩。早白垩世早期，鄂尔多斯盆地洛河组和罗汉洞组发育两层风成砂沉积[66-68]，分别代表两次明显的干旱气候事件(C_{2-2}、C_{2-3})，除塔里木西南克孜勒苏群中含有风成砂沉积外[69]，多为灰色色调的碎屑沉积和碳酸盐沉积，并持续到晚白垩世，总体处于半干旱环境。早白垩世中期，东部银—额盆地和六盘山盆地沉积一套油页岩层，可能是对全球白垩纪大洋缺氧事件(OAE 1b)的响应[70]，而西部准噶尔、吐鲁番、酒泉等盆地灰岩、石膏夹层出现，指示气候变干，但水汽可能略有增加(C_{2-4})。早白垩世晚期银—额盆地和六盘山盆地再次出现油页岩沉积，但伴随着膏盐层及白云质灰岩沉积，说明气候再次湿润(C_{2-5})。

晚白垩世末—古近纪初，印度板块开始碰撞亚洲板块，新生代西北内陆气候逐渐干旱，经历了若干次气候突变事件。古新世至始新世塔里木和柴达木盆地以沉积红色钙质碎屑岩为主，说明气候转为干旱。在陇中盆地西宁、兰州、河西等地，始新世沉积了巨厚的膏盐层，反映干旱环境的麻黄类分子明显增多，说明气候更为干热(C_{3-1})，在东部六盘山、鄂尔多斯则缺乏这一时期的沉积。进入渐新世，几乎各大盆地都发育红色含石膏质碎屑岩建造，草本植物增加、松科花粉含量上升，充分指示气候冷干(C_{3-2})。早—中中新世各盆地红色碎屑岩及碳酸盐沉积发育，并在陇中盆地东南部出现风成沉积[71-72]表明气候进一步变干(C_{3-3})。晚中新世至上新世，特别是 8 Ma以来，东部鄂尔多斯等地大量出现红色黏土质沉积，中部临夏、西宁一带[73-74]湖泊沉积中发现粉尘沉积也说明此时可能有一次强烈的干旱化(C_{3-4})。晚上新世—第四纪以来，在各大山系山前形成巨厚的砾石堆积层，第四纪以来(C_{3-5})塔里木、柴达木、准噶尔等盆地出现大量的硫酸盐及卤盐沉积，而在山前及山坡上出现黄土沉积，在东部黄土高原形成[50]、几大沙漠形成[52]、现代干旱性气候格局形成。

3 中—新生代西北干旱区演化的动力学机制

气候环境演化的动力学机制，包括全球性的构造—气候变化和局地构造活动及其气候环境效应。中—新生代全球构造格局演变主要表现为 Pangaea 泛大陆的解体和古特提斯洋的闭合与中、新特提斯洋的开合[46,77]，相应的气候状态大致可以划分两个阶段，即三叠纪至始新世全球“温室地球”阶段(包括我国在内的中纬度地区存在一个巨大的干旱带)和渐新世以来全球显著降温，逐步进入两极有冰的“冰室地球”阶段[75-76]，我国西北地区构造—气候环境演变是在全球变化的背景下，叠加了局地的构造活动而形成的，从图 4 可以看出，西北地区构造活动总是先于气候变化发生，构造活动改变了该区的下垫面条件，对气候环境的变化有一定的控制作用。

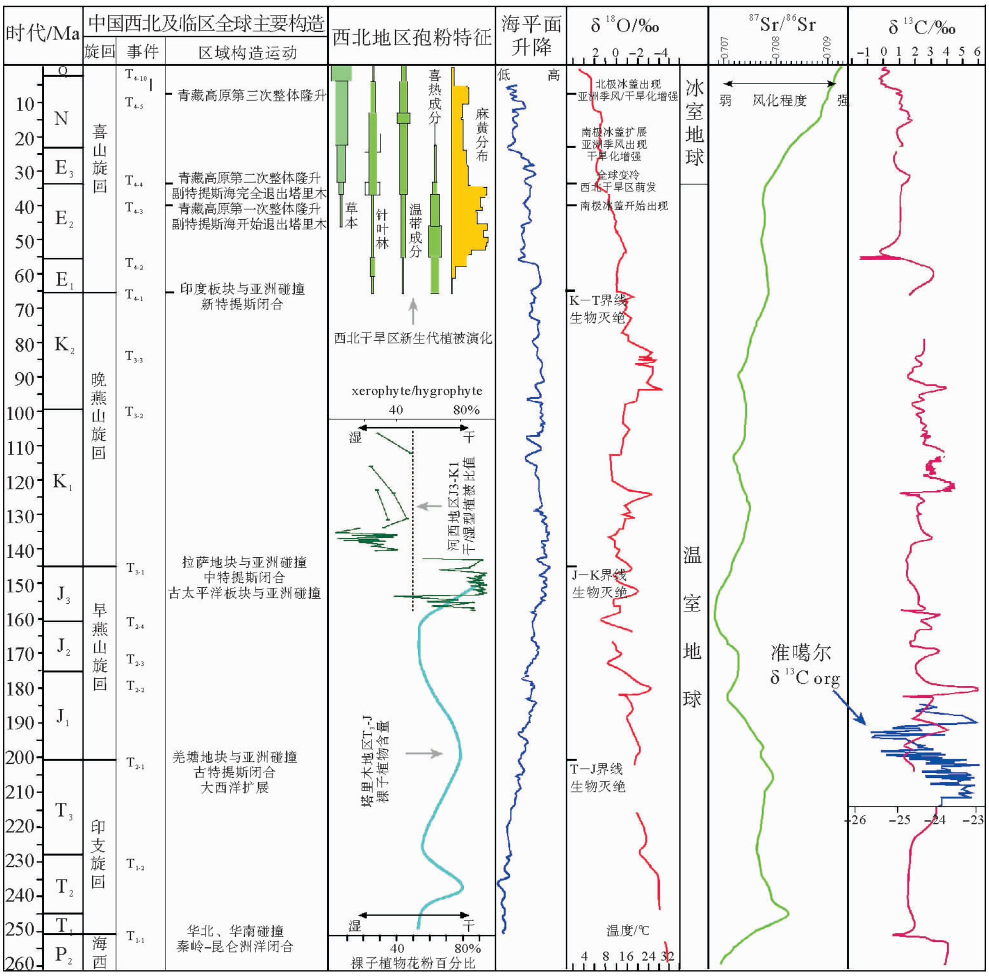

图 4　我国西北地区中—新生代构造—气候演变(据文献[13,28,65,75-81]编)

Fig. 4　the Mesozoic-Cenozoic evolution of the tectonic and climate in the NW china

3.1　三叠纪　我国西北地区三叠纪气候和全球其他地方相比相对湿润,这与当时我国塔里木—华北位于 Pangaea 泛大陆北部中纬度温湿带,且处于泛大陆东部外延部分、呈“半岛”状分隔南部特提斯海和北部泛大洋有关[13,46,82]。三叠纪 Pangaea 大陆形成,全球海平面较低、温度高、陆地风化作用强,气候比较干旱(图 4)。三叠纪初,我国东部华南板块与华北板块碰撞缝合、秦岭洋闭合,西部昆仑洋闭合,使得西北地区处于内陆地区,而南部基梅里大陆裂解出的羌塘地块阻隔了泛大洋的水汽来源,使得西北地区气候总体干旱,这种影响可能一度延续至晚三叠世初。晚三叠世由于南部古特提斯洋扩张,在松潘—甘孜一带形成一个巨大的海槽,西北地区水汽较充足,气候变得潮湿(图 3a),出现了煤层及油页岩沉积(图 2、图 3a)。

3.2　侏罗纪　晚三叠世末至早侏罗纪初,亚洲南部从西向东,羌塘地块、印支地块及印尼地块俯冲拼贴在亚洲板块上,古特提斯洋闭合,我国西部陆地面积进一步扩大。准噶尔南缘郝家沟剖面上三叠统—侏罗统界线层出现明显的有机质碳同位素负偏移现象[81](图 4),反映全球气候在界线期附近变湿,高等植物大量繁盛。这一特征可以和全球多个地区如格陵兰[83]、匈牙利[84]、加拿大[85]和美国西部[86]进行对比,说明西北地区气候变化是对全球气候变化的响应。侏罗纪全球海平面上升、温度有所下降、陆地风化作用较弱(图 4)。而西北部乌拉尔海槽廻返,乌拉尔及周边大片地区隆起[82],亚洲东北部 Mongol-Okhotsk 洋打开及其水汽来源,使得西北地区总体处于湿温带(图 3b),形成大面积的含煤及油页岩沉积(图 2)。

中侏罗世开始,联合大陆开始解体,在北方大陆(包括现在的欧洲、亚洲和北美洲)和南方大陆(包括现在的非洲、南美洲、大洋洲、印度、南极洲和马达加斯加岛)中间形成中特提斯海,Mongol-Okhotsk 洋

闭合[34]；古亚洲陆地面积广阔，此时的西北地区区域构造活动较弱，古天山、祁连山受夷平作用，区域地势低缓，来自特提斯海及古太平洋的水汽得以长驱直入，可能造成了西北地区湿润多雨。晚侏罗世全球气候进入长期平静温室气候状态，全球风化作用降至中生代以来最低水平（图4），地中海碳酸盐台地大规模发育，期间我国西北地区长期干旱环境可能是对全球气候的响应。

3.3　白垩纪　晚侏罗世南大西洋板块扩张加速，冈瓦纳大陆大规模解体[13,87]，南美和非洲大陆脱离南方大陆并向北漂移，中特提斯洋开始进入消减萎缩阶段，大西洋和印度洋开始孕育。晚侏罗世末—早白垩世初，大洋快速扩张[88]导致环赤道海槽关闭，拉萨地块与亚洲板块碰撞、中特提斯洋闭合[13,49,77]，太平洋板块与亚洲大陆碰撞[48]。白垩纪全球海平面[89-90]、温度[91]持续处于高位，大气CO_2含量高[92-94]、陆地风化作用和海洋碳埋藏量大增（图4），大型火成岩省喷发[88,95]）和超地幔柱的强烈活动[96]。热带暖湿气候带范围向西向南扩展，南极地区冷湿气候带向北扩展，北半球干旱区范围有所缩小，被称为典型的温室地球时期[91]。

白垩纪我国大陆构造格局基本形成[14,97]。在库拉－太平洋板块（东部）、西伯利亚板块（北部）和基梅里大陆（西南部）共同作用下，进入了构造调整阶段。早白垩世东部郯庐断裂[98]和西部阿尔金断裂[29]复活，西部准噶尔、塔里木、柴达木和拉萨地块等主要块体发生向北移动、南北向缩短和水平旋转[99-101]东部大陆构造体制由挤压环境变为伸展环境[35,102]、深部岩石圈地幔快速减薄[103-104]岩浆活动强烈[35]，断陷型沉积盆地大规模发育[102,105]；青藏高原北部[29,106-107]和天山[31,108]再次隆升，东部高地被剥蚀夷平，横贯我国西北—东南的大面积沙漠出现[109]，我国地貌格局由此前的东高西低开始向西高东低转变。仅在藏南地区还残留新特提斯海[110-113]。

早白垩世西北地区气候总体干旱，早期出现沙漠沉积，晚期出现膏盐层（图2），并且南干北湿。这与前述全球气候变化及我国构造、地貌格局密切相关。对西北地区东部陇中盆地、六盘山盆地早白垩世沉积物的孢粉及气候代用指标的测量发现，早白垩世气候总体干热，除存在构造尺度的气候波动外，如141～137 Ma气候相对湿热、137～127 Ma气候相对温湿、127～124 Ma气候相对干热和124～116 Ma气候相对温湿[65,114-118]，还存在万年尺度的气候波动[119]，这种波动可能预示着亚洲古季风的存在。

晚白垩世新特提斯海极度萎缩，南美大陆和非洲大陆继续向北移动，印度和澳大利亚板块也从南方大陆解体出来并向北漂移，大西洋和太平洋雏形显现，印度洋也开始发育。同时，海平面的大幅度上涨使大陆周边一些低地没入水下而形成一系列岛链；全球纬度地带性格局初步形成，热带暖湿气候带位于赤道两侧（其范围要比现在的窄一些），中低纬度干旱区呈带状延展，且南半球干旱带范围比北半球干旱带范围略靠近高纬度地区，北极地区冷湿气候带范围有所缩小，北半球中高纬度地区以温湿气候为主。我国西北地区大部分处于持续隆升剥蚀状态，仅在准噶尔、塔里木及银-额盆地有少量的紫红色粗碎屑沉积，显示气候环境极度干旱。

3.4　古、新近纪和第四纪　南方大陆解体并持续到古近纪的南北大陆碰撞[38,49,77,120]可能导致全球变冷[76]和南极冰盖出现[76,121]，使“温室地球”转变为“冰室地球”，全球海平面发生了两次阶段性的降低，全球温度持续降低，陆地风化作用急剧增强（图4）。全球变化[9-10,76]青藏高原的隆升[2-5,8,39-40,122-124]和副特提斯海的退出[6,8]，是中国西北内陆干旱化[2-11,40,71]和东亚季风增强的主要原因[122,125-126]，东亚冬季风的增强进一步加剧了西北内陆的干旱化。

印度板块与亚洲板块的碰撞效应向北穿越我国西北地区，可达贝加尔湖地区[15]。距今约65 Ma，印度板块与亚洲板块发生初始碰撞[38,49,127-128]，但并未影响到西北地区[17-27]，西北地区整体还处于剥蚀阶段。55～40 Ma板块整体碰撞[127-130]，西北地区柴达木、塔里木和准噶尔等大型盆地开始发育。此时青藏高原发生差异性的块体隆升，表现为各大盆地断陷和山脉抬升[49,18-19,131]及高原南部冈底斯带的岩浆活动[132-134]，副特提斯海开始入侵塔里木西南[135-137]。西北地区处于干旱—半干旱环境，气候干热，在东部兰州、西宁等地沉积了巨厚的石膏层，在西宁还一度出现极端干旱的芒硝层。距今约40 Ma开始，南极冰盖开始出现[76,121]（图4），高原开始整体隆升[19,138]，高原南北外缘及天山山前开始出现磨拉石沉积，高原内部发生岩石圈拆沉[133]，高原中部伦坡拉一带可能达到4 000 m左右[139]，副特提斯海开始退出塔里木盆地。西北内陆总体为显著的行星风系下北亚热带副高控制下的干旱—半干旱荒漠植被生态景观[140]。距今约33 Ma，全球急剧降温，南极冰盖形成，青藏高原北部及天山地区开始第二次整体隆升[19]，副特提斯海完全退出塔里木盆地[135]，亚洲内陆气候的大陆度增加，干旱化加强[8,11]。

中新世南极冰盖大规模扩张[76,141]，包括青藏高原[3-8]在内的北半球高大山系再次隆升，青藏高原中南部囊谦一带可能达到最大高度[142]全球风化作用急剧增强[143]，我国西北地区大多被大型湖泊覆盖，局部开始发育较为典型的风成沉积[71-72]，东亚季风开始孕育[3-5]，改变了此前长期控制我国西北地区的大致东西向的大气环流（西风）格局[3-5,144]，数值模拟也支持这一认识[7,145]。距今约 8 Ma，北极冰盖开始形成，青藏高原及天山发生了强烈隆升[3,22,24-25]，并可能达到了垮塌（最大）高度[122]，我国黄土高原地区红黏土序列开始沉积[146-148]，在临夏盆地湖泊中有风成沙的输入[73]，此后塔吉克沙漠开始发育[149]，说明 8 Ma 左右北极冰盖的形成和青藏高原的强烈隆升，导致西北地区干旱化加强，大量的粉尘被传输到太平洋[150]。

距今约 3.6～2.6 Ma 全球冰量急剧增加，此后逐步扩张[76,151]，全球进入第四纪冰期，东亚冬夏季风增强。青藏高原和天山山脉强烈隆升（青藏运动 A 幕，李吉均）[39-40]，在高原南北及天山山前再次形成大规模的磨拉石建造（西域砾岩，玉门砾岩、积石砾岩等）。距今 2.6 Ma 以来，我国西北地区干旱化程度进一步增强，黄土高原开始堆积，并在约 1.8 Ma 黄河开始形成，此后 1.2～0.6 Ma 的昆黄运动（高原进入冰冻圈）及 0.14 Ma（气候变干、马兰黄土堆积）的共和运动[39-40]，西北地区干旱化作用持续增强，形成了现今西北干旱区的状态。

4　结论

（1）我国西北地区中—新生代构造格局演变经历了三叠纪（印支）、早燕山（侏罗纪）、晚燕山（白垩纪）和喜马拉雅（古新近纪和第四纪）4 个构造旋回，最少 19 次构造事件的叠加改造而形成的。构造格局的形成与古亚洲洋、古特提斯海、中特提斯海、新特提斯海的闭合有关。

（2）我国西北地区中—新生代气候环境格局在三叠纪—古近纪始新世总体为干热，但也存在晚三叠世—早侏罗世湿热、晚侏罗世—早白垩世干热和渐新世—第四纪干冷 3 个大的气候转型阶段、13 次气候波动事件。在渐新世至第四纪为冷干环境，并经历了距今约 33、22、8 及 2.4～0.1 Ma 4 次明显的冷干事件。

（3）我国西北地区中—新生代气候环境格局的形成与演化是全球变化和区域构造活动共同作用的结果，全球变化控制本区的大气环流格局和水汽配置，区域构造活动改变本区的海陆分布、下垫面粗糙程度及水汽输送和降水条件。构造作用如青藏高原隆升、特提斯海退出先于全球气候变化影响本区的气候环境变化。

（4）本文对于气候环境事件的厘定主要根据宏观沉积特征，缺乏气候（代用）指标的资料。对于构造、气候事件的区域对比是根据生物地层年代来进行的，缺乏精确的年代控制，因而对这些事件发生的确切年代、持续时间及区域对比均有待于进一步的工作来厘定。

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THE MESOZOIC-CENOZOIC EVOLUTION OF THE TECTONIC AND CLIMATIC PATTERNS, NW CHINA

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Abstract: The formation of the arid northwest China (ANW) is significant to the understanding of the present tectonic and environmental patterns of China. Based on the integrated study of the tectonic and environmental events in northwest China, we found four-phases of tectonic movement, including Indosinian, Early Yanshanian, Late Yanshanian and Himalayan, occurred in this region during Mesozoic and Cenozoic, which had played important role in the formation of ANW. Generally, it was dry and hot during the period from Triassic to Eocene but has been dry and cool since Oligocene in this region. The closure of the Paleo-Asian ocean and the subsequent collision of Qiangtang, Lhasa and India with Asia made northwest China gradually moving away from the ocean and resulted in the dropping of moisture. The climate has changed through three transitional phases, i. e., the wet and hot Late Triassic -Early Jurassic including 5 wet and hot climatic events, the dry and hot Late Jurassic-Late Cretaceous, including 5 dry and hot climatic events, and the dry and cool Oligocene-Quarternary, including 5 dry and cool climate events. We also found that the tectonic and the climate patterns were different in the north and south of this region. Taking the Paleo-Tienshan and Paleo-Qilian Mts. as a boundray, strong tectonic movement and dry climate occurred in the north, but relatively steady and wet climate in the south during the period of Late Triassic-Jurassic. However, in Cretaceous, as the tectonic movement was intensified in the west but remained steady in the east, and climate was dry in the south but wet in the north of NW China. The formation of ANW is the consequence of both the global change and the local tectonic movement. The local tectonic movement happened usually prior to the global change. The occurrence of the dipolar ice-sheet, the uplift of the Tibetan Plateau and the retreating of the Paratethys from the Tarim jointly caused the formation of ANW since Oligocene.

Key words: Evolution, Tectonic pattern, Climatic pattern, Arid northwest China (ANW), Mesozoic-Cenozoic