DOI:10. 19826/j. cnki. 1009-3850. 2021. 02004

从多岛弧盆系构造看西特提斯造山系构造演化

袁四化[1,5], 刘永江[2,3], 常瑞虹[4], Franz Neubauer[4],
Johann Genser[4], 关庆彬[2,3], 黄倩雯[2,3]

(1. 防灾科技学院 地球科学学院, 河北 三河 065201; 2. 中国海洋大学深海圈层与地球系统前沿科学中心, 海底科学与探测技术教育部重点实验室, 海洋地球科学学院, 山东 青岛 266100; 3. 青岛海洋科学与技术国家实验室, 海洋矿产资源评价与探测技术功能实验室, 山东 青岛 266237; 4. 萨尔茨堡大学地质与地理系, 萨尔茨堡 5020 奥地利; 5. 河北省地震动力学重点实验室, 河北 三河 605201)

摘要:本文通过综述近年西特提斯带主要缝合带的研究进展及所代表洋盆的发育特征,提出了古特提斯缝合带可能的位置和俯冲消亡方式。结合区域资料探讨了西特提斯带古生代末—中生代洋陆构造格局,认为东、西古特提斯洋完全可以类比,自晚古生代末西特提斯带主要受古特提斯大洋双向俯冲制约,在俯冲带后缘以二叠纪裂谷带为基础逐渐发展成中生代多岛弧盆系的新特提斯构造格局,西特提斯造山系主要表现为弧后洋盆消减造山作用。

关 键 词:多岛弧盆系;特提斯造山系;缝合带;洋板块地质

中图分类号:P541 **文献标识码**:A

西特提斯带现今构造格局通常认为与阿尔卑斯期新特提斯洋闭合有关(Bernoulli and Jenkyns, 1974; Burchfiel, 1980),目前对于阿尔卑斯期的构造单元划分和中生代以来构造演化相对较清晰(Schmid et al., 2008, 2020; van Hinsbergen et al., 2020)。但是古生代和中生代之交的构造演化历史研究相对薄弱(Stampfli and Hochard, 2009;耿全如等,2021)。传统观点认为新特提斯洋代表较单一的大洋(Bernoulli and Laubscher, 1972),随着多条中生代蛇绿(混杂)岩带的确立(Kozur, 1991; Bonev et al., 2015; Maffione and van Hinsbergen, 2018; Gawlick and Missoni, 2019),越来越多证据表明中生代是多洋盆相间排列的复杂格局(Stampfli et al., 1991; Channell and Kozur, 1997; Stampfli and Kozur, 2006; Papanikolaou, 2009, 2013; Argnani, 2018)。尽管学者们对这些蛇绿岩的年龄和地球化学特征做了大量研究,积累了相当丰富的资料,但这些洋盆的空间匹配依然存在很大争议,再加上经历了晚白垩世—古近纪的逆冲推覆、新近纪的走滑和潘诺尼亚盆地的伸展(Ratschbacher et al., 1991; Wölfler et al., 2011),还有渐新世以来随西地中海不断打开,亚平宁半岛大规模逆时针旋转等一系列的构造运动(Goes et al., 2004; Billi et al., 2011; van Hinsbergen et al., 2014),导致洋盆分布范围、延伸、规模以及形成过程十分不明确。例如中生代梅里阿塔洋由于被强烈逆冲改造导致蛇绿岩的露头有限,其演化过程仍有分歧(Neubauer et al., 2000; Schmid et al., 2008),此外还有彭尼内(Penninic)带与瓦尔达尔(Vardar)–萨瓦(Sava)带关系问题。近年来陆续发现了晚古生代到早中生代的蛇绿(混杂)岩(Masson et al., 2008; Liu et al., 2019)和俯冲增生杂岩(Robertson and Ustaömer, 2009; Zulauf et al., 2019)的新证据,使得古特提斯西延和展布问题再次被大家关注。本文在阿尔卑斯带前中生代

收稿日期: 2020-01-02; **改回日期**: 2020-02-05
作者简介: 袁四化(1980—),男,博士,副教授,主要从事区域构造研究。E-mail: yuansihua@126.com
资助项目: 国家自然科学基金项目(91755212; 41772200),中央高校教师基金(ZY20110202),泰山学者(ts20190918),青岛市创新领军人才计划(19-3-2-19-zhc),41772200,91755212),防灾科技学院精品课程建设项目(Nos. JPJS2018001,JPJS2018005),国家重点研发计划项目(2016YFC0303902-04)

演化总结的基础上(von Raumer et al., 2013; 袁四化等, 2020),重点梳理了有关古生代晚期到中新生代西特提斯带构造尤其是主要缝合带(蛇绿岩带)的研究进展,指出多岛弧盆系构造是解析西特提斯带和古特提斯洋向新特提洋转化过程行之有效的方法。另外,本文在 Stampfii et al. (2002)、Stampfli and Borel(2004)和 van Hinsbergen et al. (2020)的板块重建的基础上,结合 Schmid 等对缝合带的划分(Schmid et al., 2008, 2020)以及最新发现的东阿尔卑斯古特提斯蛇绿岩(Liu et al., 2019)提出古特提斯洋向新特提斯洋转换的新设想。

1　多岛弧盆系构造

多岛弧盆系构造是潘桂棠等以板块构造学说为指导,基于东特提斯构造演化提出的大地构造观(潘桂棠, 1994; 潘桂棠等, 1997, 2004, 2012),并不断从显生宙大地构造拓展到前寒武纪大陆地质,将青藏特提斯构造单元划分(潘桂棠等, 2002; Pan et al., 2012)运用到中国大地构造单元划分(潘桂棠等, 2009)。多岛弧盆系构造系统是指在大陆岩石圈与大洋岩石圈构造体制转换的时空结构中,由大洋岩石圈俯冲作用制约弧后扩张,导致众多岛弧(残余弧或微陆块)与弧后盆地相间错列,形成具有特定结构、构造和时间演化特征的构造系统(潘桂棠等, 2004, 2012)。西太平洋是当今地球上多岛弧盆系构造最发育的地区(图 1),认识其物质组成、结构和构造特点,对理解古造山带非常重要(潘桂棠等, 1997; Xiao et al., 2004; Windley et al., 2007; 袁四化等, 2009b),它常被用来作为大陆造山带组成的模型(李春昱等, 1982; Hsü et al., 1995; Windley et al., 2007; Pan et al., 2012; Xiao et al., 2015)。在现今的西太平洋我们看到其俯冲带形成的前锋弧及其之后的一系列岛弧、火山弧、海岭、岛链、洋岛、海山、微陆块和相应的弧后洋盆、弧间盆地或边缘海盆地并存的构造现象(图 1),而弧后盆地消减所引发的洋壳俯冲或仰冲、洋岛(海山)-岛弧碰撞(如翁通-爪哇)、弧-弧碰撞(马鲁古海)、弧-陆碰撞(如台湾)等多岛弧造山作用并存的现象非常丰富。可以想象,处于洋-陆过渡带的多岛弧盆系不但物质组成复杂,其演化历史更为复杂,存

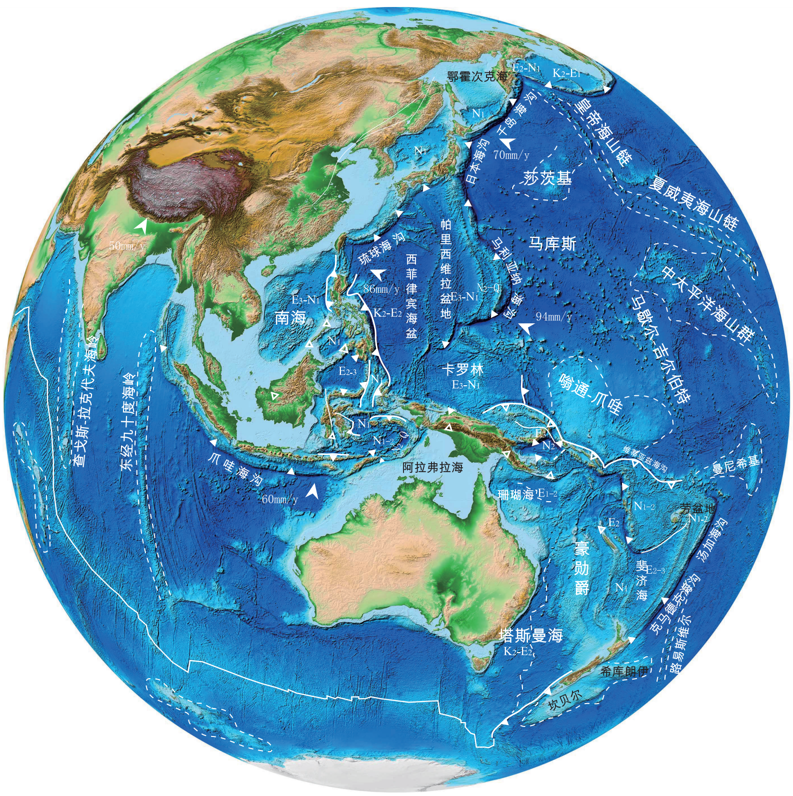

图 1　西太平洋多岛弧盆系构造简图(底图据 Amante and Eakins, 2009)

Fig. 1　Schematic tectonic map of the archipelagic arc-basin systems of the west Pacific(global relief model from Amante and Eakins, 2009)

在各种构造样式,挤压、拉张和旋扭同时并存的现象(袁四化等, 2009b)。如果主洋盆关闭,多岛弧盆系构造系统可以看作洋陆转换过程的增生造山系统(袁四化等, 2009a)。纵观西特提斯构造域,由于特提斯洋和冈瓦纳、劳亚大陆陆缘带相互作用形成复杂的洋陆格局(Stampfli and Borel, 2002; Cavazza et al., 2004; Stampfli and Kozur, 2006; Stampfli and Hochard, 2009),尤其是多条缝合带的存在,它们的构造属性和相互关系还存在诸多不确定性,用多岛弧盆系构造系统来审视西特提斯带有助于澄清相关问题。

2 西特提斯带

特提斯是奥地利地质学家休斯(E. Suess)于1893年提出的地质学术语,指的是从阿尔卑斯山、土耳其-伊朗高原、喜马拉雅山到东南亚消失的古大洋,国内较系统介绍特提斯的论文正是本刊前身之一《特提斯地质》创刊号的两篇重要论文,潘桂棠先生和陈智梁先生从不同角度综述了东特提斯地质演化,值得一提的是两位先生同时提出晚古生代全球大陆“三分天下”的概念(陈智梁, 1994; 潘桂棠, 1994),这一重要认识,对于重建晚古生代以来中国区域构造背景和大地构造单元划分意义重大。

特提斯洋通常被分原、古和新三个时期的大洋(Stampfli and Borel, 2002; 吴福元等, 2020),不过原特提斯洋这一术语在欧洲更多被称为伊阿珀托斯洋(Iapetus)和Tornquest洋(Cocks and Torsvik, 2011),而原特提斯洋在亚洲地区被广泛应用(李三忠等, 2016; Li et al., 2018; Zhao et al., 2018),其关闭时间完全一致,通常称为加里东期构造运动。值得注意的是东西原提斯洋打开和关闭方式完全不一样,不能直接对比。而古特提斯洋和新特提斯洋总体可以对比,但是具体的演化细节存在差异。欧洲学者还常用另外一个术语阿尔卑斯特提斯,通常将阿尔卑斯及其以西的新特提斯洋称为阿尔卑斯特提斯洋(Alpine Tethys)(Favre and Stampfli, 1992; Schmid et al., 2008),主洋盆为皮埃蒙特-利古里亚(Piemont-Liguria)洋,北侧为瓦莱(Valais)洋,二者合称彭尼内洋,二者中间为布里昂松-(伊比利亚)微地块。还有学者提出中特提斯洋的概念(Metcalfe, 1996, 2013b),主要针对基梅里大陆内部,通常将班公湖-怒江缝合带代表的洋称为中特提斯洋(Metcalfe, 2013b)。本文的西特提斯带主要指西班牙到土耳其环地中海造山系,由多个造山带组成(图2),本文重点讨论东阿尔卑斯-巴尔干一带从古特提斯洋到新特提斯洋的转换。

2.1 古特提斯洋

古特提斯洋在东部的缝合带是比较清楚的(李才, 2008; Metcalfe, 2013a; Zhai et al., 2019; 潘桂棠等, 2021),尽管在西部俯冲方向争议很大,但通常认为古特提斯洋延伸到土耳其没有异议,但在土耳其以西的位置争议很大。新特提斯洋侏罗—白垩纪蛇绿岩在西部比较发育,但一直未发现代表古特提斯洋的二叠—三叠纪蛇绿岩。近年在斯特兰贾西面的罗多彼地块发现包括许多超基性岩和榴辉岩(可能达超高压), Turpaud and Reischmann (2010)将其解释为混杂带,称奈斯托斯(Nestos)缝合带(图2中N)。变质年龄主要为三叠纪至侏罗纪(Krenn et al., 2010; Petrík et al., 2016),蛇绿岩的原岩年龄是二叠纪末和三叠纪(Bauer et al., 2007; Liati et al., 2016),报道还有牛津期的年龄(Froitzheim et al., 2014),此外,还有侏罗纪的变质花岗岩(Turpaud and Reischmann, 2010)。这表明了奈斯托斯缝合带的复杂性,后期可能又卷入了新特提斯洋蛇绿岩。Schmid et al. (2020)认为这条缝合带是三叠纪至侏罗纪俯冲期间形成的,代表古特提斯洋的最西端。最近,我们在奥地利阿尔卑斯也发现了二叠—三叠纪的Plankogel蛇绿混杂岩(Liu et al., 2019)(图2中P),这表明古特提斯洋缝合带还可往西延。这与van Hinsbergen et al. (2020)最近通过古地磁恢复的古地理图不谋而合。虽然这两条缝合带规模不大,一方面大部分洋壳可能俯冲下去,另一方面和新特提斯带大致重合,导致很难寻觅其踪迹。

还有一观点来自希腊克里特岛的认识,研究认为岛上千枚岩-石英岩单元原岩由石炭纪至三叠纪的泥岩、砂岩和砾岩互层的海相地层组成,覆盖在古生代变质基底上(Romano et al., 2004; Xypolias et al., 2006)。van Hinsbergen et al. (2005)认为千枚岩-石英岩单元可能形成了特里波利(Tripolitza)地块(图2中T)的基底,并推断源自二叠纪火山弧的侵蚀,这被解释为古特提斯洋向北俯冲的证据(Kock et al., 2007; Marsellos et al., 2012; Zulauf et al., 2015, 2018),这样就等同把古特提斯洋放在品都斯缝合带以西(南)。如果把奈斯托斯缝合带作为古特提斯缝合带,那这条火山弧完全可以用古

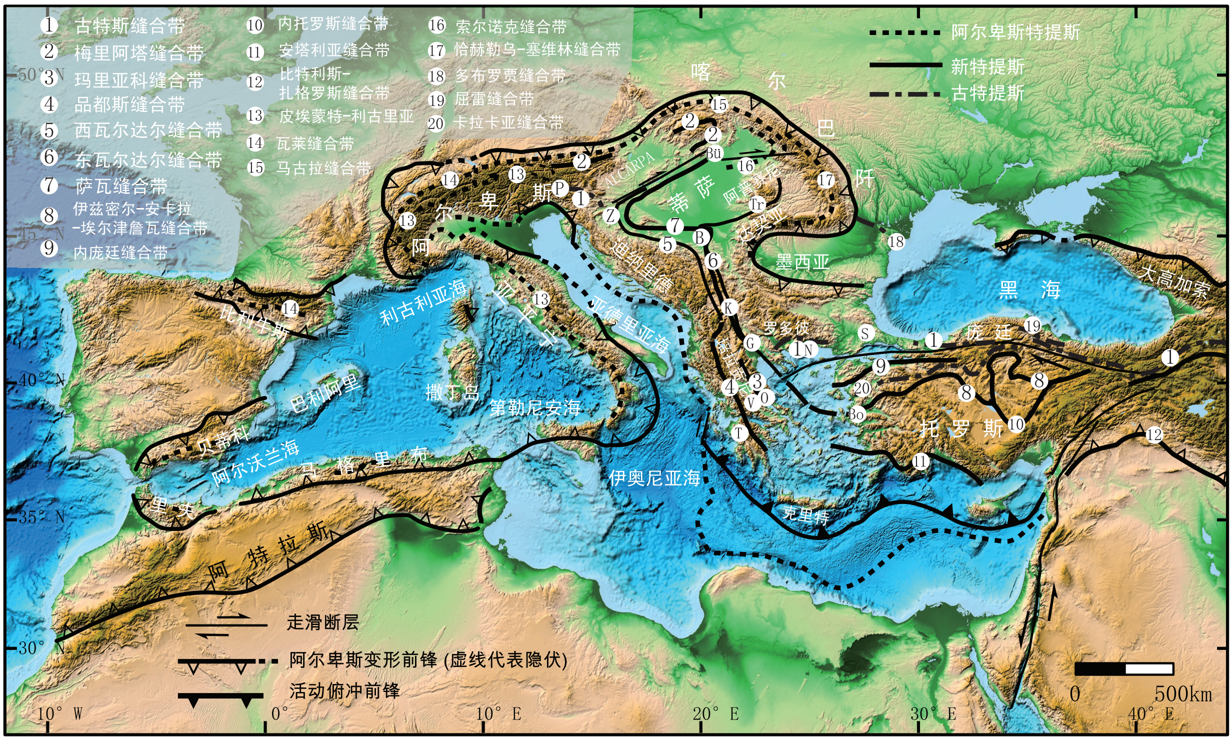

图 2　西特提斯带大地构造简图

(底图据 Amante and Eakins, 2009; 缝合带根据 Kozur, 1991; Pamić and Jurković, 2002; Stampfli and Kozur, 2006; Robertson et al., 2013; Ferriere et al., 2016; Okay et al., 2020; Schmid et al., 2020).

Fig. 2　Overview map of the west Tethysides

(global relief model from Amante and Eakins, 2009; suture compiled from Kozur, 1991; Pamić and Jurković, 2002; Stampfli and Kozur, 2006; Robertson et al., 2013; Ferriere et al., 2016; Okay et al., 2020; Schmid et al., 2020).

特提斯洋向南俯冲来解释。此外,在瓦尔祖夏山(图 2 中 V)和俄特律斯山(图 2 中 O)发育有三叠纪的钙碱性火山岩,带有俯冲相关的地球化学特征(Pe-Piper and Piper, 1991; Pe-Piper, 1998; Koutsovitis et al., 2009),也应对应于古特提斯洋的俯冲弧。在科帕奥尼克(Kopaonik)(图 2 中 K)古生代碎屑沉积物上覆的二叠纪/三叠纪碳酸盐岩夹火山岩,与俯冲相关(Zelić et al., 2005),这样也完全符合我们对缝合带位置的推断。再考虑 Natal' in 等对斯特兰贾(Strandja)地块(图 2 中 S)古生代—三叠纪岩浆的研究,将其解释为古特提斯洋向北俯冲产生的岩浆弧(Natal' in et al., 2016)。这样一来,古特提斯洋极可能是双向俯冲。综上,根据弧盆系的配套关系基本可勾画出古特提斯洋的遗迹,考虑亚德里亚新生代的旋转,当时的古特提斯洋在西端的俯冲带可能是马蹄形状(图 3a,b)。

2.2　新特提斯洋

2.2.1　梅里阿塔缝合带

梅里阿塔(–哈尔施塔特)(Meliata 或 Meliata-Hallstatt)缝合带(图 2 中 2)保留的蛇绿岩序列不完整,主要是根据沿着 ALCAPA(阿尔卑斯山脉东部、喀尔巴阡山脉西部和潘诺尼亚山脉的合称)地块(图 2)的西北和东南边界断续分布的构造岩片、混杂岩推断出来的(Kozur, 1991)。通常认为梅利阿塔洋是新特提斯洋北部的一条分支(Kozur, 1991; Faryad et al., 2005; Plašienka et al., 2019; Putiš et al., 2019),Schmid et al. (2008)认为有可能与瓦尔达尔洋相联系。缝合带中分布最广的是深海沉积物、玄武质(枕状)熔岩。这些岩石的大部分露头集中在喀尔巴阡山脉的中西部,称为梅里阿塔单元。蒸发岩和海相沉积研究表明裂谷作用在晚二叠世开始(Csontos and Vörös, 2004),一直持续到早—中三叠世(Putiš et al., 2019)。三叠纪洋壳可能出现(Mandl, 2000),匈牙利北部–斯洛伐克南部的梅里阿塔镁铁质岩与中、晚三叠世和中侏罗世放射虫相伴(Dosztály and Józsa, 1992),这表明中三叠世洋盆彻底打开。玄武岩地球化学特征揭示了梅里阿塔洋形成于上俯冲带环境(Ivan, 2002),一种观点认为

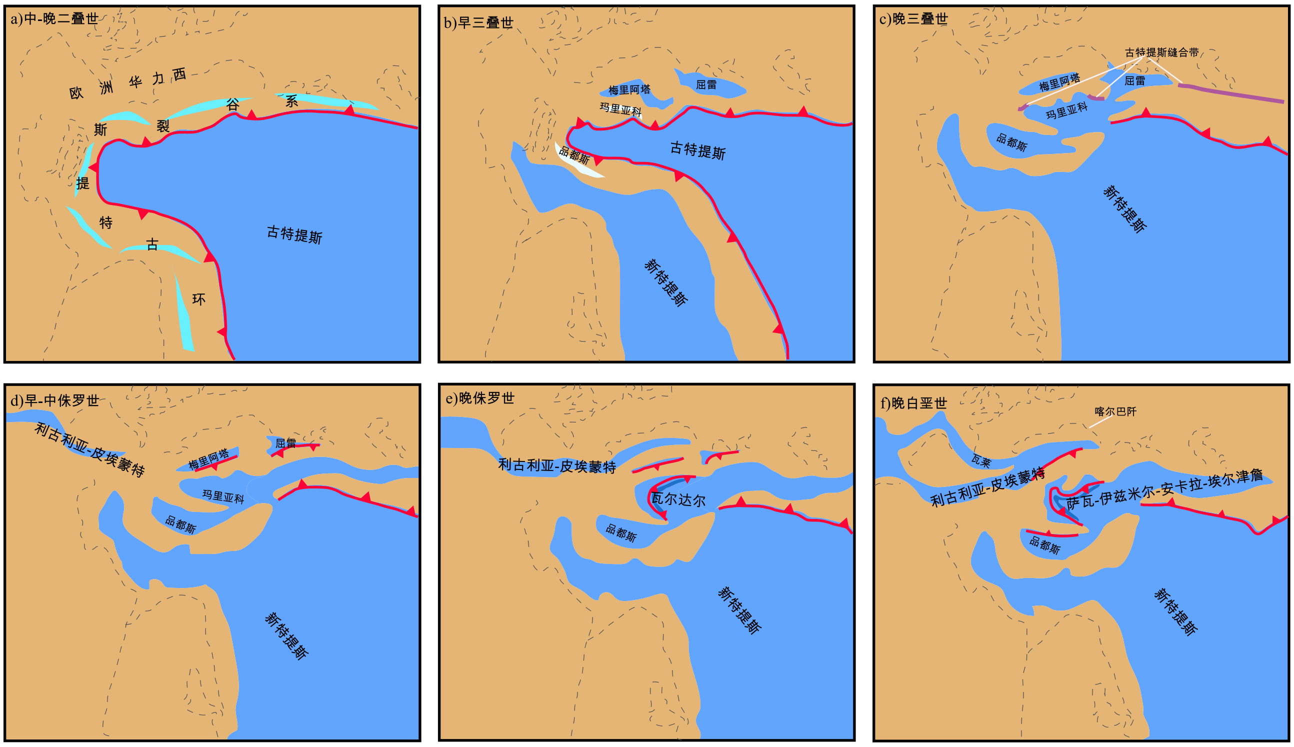

图 3 西特提斯二叠以来古地理重建示意图(据 Stampfli and Borel, 2004 简化并作较大修改)

Fig. 3 Schematic paleogeographic reconstruction of the west Tetlysides from the Permian to Cretaceous (strongly modified from Stampfli and Borel, 2004)

是古特提斯洋俯冲产生的弧后盆地(Golonka, 2004; Stampfli and Borel, 2004),但也有人认为它是在新特提斯洋被动大陆边缘裂谷作用期间形成的(Gawlick and Missoni, 2019)。中侏罗世,可能位于 ALCAPA 地块南侧原始位置的梅里阿塔洋向南俯冲(Neubauer et al., 2000; Schmid et al., 2004; Plašienka, 2018; Gawlick and Missoni, 2019;Yuan et al., 2020),在白垩纪推覆过程中,梅里阿塔缝合带遭到破坏。Kozur et al. (1999)认为梅里阿塔缝合带可能与土耳其庞廷中部的屈雷(Küre)蛇绿岩带相连(图 2 中 18)。屈雷洋盆形成演化与梅里阿塔洋非常相似,但屈雷蛇绿岩具有更完整的序列,并具有明显的上俯冲带地球化学特征,屈雷洋于晚奥伦尼克期打开,被认为是古特提斯洋向北俯冲在欧亚大陆边缘产生的弧后盆地(Ustaömer and Robertson, 1993, 1994; Alparslan and Dilek, 2018)(图 3b)。沉积相分析表明北部存在晚三叠世哈尔施塔特型灰岩的被动边缘,南部边缘存在硅质碎屑复理石(Kozur et al., 2000),表明屈雷洋与梅里阿塔洋都大致于中侏罗世向南开始俯冲(图 3d)。

2.2.2 马利亚科缝合带

马利亚科(Maliac)缝合带的蛇绿岩块主要分布在培拉贡尼地块内部,其它部分主要残留在瓦尔达尔蛇绿岩带中。大多数作者认为现今蛇绿岩均来自于培拉贡尼亚地块东部(Saccani et al., 2011; Ferrière et al., 2012; Robertson, 2012; Bortolotti et al., 2013),向北在阿尔巴尼亚(Bortolotti et al., 1996; Gawlick et al., 2008)、萨格勒布(图 2 中 Z)(Halamić and Goričan, 1995)、克罗地亚西北部(Halamić and Goričan, 1995)、比克山(图 2 中 Bü)(Dimitrijević et al., 2003)能找到三叠纪的蛇绿岩,东面特兰西瓦尼亚推覆体(图 2 中 Tr)可能是源自三叠纪马利亚科洋壳的残留(Schmid et al., 2008; Hoeck et al., 2009)。多数人认为马利亚科洋是个弧后盆地(Stampfli and Borel, 2004; Saccani et al., 2011; Ferrière et al., 2012; Robertson, 2012; Bortolotti et al., 2013),在大陆岩浆弧背景下形成的(Hoeck et al., 2009),可能和古特提洋俯冲有关(Stampfli and Borel, 2004),而 Spahić et al. (2020)认为它也有可能与屈雷弧后盆地相连。马利亚科海底扩张始于晚安尼—早拉丁期持续到巴柔期,巴柔期后开始俯冲(Ferrière et al., 2012; Ferriere et al., 2016)(图 3e)。现有资料表明马利亚科洋比梅

里阿塔洋稍晚,也不能完全排除它们是同一个弧后洋盆的可能(Schmid et al., 2008),或者是联在一起作为梅里阿塔 - 马利亚科弧后洋盆(Saccani et al., 2008; Bortolotti et al., 2013)。

2.2.3　瓦尔达尔缝合带

瓦尔达尔(Vardar)缝合带是西特提斯著名的缝合带,规模非常大,晚期萨瓦缝合带(见后)将这个蛇绿岩带分为东西两个带(Schmid et al., 2008, 2020)(图 2 中 5,6)。尽管对瓦尔达尔蛇绿岩(洋)仍存在争议,但多数人同意东、西瓦尔达蛇绿岩都是在晚侏罗世—早白垩世期间被仰冲到两侧地块上(Pamić et al., 2002b; Schmid et al., 2008; Hoeck et al., 2009; Ionescu et al., 2009; Kounov and Schmid, 2013)。目前通常认为(梅里阿塔 -)马利亚科洋俯冲后退导致了瓦尔达尔洋的开启(Saccani et al., 2008; Bortolotti et al., 2013)(图 3e)。

(1)东瓦尔达尔蛇绿(混杂)岩带

东瓦达尔蛇绿(混杂)岩带沿北马其顿和塞尔维亚东部展布,进入潘诺尼亚盆地最西端被覆盖,过伏伊伏丁那省(Vojvodina)进入阿普赛尼山南部,阿普赛尼山南部蛇绿岩由 MORB 型洋壳组成,被钙碱性岩浆岩侵入并覆盖(Nicolae and Saccani, 2003; Božović et al., 2013; Gallhofer et al., 2017)。蛇绿岩的年龄为中侏罗世,构造混杂岩中还有中—晚三叠世的深水相沉积 (Hoeck et al., 2009; Ionescu et al. , 2009; Kukoč et al., 2015),与南阿普塞尼蛇绿岩相匹配的还有晚侏罗世洋内弧火山岩(Bortolotti et al., 2002a; Nicolae and Saccani, 2003; Bortolotti et al., 2004)。最终侵位年龄根据地层(Bortolotti et al., 2002b; Karamata, 2006; Kukoč et al., 2015)和年代学证据(Anders et al., 2005; Božović et al., 2013)限定为侏罗纪末。仰冲数十千米叠置在达契亚地块上,后期还有向东逆冲构造叠加(Tilită et al., 2013)。向南在希腊北部称盖夫盖利亚(Guevgeli)(图 2 中 G)蛇绿岩,年龄为 164 ~ 155 Ma(Anders et al., 2005),被认为形成于岛弧或弧后环境(Brown and Robertson, 2004)。地震层析成像揭示了爱琴海下方存在一个异常体(Maffione and van Hinsbergen, 2018),该异常可能包含 100 Ma 左右爱琴海俯冲带开始之前俯冲在东瓦尔达尔蛇绿岩下方的岩石圈,即古特提斯洋的岩石圈(Maffione and van Hinsbergen, 2018)。因此,东瓦尔达蛇绿岩形成于古特提斯俯冲带之上(Maffione and van Hinsbergen, 2018)。

基于对众多钻孔、重力、磁力和地震数据的解译(de Broucker et al., 1998),表明保存在特兰西瓦尼亚盆地上白垩统至新生界之下的蛇绿岩,是南阿普赛尼山蛇绿岩的延续,都有晚侏罗世—早白垩世礁灰岩直接覆于蛇绿岩之上的证据(Schmid et al., 2008)。

东瓦尔达尔蛇绿带可能与土耳其的内庞廷(图 2 中 9)蛇绿岩带相连,内庞廷带同样具有上俯冲带地球化学特征,广泛发育中—晚侏罗世的放射虫硅质岩(Ustaömer and Robertson, 1999; Robertson and Ustaömer, 2004; Göncüoglu et al., 2014; Sayit et al., 2016),内庞廷弧后盆地白垩纪早期关闭(Akbayram et al., 2013)。

(2)西瓦尔达尔蛇绿(混杂)岩带

西瓦尔达尔蛇绿(混杂)岩带的北面被大多数学者称为迪纳里德蛇绿岩(Pamić et al., 2002b; Karamata, 2006),又称中迪纳里德蛇绿岩带(Lugović et al., 1991),蛇绿岩的年龄主要为侏罗纪,辉长岩和玄武岩的年龄集中在约 174 Ma ~ 158 Ma(Dilek et al., 2008; Ustaszewski et al., 2009; Slovenec et al., 2011; Lugović et al., 2015),放射虫硅质岩为巴柔期—早牛津期(168 ~ 166 Ma;Kane et al., 2005),萨格勒布附近蛇绿混杂岩基质包含孢粉,年龄为赫塘期—晚巴柔期(Babić et al., 2002)。变质底板的年龄与蛇绿岩极其接近,表明形成后很快发生洋内俯冲(Dilek et al., 2008; Maffione and van Hinsbergen, 2018),Schmid et al. (2008)综合分析区域地层认为大约洋壳形成 10 Ma 后发生洋内俯冲,最终仰冲就位主要发生在钦莫利—贝里阿斯期(Schmid et al., 2020),随后被阿尔布—塞诺曼统地层不整合覆盖(Stampfli and Kozur, 2006)。阿尔巴尼亚超镁铁质蛇绿岩与深成岩体同位素年龄均为中侏罗世—晚侏罗世早期(163 ~ 148 Ma;卡洛夫期至早堤塘期)(Spray et al., 1984; Ustaszewski et al., 2009),上覆最老沉积地层含晚巴柔期—早牛津期放射虫(Prela et al., 2000; Chiari et al., 2002)。在仰冲的蛇绿岩底部变质基底的年龄较老(174 ~ 157 Ma;Dimo-Lahitte et al., 2001),可能代表马利亚科洋壳的残留。

西瓦尔达尔蛇绿岩主要为 SSZ 型(Lugović et al., 1991; Dilek and Furnes, 2009),仅在米尔迪塔(Mirdita)同时存在 MORB 型蛇绿岩(Dilek and

Furnes, 2009)。

2.2.4 萨瓦缝合带

Schmid 和 Ustaszewski 等人近些年从原来瓦尔达尔带中划分出萨瓦(Sava)缝合带(Schmid et al., 2008; Ustaszewski et al., 2009; Schmid et al., 2020),主要基于萨瓦缝合带所代表的洋壳年龄比瓦尔达尔明显年轻。萨瓦带(图2中7)从萨格勒布一直延伸到贝尔格莱德(图2中B)并沿着瓦尔达尔－阿克西奥斯(Axios)河一直延伸到萨洛尼卡湾,萨瓦带将迪纳里德造山带(包括西瓦尔达尔蛇绿岩)与喀尔巴阡－巴尔干造山带(包括东瓦尔达尔蛇绿岩)分开。

萨瓦缝合带在波斯尼亚北部以及贝尔格莱德周围和南部的潘诺尼亚盆地中隆起出露最好。在中新世沉积物包围的残丘中,见上白垩统硅质碎屑沉积物作为萨瓦缝合带增生楔的重要组成部分(Schmid et al., 2020)。在波斯尼亚北部剥露的增生楔深部经历了角闪岩相变质作用,直接影响了白垩系顶部(~65 Ma)沉积物(Ustaszewski et al., 2010)。该区域还暴露出一套晚白垩世的双峰式火成岩,包括均质辉长岩,辉绿岩墙,玄武质枕状熔岩和流纹岩(Ustaszewski et al., 2009),枕状熔岩的深海灰岩夹层中产有坎潘期球藻类化石,这与辉绿岩墙和流纹岩锆石U-Pb年龄(~81 Ma)基本一致。这进一步表明萨瓦洋盆至少持续到坎潘期(Grubić et al., 2009; Ustaszewski et al., 2009; Vishnevskaya et al., 2009)。基于地球化学证据表明,萨瓦洋壳起源于洋内,与洋岛或弧后盆地环境有关(Pamić et al., 2002a; Ustaszewski et al., 2009)(图3f),至少这些蛇绿岩是异常洋脊或者离洋脊不远的洋底高原(Cvetković et al., 2014)。

在贝尔格莱德西部的残丘出露蓝片岩和蛇绿岩(Milovanovic et al., 1995; Dimitrijević, 1997)。萨瓦缝合带进一步追随到贝尔格莱德西北,和瓦尔达尔带挤到一齐变得很窄,最近 Bragin et al.(2019)界定出萨瓦缝合带和两侧东、西瓦尔达尔带。在贝尔格莱德北的潘诺尼亚盆地下东瓦尔达尔带也报道了含坎潘期至马斯特里赫期有孔虫的远洋沉积(Dunčić et al., 2017),侵入到上白垩统沉积物约85 Ma的煌斑岩(Sokol et al., 2017),与 Ustaszewski 等报道的波斯尼亚北部萨瓦缝合带的辉绿岩和流纹岩的年龄相近。

在贝尔格莱德以南,萨瓦缝合带突然弯曲成南北走向,发育白垩纪至古近纪早期的弧前盆地,明显区分两套层序,下部为深水浊积岩,上部为浅水碎屑－碳酸盐岩(Toljić et al., 2018)。在科帕奥尼克,萨瓦缝合带是由后土伦期强烈变形和等斜褶皱的低绿片岩相复理石组成(Zelic et al., 2010; Schefer et al., 2011)。萨瓦缝合带的晚白垩世复理石向南可延到北马其顿,上白垩统直接超覆到培拉贡尼前三叠的基底(Robertson et al., 2013)。萨瓦缝合带沿上白垩统复理带东边界,为强剪切片理化带(Prelević et al., 2017),其东侧存在一对应的晚白垩世岩浆弧展布于阿普塞尼—巴纳特—蒂莫克—斯雷那山(向东可沿东黑海)一线(Berza et al., 1998; Popov et al., 2002; von Quadt et al., 2004; Gallhofer et al., 2015)。萨瓦带所代表的新特提斯洋的晚白垩世俯冲与残留增生楔,弧前盆地以及俯冲相关的岩浆发生是一致的(Gallhofer et al., 2015, 2017; Toljić et al., 2018),基本表明萨瓦洋在白垩纪末至古新世关闭,代表古近纪的缝合(Pamić et al., 2002b; Karamata, 2006; Ustaszewski et al., 2009, 2010)。

过爱琴海可能与土耳其的博尔诺瓦(图2中Bo)复理石带相连,与伊兹密尔－安卡拉－埃尔津詹(Izmir-Ankara-Erzincan)缝合带一起代表新特提斯北部主分支(Schmid et al., 2020; van Hinsbergen et al., 2020)。

2.2.5 品都斯缝合带

品都斯(Pindos)缝合带(图2中4)位于亚德里亚板块和培拉贡尼地块之间,是三叠纪晚期的深水盆地,晚三叠世至古新世为连续的远洋相沉积,包括深水碳酸盐岩、硅质碎屑岩和硅质岩(Degnan and Robertson, 1998),之后是古新世—渐新世复理石(Faupl et al., 1999; Piper, 2006),代表俯冲消亡(Degnan and Robertson, 1998)。早—中卡尼期玄武岩熔岩流和凝灰岩的地球化学判别图显示了火山弧和轻微的 E-MORB 特征,确定了品都斯洋的弧后盆地性质,其形成与古特提洋后退式俯冲有关(Stampfli et al., 2003)。品都斯带向东可能与土耳其的安塔利亚(Antalya)带(图2中11)相连(Brunn et al., 1976; Robertson et al., 1991)。

2.3 阿尔卑斯特提斯洋

阿尔卑斯特提斯蛇绿岩主要展布于亚平宁半岛,向北环阿尔卑斯－喀尔巴阡山分布。西部有两个洋盆展布非常清楚(图2),向东合并为一个洋盆

(图 3f)。最西边皮埃蒙特－利古里亚蛇绿岩(图 2 中 13)在西阿尔卑斯和亚平宁半岛保存最好,在阿尔卑斯山脉的称为彭尼内推覆体,在亚平宁称为托斯卡纳(Tuscan)推覆体,蛇绿岩年龄和古地理重建表明皮埃蒙特－利古里亚洋于中侏罗世打开(Smith, 2006; Gaina et al., 2013; Vissers et al., 2013),晚侏罗—早白垩世(Florineth and Froitzheim, 1994; Stampfli et al., 1998; Schmid et al., 2004; Liati et al., 2005; Handy et al., 2010)北面打开一条分支洋盆瓦莱洋,中间为伊比利亚－布里昂松(Briançonnais)地块。皮埃蒙特－利古里亚洋(有时只使用其中一个,向东也可称彭尼内洋)和瓦莱洋被称为阿尔卑斯特提斯,古新世皮埃蒙特－利古里亚洋消亡(Handy et al., 2010; Decarlis et al., 2013)。瓦莱向东和莱茵多瑙复理石带对应,在西喀尔巴阡山称为马古拉(Magura)复理石(Schmid et al., 2008)(图 2 中 15)。皮埃蒙特－利古里亚向东蛇绿岩主要出露在陶恩构造窗里,到西喀尔巴阡山与皮耶尼内(Pieniny)复理石带相对应,称瓦赫(Váhic)洋(Plašienka, 1995, 2003),塞诺曼期开始向南俯冲(Plašienka, 1995)。在东喀尔巴阡山称为恰赫勒乌－塞维林(Ceahlău-Severin)缝合带(图 2 中 16),但蛇绿岩并不典型(Schmid et al., 2008),可能代表阿尔卑斯特提斯洋的终点。

3 古特提斯洋与新特提斯洋转换的新设想

早石炭世(340～320 Ma)劳亚大陆和西冈瓦纳大陆拼合成潘吉亚超大陆(Gutiérrez-Alonso et al., 2008; Stampfli et al., 2013)。西冈瓦纳大陆与北美克拉通主要表现为大陆碰撞造山,形成著名的华力西造山带,而东南欧的华力西造山作用发生在环冈瓦纳地体群和劳亚大陆之间,主要表现为拼贴增生造山(袁四化等, 2020),并没有发生大陆碰撞造山,华力西带直接面向古特提斯大洋,区域构造受其影响和制约,主要发生古特提斯洋的关闭和新特提斯洋的弧后打开(Şengör, 1979, 1987)。但是,在西特提斯带有关西古特提斯缝合带位置和俯冲方式一直存在不同的认识(Stampfli and Borel, 2002; Zulauf et al., 2015; Schmid et al., 2020; van Hinsbergen et al., 2020),另外古特提斯洋向新特提斯洋是如何过渡的也不清楚。以下是我们的初步认识。

最近在罗多彼(Turpaud and Reischmann, 2010; Schmid et al., 2020)和奥地利阿尔卑斯(Liu et al., 2019)发现的二叠—三叠纪蛇绿岩,使得古特提斯缝合带进一步向西延进巴尔干和奥地利阿尔卑斯有了确凿的依据。虽然 van Hinsbergen et al. (2020)没有注意我们在奥地利阿尔卑斯的最新发现,但是其复原图基本将古特提斯的最西端放在奥地利阿尔卑斯。但对于罗多彼和奥地利阿尔卑斯之间古特提斯缝合带的具体位置,如上文 2.1 中的叙述,我们倾向于放在达契亚地块西边而不同于他们将其放在东边(van Hinsbergen et al., 2020)。尽管在罗多彼地块和奥地利阿尔卑斯之间没有发现古特提斯洋的蛇绿岩,但我们认为可能由于后期缝合带的叠加改造,使得古特提斯缝合带可能再卷入瓦尔达尔缝合带和萨瓦缝合带中。在萨格勒布附近的瓦尔达尔蛇绿混杂岩带除了满足本文 2.1 中所述的弧盆系配套之外,还在提塘期到巴列姆期的砾岩中发现了晚二叠世的花岗岩砾石(Neubauer and Heinrich, 2003),这可能是古特提斯洋俯冲的产物,因此我们将古特提斯放在达契亚的西边,可能和西瓦达尔(萨瓦带)大致叠置在一起。

虽然古特提斯洋俯冲极性仍然存在争议,但按上述缝合带的展布,我们赞同古特提斯洋双向俯冲的观点(Göncüoglu et al., 2000; Robertson and Ustaömer, 2009; Sayit et al., 2011; Candan et al., 2016; Sayit et al., 2017; van Hinsbergen et al., 2020),这样能合理解释区域上很多构造事件。首先,对古特提斯洋制约的多岛弧盆系解释非常合理,从二叠纪开始环古特提斯洋俯冲带后缘二叠—三叠纪普遍发育裂谷型沉积盆地(Gutiérrez-Alonso et al., 2008; de Lamotte et al., 2015)(图 3a),而后依次沿俯冲带对称出现新生的弧后盆地(洋盆)(图 3a,b),可归因于古特提斯洋俯冲板片后退效应(Şengör, 1979; Stampfli and Borel, 2002)。在冈瓦纳大陆北面依次打开新特提斯洋的主支(南支)洋盆和品都斯弧后盆地,在欧亚大陆南缘依次打开梅里阿塔、马利亚科弧后盆地。这种后退俯冲再依次打开弧后盆地可在西太平洋马利亚纳俯冲带后缘(图 1)看到现实的例子。双向俯冲还可以和区域上同时代的弧岩浆相配套,从西班牙比利牛斯到意大利的卡拉布里亚、撒丁－科西嘉岛再到南阿尔卑斯山然后再转向东南的迪纳里德－希腊造山带,这些地区广泛存在二叠纪—三叠纪钙碱性火山岩

(Castellarin et al., 1988; Reischmann et al., 2001; Stampfli et al., 2001; Anders et al., 2006; Storck et al., 2019),与古特提斯洋向南(西)俯冲有关,而斯特兰贾和旁廷带弧岩浆(Natal'in et al., 2016; Aysal et al., 2018)正好与古特提斯洋向北俯冲相对应。

根据蛇绿岩最新年龄为晚三叠和弧岩浆作用基本消失在三叠纪末,目前可以推断古特提斯洋消亡的年龄发生在三叠纪末,与东特提斯洋基本一致,此后,进入新特提斯洋(古特提斯弧后盆地)和阿尔卑斯山特提斯洋的演化阶段(图3)。阿尔卑斯特提斯洋可能和瓦尔达尔洋有连接(Schmid et al., 2008, 2020)。侏罗纪马利亚科俯冲在弧后依次打开瓦尔达尔洋,新特提斯洋和瓦尔达尔洋的俯冲制约了萨瓦-伊兹密尔-安卡拉-埃尔津詹洋(图3),晚中生代以来新特提斯造山主要表现为弧后盆地消减造山作用。

4 结语

尽管西特提斯造山带各个缝合带研究程度都很高,积累了丰富的资料,但对于多洋盆之间的相互关系并不十分清楚,也未认识到古特提斯洋所扮演的角色。本文在综合分析基础上提出古特提斯带对西特提斯带演化起到了重要作用,而这在西特提斯带研究中一直被忽略。晚古生代西特提斯带在华力西造山作用结束后开启了受古特提斯洋俯冲制约的多岛弧盆系构造,由于受阿尔卑斯期强烈地叠加改造,使得古特提斯缝合带支解分散在许多次级构造单元中,很难识别。针对古特提斯洋俯冲方向和俯冲带的位置还存在不同的认识,本文基于多岛弧盆系的空间匹配关系,给出了古特提斯洋是双向俯冲的以及可能的位置,这合理的解释了古特提斯西缘在二叠纪—三叠纪弧亲源的火山岩浆带和弧后盆地的展布。纵观西特提斯洋晚古生代—中生代的演化历史,多岛弧盆系构造格局存在是毫无疑问的。所以,古特提斯大洋岩石圈双向俯冲开启了新特提斯洋的演化,这不但与东特提斯洋演化可以很好的对比,更重要的是这充分体现了多岛弧盆系构造是认识大陆地质的关键(潘桂棠等, 2012)。

本文第一作者曾有幸师从于潘桂棠先生,跟随先生系统学习了多岛弧盆系构造,当然先生的学术贡献远不止于此,但学生天资愚鲁,只能领略其中一二,十分惭愧。先生也是我地质学道路上的一盏明灯,先生的青藏精神一直激励我探索特提斯地质构造。谨以此文祝贺潘先生八十华诞,愿先生福如东海,寿比南山!

参考文献(References):

Akbayram K, Okay A I, Satır M, 2013. Early Cretaceous closure of the Intra-Pontide Ocean in western Pontides (northwestern Turkey) [J]. Journal of Geodynamics, 65: 38-55.

Alparslan G, Dilek Y, 2018. Seafloor spreading structure, geochronology, and tectonic evolution of the Küre ophiolite, Turkey: a Jurassic continental backarc basin oceanic lithosphere in southern Eurasia[J]. Lithosphere, 10(1): 14-34.

Amante C, Eakins B W, 2009. ETOPO1 1 arc-minute global relief model: procedures, data sources and analysis [R]. NOAA Technical Memorandum NESDIS NGDC-24. Boulder: NOAA.

Anders B, Reischmann T, Kostopoulos D, et al., 2006. The oldest rocks of Greece: first evidence for a Precambrian terrane within the Pelagonian Zone[J]. Geological Magazine, 143(1): 41-58.

Anders B, Reischmann T, Poller U, et al., 2005. Age and origin of granitic rocks of the eastern Vardar Zone, Greece: new constraints on the evolution of the Internal Hellenides [J]. Journal of the Geological Society, 162(5): 857-870.

Argnani A, 2018. Subduction evolution of the dinarides and the cretaceous orogeny in the eastern alps: hints from a new paleotectonic interpretation[J]. Tectonics, 37(2): 621-635.

Aysal N, Şahin S Y, Güngör Y, et al., 2018. Middle Permian-early Triassic magmatism in the Western Pontides, NW Turkey: geodynamic significance for the evolution of the Paleo-Tethys[J]. Journal of Asian Earth Sciences, 164: 83-103.

Babić L, Hochuli P A, Zupanic J, 2002. The Jurassic ophiolitic mélange in the NE Dinarides: dating, internal structure and geotectonic implications [J]. Eclogae Geologicae Helvetiae, 95(3): 263-275.

Bauer C, Rubatto D, Krenn K, et al., 2007. A zircon study from the Rhodope metamorphic complex, N-Greece: time record of a multistage evolution[J]. Lithos, 99(3-4): 207-228.

Bernoulli D, Jenkyns H C, 1974. Alpine, mediterranean, and central atlantic mesozoic facies in relation to the early evolution of the tethys [M]//Dott R H Jr, Shaver R H. Modern and Ancient Geosynclinal Sedimentation. SEPM Special Publications. 129-160.

Bernoulli D, Laubscher H, 1972. The palinspastic problem of the hellenides[J]. Eclogae Geologicae Helvetiae, 65(1): 107-118.

Berza T, Constantinescu E, Vlad S-N, 1998. Upper cretaceous magmatic series and associated mineralisation in the carpathian -balkan orogen [J]. Resource Geology, 48(4): 291-306.

Billi A, Faccenna C, Bellier O, et al., 2011. Recent tectonic reorganization of the Nubia-Eurasia convergent boundary heading for the closure of the western Mediterranean[J]. Bulletin de la Société Géologique de France, 182(4): 279 – 303.

Bonev N, Marchev P, Moritz R, et al., 2015. Jurassic subduction zone tectonics of the Rhodope Massif in the Thrace region (NE Greece) as revealed by new U-Pb and $^{40}Ar/^{39}Ar$ geochronology of the Evros ophiolite and high-grade basement rocks[J]. Gondwana Research, 27(2): 760 – 775.

Bortolotti V, Chiari M, Marroni M, et al., 2013. Geodynamic evolution of ophiolites from Albania and Greece (Dinaric-Hellenic belt): one, two, or more oceanic basins? [J]. International Journal of Earth Sciences, 102(3): 783 – 811.

Bortolotti V, Kodra A, Marroni M, et al., 1996. Geology and petrology of ophiolitic sequences in Mirdita region (northern Albania) [J]. Ofioliti, 21(1): 3 – 20.

Bortolotti V, Marroni M, Nicolae I, et al., 2002a. Geodynamic implications of jurassic ophiolites associated with island-arc volcanics, south Apuseni Mountains, western Romania [J]. International Geology Review, 44(10): 938 – 955.

Bortolotti V, Marroni M, Nicolae I, et al., 2004. An update of the Jurassic ophiolites and associated Calc-alkaline rocks in the South Apuseni Mountains (Western Romania) [J]. Ofioliti, 29(1): 5 – 18.

Bortolotti V, Marroni M, Pandolfi L, et al., 2002b. Interaction between mid-ocean ridge and subduction magmatism in Albanian ophiolites [J]. The Journal of Geology, 110(5): 561 – 576.

Božović M, Prelević D, Romer R L, et al., 2013. The demir kapija ophiolite, macedonia (FYROM): a snapshot of subduction initiation within a back-arc[J]. Journal of Petrology, 54(7): 1427 – 1453.

Bragin N, Bragina L, Spajić N G, et al., 2019. New radiolarian data from the Jurassic ophiolitic mélange of Avala Mountain (Serbia, Belgrade Region)[J]. Swiss Journal of Geosciences, 112(1): 235 – 249.

Brown S A M, Robertson A H F, 2004. Evidence for Neotethys rooted within the Vardar suture zone from the Voras Massif, northernmost Greece[J]. Tectonophysics, 381(1 – 4): 143 – 173.

Brunn J H, Argyriadis I, Ricou L E, et al., 1976. Elements majeurs de liaison entre Taurides et Hellenides [J]. Bulletin de la Société Géologique de France, 18(2): 481 – 497.

Burchfiel B C, 1980. Eastern European Alpine system and the Carpathian orocline as an example of collision tectonics [J]. Tectonophysics, 63(1 – 4): 31 – 61.

Candan O, Akal C, Koralay O E, et al., 2016. Carboniferous granites on the northern margin of Gondwana, Anatolide-Tauride Block, Turkey-Evidence for southward subduction of Paleotethys [J]. Tectonophysics, 683: 349 – 366.

Castellarin A, Lucchini F, Rossi P L, et al., 1988. The Middle Triassic magmatic-tectonic arc development in the Southern Alps [J]. Tectonophysics, 146(1 – 4): 79 – 89.

Cavazza W, Roure F, Spakman W, et al., 2004. The TRANSMED Atlas. The Mediterranean Region from Crust to Mantle[M]. Berlin: Springer. 141.

Channell J E T, Kozur H W, 1997. How many oceans? Meliata, Vardar and Pindos oceans in Mesozoic Alpine paleogeography[J]. Geology, 25(2): 183 – 186.

Chiari M, Marcucci M, Prela M, 2002. New species of Jurassic radiolarians in the sedimentary cover of ophiolites in the Mirdita area, Albania[J]. Micropaleontology, 48(1): 61 – 87.

Cocks L R M, Torsvik T H, 2011. The Palaeozoic geography of Laurentia and western Laurussia: a stable craton with mobile margins[J]. Earth-Science Reviews, 106(1 – 2): 1 – 51, doi: 10.1016/j.earscirev.2011.01.007.

Csontos L, Vörös A, 2004. Mesozoic plate tectonic reconstruction of the Carpathian region [J]. Palaeogeography, Palaeoclimatology, Palaeoecology, 210(1): 1 – 56.

Cvetković V, Šarić K, Grubić A, et al., 2014. The Upper Cretaceous ophiolite of North Kozara-remnants of an anomalous mid-ocean ridge segment of the Neotethys? [J]. Geologica Carpathica, 65(2): 117 – 130.

de Broucker G, Mellin A, Duindam P, 1998. Tectono-stratigraphic evolution of the Transylvanian Basin pre-salt sequence Romania [M]//Dinu C, Mocanu V H. Geological Structure and Hydrocarbon Potential of the Romanian Area. Bucharest Geoscience Forum. 36 – 69.

de Lamotte D F, Fourdan B, Leleu S, et al., 2015. Style of rifting and the stages of Pangea breakup[J]. Tectonics, 34(5): 1009 – 1029.

Decarlis A, Dallagiovanna G, Lualdi A, et al., 2013. Stratigraphic evolution in the Ligurian Alps between Variscan heritages and the Alpine Tethys opening: a review[J]. Earth-Science Reviews, 125: 43 – 68.

Degnan P J, Robertson A H F, 1998. Mesozoic-early Tertiary passive margin evolution of the Pindos ocean (NW Peloponnese, Greece) [J]. Sedimentary Geology, 117(1 – 2): 33 – 70.

Dilek Y, Furnes H, 2009. Structure and geochemistry of Tethyan ophiolites and their petrogenesis in subduction rollback systems[J]. Lithos, 113(1 – 2): 1 – 20.

Dilek Y, Furnes H, Shallo M, 2008. Geochemistry of the Jurassic Mirdita Ophiolite (Albania) and the MORB to SSZ evolution of a marginal basin oceanic crust[J]. Lithos, 100(1 – 4): 174 – 209.

Dimitrijević M D, 1997. Geology of Yugoslavia [M]. Belgrade: Geological Institute GEMINI Special Publication. 187.

Dimitrijević M N, Dimitrijević M D, Karamata S, et al., 2003. Olistostrome/mélanges-an overview of the problems and preliminary comparison of such formations in Yugoslavia and NE Hungary[J]. Slovak Geological Magazine, 9(1): 3 – 21.

Dimo-Lahitte A, Monié P, Vergély P, 2001. Metamorphic soles from the Albanian ophiolites: petrology, $^{40}Ar/^{39}Ar$ geochronology, and geodynamic evolution[J]. Tectonics, 20(1): 78 – 96.

Dosztály L, Józsa S, 1992. Geochronological evaluation of Mesozoic formations of Darnó Hill at Recsk on the basis of radiolarians and K-Ar age data[J]. Acta Geologica Hungarica, 35(4): 371 – 393.

Dunčić M, Dulić I, Popov O, et al., 2017. The Campanian-

Maastrichtian foraminiferal biostratigraphy of the basement sediments from the southern Pannonian Basin (Vojvodina, northern Serbia): implications for the continuation of the Eastern Vardar and Sava zones[J]. Geologica Carpathica, 68(2): 130 - 146, doi: 10.1515/geoca-2017-0011.

Faryad S W, Spišiak J, Horváth P, et al., 2005. Petrological and geochemical features of the Meliata mafic rocks from the sutured Triassic Oceanic Basin, Western Carpathians[J]. Ofioliti, 30(1): 27-35.

Faupl P, Pavlopoulos A, Migiros G, 1999. The Paleogene history of the Pelagonian zone s. l. (Hellenides, Greece): heavy mineral study from terrigenous flysch sediments[J]. Geologica Carpathica, 50(6): 449-458.

Favre P, Stampfli G M, 1992. From rifting to passive margin: the examples of the Red Sea, Central Atlantic and Alpine Tethys[J]. Tectonophysics, 215(1-2): 69-97.

Ferriere J, Baumgartner P O, Chanier F, 2016. The Maliac Ocean: the origin of the Tethyan Hellenic ophiolites[J]. International Journal of Earth Sciences, 105(7): 1941-1963.

Ferrière J, Chanier F, Ditbanjong P, 2012. The Hellenic ophiolites: eastward or westward obduction of the Maliac Ocean, a discussion [J]. International Journal of Earth Sciences, 101(6): 1559-1580.

Florineth D, Froitzheim N, 1994. Transition from continental to oceanic basement in the Tasna nappe (Engadine window, Graubünden, Switzerland): evidence for early Cretaceous opening of the Valais Ocean [J]. Schweizerische Mineralogische und Petrographische Mitteilungen, 74(3): 437-448.

Froitzheim N, Jahn-Awe S, Frei D, et al., 2014. Age and composition of meta-ophiolite from the Rhodope Middle Allochthon (Satovcha, Bulgaria): a test for the maximum-allochthony hypothesis of the Hellenides[J]. Tectonics, 33(8): 1477-1500.

Gaina C, Torsvik T H, van Hinsbergen D J J, et al., 2013. The African Plate: a history of oceanic crust accretion and subduction since the Jurassic[J]. Tectonophysics, 604: 4-25, doi: 10.1016/j.tecto.2013.05.037.

Gallhofer D, van Quadt A, Peytcheva I, et al., 2015. Tectonic, magmatic, and metallogenic evolution of the Late Cretaceous arc in the Carpathian-Balkan orogen [J]. Tectonics, 34(9): 1813-1836.

Gallhofer D, von Quadt A, Schmid S M, et al., 2017. Magmatic and tectonic history of Jurassic ophiolites and associated granitoids from the South Apuseni Mountains (Romania) [J]. Swiss Journal of Geosciences, 110(2): 699-719.

Gawlick H-J, Frisch W, Hoxha L, et al., 2008. Mirdita Zone ophiolites and associated sediments in Albania reveal Neotethys Ocean origin [J]. International Journal of Earth Sciences, 97(4): 865-881.

Gawlick H-J, Missoni S, 2019. Middle-Late Jurassic sedimentary mélange formation related to ophiolite obduction in the Alpine-Carpathian-Dinaridic Mountain Range [J]. Gondwana Research, 74: 144-172.

Goes S, Giardini D, Jenny S, et al., 2004. A recent tectonic reorganization in the south-central Mediterranean[J]. Earth and Planetary Science Letters, 226(3-4): 335-345.

Golonka J, 2004. Plate tectonic evolution of the southern margin of Eurasia in the Mesozoic and Cenozoic[J]. Tectonophysics, 381(1-4): 235-273.

Göncüoglu M C, Marroni M, Pandolfi L, et al., 2014. The Arkot Dağ Mélange in Araç area, central Turkey: evidence of its origin within the geodynamic evolution of the Intra-Pontide suture zone [J]. Journal of Asian Earth Sciences, 85: 117-139.

Göncüoglu M C, Turhan N, Şentürk K, et al., 2000. A geotraverse across northwestern turkey: tectonic units of the central sakarya region and their tectonic evolution[J]. Geological Society, London, Special Publications, 173(1): 139-161.

Grubić A, Radoičić R, Knežević M, et al., 2009. Occurrence of Upper Cretaceous pelagic carbonates within ophiolite-related pillow basalts in the Mt. Kozara area of the Vardar zone western belt, northern Bosnia[J]. Lithos, 108(1-4): 126-130.

Gutiérrez-Alonso G, Fernández-Suárez J, Weil A B, et al., 2008. Self-subduction of the Pangaean global plate[J]. Nature Geoscience, 1(8): 549-553.

Halamić J, Goričan Š, 1995. Triassic radiolarites from Mts. kalnik and medvednica (Northwestern Croatia) [J]. Geologia Croatica, 48(2): 129-146.

Handy M R, Schmid S M, Bousquet R, et al., 2010. Reconciling plate-tectonic reconstructions of Alpine Tethys with the geological-geophysical record of spreading and subduction in the Alps[J]. Earth-Science Reviews, 102(3-4): 121-158.

Hoeck V, Ionescu C, Balintoni I, et al., 2009. The Eastern Carpathians "ophiolites" (Romania): remnants of a Triassic ocean[J]. Lithos, 108(1-4): 151-171.

Hsü K J, Pan G T, Sengör A M C, 1995. Tectonic evolution of the Tibetan Plateau: a working hypothesis based on the archipelago model of orogenesis[J]. International Geology Review, 37(6): 473-508.

Ionescu C, Hoeck V, Tomek C, et al., 2009. New insights into the basement of the Transylvanian Depression (Romania)[J]. Lithos, 108(1-4): 172-191.

Ivan P, 2002. Relics of the Meliata Ocean crust: geodynamic implications of mineralogical, petrological and geochemical proxies [J]. Geologica Carpathica, 53(4): 245-256.

Kane I, Stampolidis A, Tsokas N G, et al., 2005. The structure of the ophiolitic beltin Albania inferred from geomagnetic anomalies[J]. Annals of Geophysics, 48(2): 231-246.

Karamata S, 2006. The geological development of the Balkan Peninsula related to the approach, collision and compression of Gondwanan and Eurasian units [J]. Geological Society, London, Special Publications, 260(1): 155-178.

Kock S, Martini R, Reischmann T, et al., 2007. Detrital zircon and micropalaeontological ages as new constraints for the lowermost tectonic unit (Talea Ori unit) of Crete, Greece [J].

Palaeogeography, Palaeoclimatology, Palaeoecology, 243(3-4): 307-321.

Kounov A, Schmid S M, 2013. Fission-track constraints on the thermal and tectonic evolution of the Apuseni Mountains (Romania)[J]. International Journal of Earth Sciences, 102: 207-233.

Koutsovitis P, Magganas A, Katerinopoulos A, 2009. Calc-alkaline volcanic rocks in mélange formations from the South Othris region, Greece: petrogenetic and geotectonic implications [J]. Geochemistry, Mineralogy and Petrology, 47: 79-95.

Kozur H, 1991. The evolution of the Meliata-Hallstatt ocean and its significance for the early evolution of the Eastern Alps and Western Carpathians [J]. Palaeogeography, Palaeoclimatology, Palaeoecology, 87(1-4): 109-135.

Kozur H W, Aydin M, Demir O, et al., 1999. Geological evolution of Middle Pontide area (Northern Turkey) and eastward continuation of the Meliata-Hallstatt Ocean[J]. Geologicky Zbornik, 50: 154-155.

Kozur H W, Aydin M, Demir O, et al., 2000. New stratigraphic and palaeogeographic results from the palaeozoic and early mesozoic of the middle pontides (Northern Turkey) in the azdavay, devrekani, küre and inebolu areas: implications for the carboniferous-early cretaceous geodynamic evolution and some related remarks to the karakaya oceanic rift basin[J]. Geologia Croatica, 53(2): 209-268.

Krenn K, Bauer C, Proyer A, et al., 2010. Tectonometamorphic evolution of the Rhodope orogen[J]. Tectonics, 29(4): TC4001.

Kukoš D, Goričan Š, Košir A, et al., 2015. Middle Jurassic age of basalts and the post-obduction sedimentary sequence in the Guevgueli Ophiolite Complex (Republic of Macedonia)[J]. International Journal of Earth Sciences, 104(2): 435-447.

Li S Z, Zhao S J, Liu X, et al., 2018. Closure of the Proto-Tethys Ocean and Early Paleozoic amalgamation of microcontinental blocks in East Asia[J]. Earth-Science Reviews, 186: 37-75.

Liati A, Froitzheim N, Fanning C M, 2005. Jurassic ophiolites within the Valais domain of the Western and Central Alps: geochronological evidence for re-rifting of oceanic crust [J]. Contributions to Mineralogy and Petrology, 149(4): 446-461.

Liati A, Theye T, Fanning C M, et al., 2016. Multiple subduction cycles in the Alpine orogeny, as recorded in single zircon crystals (Rhodope zone, Greece)[J]. Gondwana Research, 29(1): 199-207.

Liu Y, Neubauer F, Yuan S, et al., 2019. The Plankogel complex within the Austroalpine nappe complex of Eastern Alps: a paleotethyan suture? [C]//Emile Argand Conference on Alpine Geological Studies 2019. Sion. 44.

Lugović B, Altherr R, Raczek I, et al., 1991. Geochemistry of peridotites and mafic igneous rocks from the Central Dinaric Ophiolite Belt, Yugoslavia[J]. Contributions to Mineralogy and Petrology, 106(2): 201-216.

Lugović B, Slovenec D, Schuster R, et al., 2015. Petrology, geochemistry and tectono-magmatic affinity of gabbroic olistoliths from the ophiolite mélange in the NW Dinaric-Vardar ophiolite zone (Mts. Kalnik and Ivanščica, North Croatia) [J]. Geologia Croatica, 68(1): 25-49.

Maffione M, van Hinsbergen D J J, 2018. Reconstructing plate boundaries in the jurassic neo-tethys from the east and west vardar ophiolites (Greece and Serbia)[J]. Tectonics, 37(3): 858-887, doi: 10.1002/2017tc004790.

Mandl G W, 2000. The Alpine sector of the Tethyan shelf-Examples of Triassic to Jurassic sedimentation and deformation from the Northern Calcareous Alps[J]. Mitt. Österr. Geo. Ges., 92: 61-77.

Marsellos A E, Foster D A, Kamenov G D, et al., 2012. Detrital zircon U-Pb data from the Hellenic south Aegean belts: constraints on the age and source of the South Aegean basement[J]. Journal of the Virtual Explorer, 42(3): 1-12.

Masson H, Bussy F, Eichenberger M, et al., 2008. Early Carboniferous age of the Versoyen ophiolites and consequences: non-existence of a "Valais ocean" (Lower Penninic, western Alps)[J]. Bulletin de la Société Géologique de France, 179(4): 337-355.

Metcalfe I, 1996. Gondwanaland dispersion, Asian accretion and evolution of eastern Tethys [J]. Australian Journal of Earth Sciences, 43(6): 605-623.

Metcalfe I, 2013a. Gondwana dispersion and Asian accretion: tectonic and palaeogeographic evolution of eastern Tethys[J]. Journal of Asian Earth Sciences, 66: 1-33.

Metcalfe I, 2013b. Gondwana dispersion and Asian accretion: tectonic and palaeogeographic evolution of eastern Tethys[J]. Journal of Asian Earth Sciences, 66: 1-33.

Milovanovic D, Marchig V, Stevan K, 1995. Petrology of the crossite schist from Fruška Gora Mts (Yugoslavia), relic of a subducted slab of the Tethyan oceanic crust[J]. Journal of Geodynamics, 20(3): 289-304.

Natal'in B A, Sunal G, Gün E, et al., 2016. Precambrian to Early Cretaceous rocks of the Strandja Massif (northwestern Turkey): evolution of a long lasting magmatic arc[J]. Canadian Journal of Earth Sciences, 53(11): 1312-1335.

Neubauer F, Genser J, Handler R, 2000. The Eastern Alps: result of a two-stage collision process[J]. Mitt. Öesterr. Geol. Ges., 92: 117-134.

Neubauer F, Heinrich C, 2003. Late Cretaceous and Tertiary geodynamics and ore deposit evolution of the Alpine-Balkan-Carpathian-Dinaride orogen [C]//Mineral Exploration and Sustainable Development. Rotterdam: Millpress.

Nicolae I, Saccani E, 2003. Petrology and geochemistry of the Late Jurassic calc-alkaline series associated to Middle Jurassic ophiolites in the South Apuseni Mountains (Romania)[J]. Swiss Bulletin of Mineralogy and Petrology, 83(1): 81-96.

Okay A I, Sunal G, Sherlock S, et al., 2020. İzmir-ankara suture as a triassic to cretaceous plate boundary—data from central anatolia[J]. Tectonics, 39(5): e2019TC005849.

Pamić J, Balen D, Herak M, 2002a. Origin and geodynamic evolution of Late Paleogene magmatic associations along the Periadriatic-Sava-

Vardar magmatic belt[J]. Geodinamica Acta, 15(4): 209 - 231.

Pamić J, Jurković I, 2002. Paleozoic tectonostratigraphic units of the northwest and central Dinarides and the adjoining South Tisia[J]. International Journal of Earth Sciences, 91(3): 538 - 554, doi: 10.1007/s00531-001-0229-8.

Pamić J, Tomljenović B, Balen D, 2002b. Geodynamic and petrogenetic evolution of Alpine ophiolites from the central and NW Dinarides: an overview[J]. Lithos, 65(1-2): 113 - 142.

Pan G T, Wang L Q, Li R S, et al., 2012. Tectonic evolution of the Qinghai-Tibet Plateau[J]. Journal of Asian Earth Sciences, 53: 3 - 14.

Papanikolaou D, 2009. Timing of tectonic emplacement of the ophiolites and terrane paleogeography in the Hellenides[J]. Lithos, 108(1-4): 262 - 280.

Papanikolaou D, 2013. Tectonostratigraphic models of the Alpine terranes and subduction history of the Hellenides [J]. Tectonophysics, 595 - 596: 1 - 24.

Pe-Piper G, 1998. The nature of Triassic extension-related magmatism in Greece: evidence from Nd and Pb isotope geochemistry [J]. Geological Magazine, 135(3): 331 - 348.

Pe-Piper G, Piper D J W, 1991. Early mesozoic oceanic subduction-related volcanic rocks, Pindos Basin, Greece[J]. Tectonophysics, 192(3-4): 273 - 292.

Petrík I, Janák M, Froitzheim N, et al., 2016. Triassic to Early Jurassic (c. 200 Ma) UHP metamorphism in the Central Rhodopes: evidence from U-Pb-Th dating of monazite in diamond-bearing gneiss from Chepelare (Bulgaria)[J]. Journal of Metamorphic Geology, 34(3): 265 - 291.

Piper D J W, 2006. Sedimentology and tectonic setting of the Pindos Flysch of the Peloponnese, Greece [J]. Geological Society, London, Special Publications, 260(1): 493 - 505.

Plašienka D, 1995. Passive and active margin history of the northern Tatricum (Western Carpathians, Slovakia) [J]. Geologische Rundschau, 84(4): 748 - 760.

Plašienka D, 2003. Dynamics of Mesozoic pre-orogenic rifting in the Western Carpathians[J]. Mitt. Österr. Geol. Ges., 94: 79 - 98.

Plašienka D, 2018. Continuity and episodicity in the early Alpine tectonic evolution of the western Carpathians: how large-scale processes are expressed by the orogenic architecture and rock record data[J]. Tectonics, 37(7): 2029 - 2079.

Plašienka D, Méres Š, Ivan P, et al., 2019. Meliatic blueschists and their detritus in Cretaceous sediments: new data constraining tectonic evolution of the West Carpathians [J]. Swiss Journal of Geosciences, 112(1): 55 - 81.

Popov P, Berza T, Grubic A, et al., 2002. Late Cretaceous Apuseni-Banat-Timok-Srednogorie (ABTS) magmatic and metallogenic belt in the Carpathian-Balkan orogen[J]. Geologica Balcanica, 32(2): 145 - 163.

Prela M, Chiari M, Marcucci M, 2000. Jurassic radiolarian biostratigraphy of the sedimentary cover of ophiolites in the Mirdita Area, ALBANIA: new data[J]. Ofioliti, 25(1): 55 - 62.

Prelević D, Wehrheim S, Reutter M, et al., 2017. The Late Cretaceous Klepa basalts in Macedonia (FYROM)—Constraints on the final stage of Tethys closure in the Balkans[J]. Terra Nova, 29(3): 145 - 153.

Putiš M, Soták J, Li Q-L, et al., 2019. Origin and age determination of the neotethys meliata basin ophiolite fragments in the late jurassic-early cretaceous accretionary wedge mélange (inner western carpathians, slovakia)[J]. Minerals, 9(11): 652.

Ratschbacher L, Frisch W, Linzer H-G, et al., 1991. Lateral extrusion in the eastern Alps, PArt 2: structural analysis[J]. Tectonics, 10(2): 257 - 271.

Reischmann T, Kostopoulos D, Loos S, et al., 2001. Late palaeozoic magmatism in the basement rocks Southwest of Mt. Olympos, Central Pelagonian zone, Greece: remnants of a permo-carboniferous magmatic arc[J]. Bulletin of the Geological Society of Greece, 34(3): 985 - 993.

Robertson A H F, 2012. Late Palaeozoic-Cenozoic tectonic development of Greece and Albania in the context of alternative reconstructions of Tethys in the Eastern Mediterranean region [J]. International Geology Review, 54(4): 373 - 454.

Robertson A H F, Clift P D, Degnan P J, et al., 1991. Palaeogeographic and palaeotectonic evolution of the Eastern Mediterranean Neotethys [J]. Palaeogeography, Palaeoclimatology, Palaeoecology, 87(1-4): 289 - 343.

Robertson A H F, Trivić B, Derić N, et al., 2013. Tectonic development of the Vardar ocean and its margins: evidence from the Republic of Macedonia and Greek Macedonia[J]. Tectonophysics, 595 - 596: 25 - 54.

Robertson A H F, Ustaömer T, 2004. Tectonic evolution of the Intra-Pontide suture zone in the Armutlu Peninsula, NW Turkey[J]. Tectonophysics, 381(1-4): 175 - 209.

Robertson A H F, Ustaömer T, 2009. Formation of the Late Palaeozoic Konya Complex and comparable units in southern Turkey by subduction-accretion processes: implications for the tectonic development of Tethys in the Eastern Mediterranean region [J]. Tectonophysics, 473(1-2): 113 - 148.

Romano S S, Dörr W, Zulauf G, 2004. Cambrian granitoids in pre-Alpine basement of Crete (Greece): evidence from U-Pb dating of zircon[J]. International Journal of Earth Sciences, 93(5): 844 - 859, doi: 10.1007/s00531-004-0422-7.

Saccani E, Beccaluva L, Photiades A, et al., 2011. Petrogenesis and tectono-magmatic significance of basalts and mantle peridotites from the Albanian-Greek ophiolites and sub-ophiolitic mélanges. New constraints for the Triassic-Jurassic evolution of the Neo-Tethys in the Dinaride sector[J]. Lithos, 124(3-4): 227 - 242.

Saccani E, Photiades A, Santato A, et al., 2008. New evidence for supra-subduction zone ophiolites in the Vardar Zone of northern Greece: implications for the tectono-magmatic evolution of the Vardar oceanic basin[J]. Ofioliti, 33(1): 65 - 85.

Sayit K, Bedi Y, Tekin U K, et al., 2017. Middle Triassic back-arc basalts from the blocks in the Mersin Mélange, southern Turkey:

implications for the geodynamic evolution of the Northern Neotethys [J]. Lithos, 268 – 271: 102 – 113.

Sayit K, Marroni M, Göncüoglu M C, et al., 2016. Geological setting and geochemical signatures of the mafic rocks from the Intra-Pontide Suture Zone: implications for the geodynamic reconstruction of the Mesozoic Neotethys[J]. International Journal of Earth Sciences, 105(1): 39 – 64, doi: 10.1007/s00531 – 015 – 1202 – 2.

Sayit K, Tekin U K, Göncüoglu M C, 2011. Early-middle Carnian radiolarian cherts within the Eymir Unit, Central Turkey: constraints for the age of the Palaeotethyan Karakaya Complex[J]. Journal of Asian Earth Sciences, 42(3): 398 – 407.

Schefer S, Cvetković V, Fügenschuh B, et al., 2011. Cenozoic granitoids in the Dinarides of southern Serbia: age of intrusion, isotope geochemistry, exhumation history and significance for the geodynamic evolution of the Balkan Peninsula[J]. International Journal of Earth Sciences, 100(5): 1181 – 1206.

Schmid S M, Bernoulli D, Fügenschuh B, et al., 2008. The Alpine-Carpathian-Dinaridic orogenic system: correlation and evolution of tectonic units[J]. Swiss Journal of Geosciences, 101(1): 139 – 183.

Schmid S M, Fügenschuh B, Kissling E, et al., 2004. Tectonic map and overall architecture of the Alpine orogen[J]. Eclogae Geologicae Helvetiae, 97(1): 93 – 117.

Schmid S M, Fügenschuh B, Kounov A, et al., 2020. Tectonic units of the Alpine collision zone between Eastern Alps and western Turkey [J]. Gondwana Research, 78: 308 – 374.

Şengör A M C, 1979. Mid-Mesozoic closure of Permo-Triassic Tethys and its implications[J]. Nature, 279(5714): 590 – 593.

Şengör A M C, 1987. Tectonics of the Tethysides: orogenic collage development in a collisional setting[J]. Annual Review of Earth and Planetary Sciences, 15: 213 – 224.

Slovenec D, Lugović B, Meyer H-P, et al., 2011. A tectono-magmatic correlation of basaltic rocks from ophiolite mélanges at the north-eastern tip of the Sava-Vardar suture zone, northern Croatia, constrained by geochemistry and petrology[J]. Ofioliti, 36(1): 77 – 100.

Smith A G, 2006. Tethyan ophiolite emplacement, Africa to Europe motions, and Atlantic spreading[J]. Geological Society, London, Special Publications, 260(1): 11 – 34.

Sokol K, Prelevic D, Romer R, et al., 2017. The Late Cretaceous lamprophyres within the Sava Zone: petrology, geochemistry and geodynamic significance[C]//Proceedings of the 13th workshop on Alpine Geological Studies. EGU Series: Emile Argand Conference Zlatibor Mts. 99.

Spahić D, Glavaš – Trbić B, Gaudenyi T, 2020. The inception of the Maliac Ocean: regional geological constraints on the western Circum-Rhodope belt (northern Greece)[J]. Marine and Petroleum Geology, 113: 104133.

Spray J G, Bébien J, Rex D C, et al., 1984. Age constraints on the igneous and metamorphic evolution of the Hellenic-Dinaric ophiolites [J]. Geological Society, London, Special Publications, 17(1): 619 – 627.

Stampfli G M, Borel G D, 2002. A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrons[J]. Earth and Planetary Science Letters, 196(1 – 2): 17 – 33.

Stampfli G M, Borel G D, 2004. The TRANSMED transects in space and time: constraints on the paleotectonic evolution of the mediterranean domain[M]//Cavazza W, Roure F, Spakman W, et al. The TRANSMED Atlas. The Mediterranean Region from Crust to Mantle: Geological and Geophysical Framework of the Mediterranean and the Surrounding Areas. Berlin: Springer. 3 – 80.

Stampfli G M, Hochard C, 2009. Plate tectonics of the Alpine realm [J]. Geological Society, London, Special Publications, 327(1): 89 – 111.

Stampfli G M, Hochard C, Vérard C, et al., 2013. The formation of Pangea[J]. Tectonophysics, 593: 1 – 19.

Stampfli G M, Kozur H W, 2006. Europe from the Variscan to the Alpine cycles[J]. Geological Society, London, Memoirs, 32(1): 57 – 82.

Stampfli G M, Mosar J, Favre P, et al., 2001. Permo-Mesozoic evolution of the western Tethyan realm: the Neotethys/East- Mediterranean connection[M]//Ziegler P A, Cavazza W, Robertson A H F, et al. Peri-tethys Memoir 6: Peri-tethyan Rift/Wrench Basins and Passive Margins. Mémoires du Muséum national d'Histoire Naturelle. 51 – 108.

Stampfli G M, Mosar J, Marquer D, et al., 1998. Subduction and obduction processes in the Swiss Alps[J]. Tectonophysics, 296(1 – 2): 159 – 204.

Stampfli G, Marcoux J, Baud A, 1991. Tethyan margins in space and time[J]. Palaeogeography, Palaeoclimatology, Palaeoecology, 87 (1 – 4): 373 – 409.

Stampfli G M, Vavassis I, De Bono A, et al., 2003. Remnants of the Paleotethys oceanic suture-zone in the western Tethyan area[M]// Stratigraphic and Structural Evolution on the Late Carboniferous to Triassic Continental and Marine Successions in Tuscany (Italy): Regional Reports and General Correlation. Bolletino della Societa Geologica Italiana. 1 – 24.

Stampfii G M, von Raumer J F, Borel G D, 2002. Paleozoic evolution of pre-Variscan terranes: from Gondwana to the Variscan collision[J]. Geological Society of America Special Paper, 364: 263 – 280.

Storck J-C, Brack P, Wotzlaw J-F, et al., 2019. Timing and evolution of Middle Triassic magmatism in the Southern Alps (northern Italy) [J]. Journal of the Geological Society, 176(2): 253 – 268.

Tiliţă M, Matenco L, Dinu C, et al., 2013. Understanding the kinematic evolution and genesis of a back-arc continental "sag" basin: The Neogene evolution of the Transylvanian Basin[J]. Tectonophysics, 602: 237 – 258.

Toljić M, Matenco L, Stojadinović U, et al., 2018. Understanding fossil fore-arc basins: inferences from the Cretaceous Adria-Europe convergence in the NE Dinarides[J]. Global and Planetary Change, 171: 167 – 184.

Turpaud P, Reischmann T, 2010. Characterisation of igneous terranes by zircon dating: implications for UHP occurrences and suture identification in the Central Rhodope, northern Greece [J]. International Journal of Earth Sciences, 99(3): 567－591.

Ustaömer T, Robertson A H F, 1993. A Late Palaeozoic-Early Mesozoic marginal basin along the actives southern continental margin of Eurasia: Evidence from the central Pontides (Turkey) and adjacent regions[J]. Geological Journal, 28(3－4): 219－238.

Ustaömer T, Robertson A H F, 1994. Late Palaeozoic marginal basin and subduction-accretion: the Palaeotethyan Küre Complex, Central Pontides, northern Turkey[J]. Journal of the Geological Society, 151(2): 291－305.

Ustaömer T, Robertson A H F, 1999. Geochemical evidence used to test alternative plate tectonic models for pre－Upper Jurassic (Palaeotethyan) units in the Central Pontides, N Turkey[J]. Geological Journal, 34(1－2): 25－53.

Ustaszewski K, Kounov A, Schmid S M, et al., 2010. Evolution of the Adria-Europe plate boundary in the northern Dinarides: from continent-continent collision to back-arc extension[J]. Tectonics, 29(6): TC6017.

Ustaszewski K, Schmid S M, Lugović B, et al., 2009. Late Cretaceous intra-oceanic magmatism in the internal Dinarides (northern Bosnia and Herzegovina): implications for the collision of the Adriatic and European plates[J]. Lithos, 108(1－4): 106－125.

van Hinsbergen D J J, Torsvik T H, Schmid S M, et al., 2020. Orogenic architecture of the Mediterranean region and kinematic reconstruction of its tectonic evolution since the Triassic[J]. Gondwana Research, 81: 79－229.

van Hinsbergen D J J, Vissers R L M, Spakman W, 2014. Origin and consequences of western Mediterranean subduction, rollback, and slab segmentation[J]. Tectonics, 33(4): 393－419.

van Hinsbergen D J J, Zachariasse W J, Wortel M J R, et al., 2005. Underthrusting and exhumation: a comparison between the External Hellenides and the "hot" Cycladic and "cold" South Aegean core complexes (Greece)[J]. Tectonics, 24(2): TC2011.

Vishnevskaya V S, Djeric N, Zakariadze G S, 2009. New data on Mesozoic Radiolaria of Serbia and Bosnia, and implications for the age and evolution of oceanic volcanic rocks in the Central and Northern Balkans[J]. Lithos, 108(1－4): 72－105.

Vissers R L M, van Hinsbergen D J J, Meijer P T, et al., 2013. Kinematics of Jurassic ultra-slow spreading in the Piemonte Ligurian ocean[J]. Earth and Planetary Science Letters, 380: 138－150.

von Quadt A, Driesner T, Heinrich C A, 2004. Geodynamics and ore deposit evolution of the alpine-carpathian-balkan-dinaride orogenic system[J]. Swiss Bulletin of Mineralogy and Petrology, 84(1): 1－2.

von Raumer J F, Bussy F, Schaltegger U, et al., 2013. Pre-Mesozoic Alpine basements—Their place in the European Paleozoic framework [J]. Geological Society of America Bulletin, 125(1－2): 89－108.

Windley B F, Alexeiev D, Xiao W J, et al., 2007. Tectonic models for accretion of the Central Asian Orogenic Belt[J]. Journal of the Geological Society, 164(1): 31－47.

Wölfler A, Kurz W, Fritz H, et al., 2011. Lateral extrusion in the Eastern Alps revisited: refining the model by thermochronological, sedimentary, and seismic data[J]. Tectonics, 30(4): TC4006.

Xiao W, Windley B F, Badarch G, et al., 2004. Palaeozoic accretionary and convergent tectonics of the southern Altaids: implications for the growth of Central Asia[J]. Journal of the Geological Society, 161(1): 339－342.

Xiao W J, Windley B F, Sun S, et al., 2015. A tale of amalgamation of three permo-triassic collage systems in central asia: oroclines, sutures, and terminal accretion[J]. Annual Review of Earth and Planetary Sciences, 43: 477－507.

Xypolias P, Dörr W, Zulauf G, 2006. Late Carboniferous plutonism within the pre-Alpine basement of the External Hellenides (Kithira, Greece): evidence from U-Pb zircon dating[J]. Journal of the Geological Society, 163(3): 539－547.

Yuan S H, Neubauer F, Liu Y J, et al., 2020. Widespread Permian granite magmatism in Lower Austroalpine units: significance for Permian rifting in the Eastern Alps [J]. Swiss Journal of Geosciences, 113: 18.

Zelić M, D'Orazio M, Malasoma A, et al., 2005. The metabasites from the Kopaonik metamorphic complex, Vardar Zone, southern Serbia: remnants of the rifting-related magmatism of the mesotethyan domain or evidence for Paleotethys closure in the Dinaric-Hellenic belt? [J]. Ofioliti, 30(2): 91－101.

Zelic M, Levi N, Malasoma A, et al., 2010. Alpine tectono-metamorphic history of the continental units from Vardar zone: the Kopaonik Metamorphic Complex (Dinaric-Hellenic belt, Serbia) [J]. Geological Journal, 45(1): 59－77.

Zhai Q-G, Chung S-L, Tang Y, et al., 2019. Late Carboniferous ophiolites from the southern Lancangjiang belt, SW China: implication for the arc-back-arc system in the eastern Paleo-Tethys [J]. Lithos, 344－345: 134－146.

Zhao G C, Wang Y J, Huang B C, et al., 2018. Geological reconstructions of the East Asian blocks: from the breakup of Rodinia to the assembly of Pangea[J]. Earth-Science Reviews, 186: 262－286.

Zulauf G, Dörr W, Fisher-Spurlock S C, et al., 2015. Closure of the Paleotethys in the External Hellenides: constraints from U-Pb ages of magmatic and detrital zircons (Crete)[J]. Gondwana Research, 28(2): 642－667.

Zulauf G, Dörr W, Marko L, et al., 2018. The late Eo-Cimmerian evolution of the external Hellenides: constraints from microfabrics and U-Pb detrital zircon ages of Upper Triassic (meta) sediments (Crete, Greece)[J]. International Journal of Earth Sciences, 107(8): 2859－2894.

Zulauf G, Dörr W, Xypolias P, et al., 2019. Triassic evolution of the western Neotethys: constraints from microfabrics and U-Pb detrital zircon ages of the Plattenkalk Unit (External Hellenides, Greece) [J]. International Journal of Earth Sciences, 108(8): 2493

-2529.
陈智梁, 1994. 特提斯地质一百年[J]. 特提斯地质, 18: 1-22.
耿全如,李文昌,王立全,等,2021. 特提斯中西段古生代洋陆格局与构造演化[J/OL]. 沉积与特提斯地质. https://doi.org/10.19826/j.cnki.1009-3850.2021.02012.
李才, 2008. 青藏高原龙木错-双湖-澜沧江板块缝合带研究二十年[J]. 地质论评, 54(1): 105-119.
李春昱, 王荃, 刘雪亚, 等, 1982. 亚洲大地构造图(1:800 万)及说明书[M]. 北京: 地图出版社. 45.
李三忠, 赵淑娟, 李玺瑶, 等, 2016. 东亚原特提斯洋(Ⅰ): 南北边界和俯冲极性[J]. 岩石学报, 32(9): 2609-2627.
潘桂棠, 1994. 全球洋-陆转换中的特提斯演化[J]. 特提斯地质, 18: 23-40.
潘桂棠, 陈智梁, 李兴振, 等, 1997. 东特提斯地质构造形成演化[M]. 北京: 地质出版社. 191.
潘桂棠, 王立全, 尹福光, 等, 2004. 从多岛弧盆系研究实践看板块构造登陆的魅力[J]. 地质通报, 23(9-10): 933-939.
潘桂棠, 李兴振, 王立全, 等, 2002. 青藏高原及邻区大地构造单元初步划分[J]. 地质通报, 21(11): 701-707.
潘桂棠, 肖庆辉, 陆松年, 等, 2009. 中国大地构造单元划分[J]. 中国地质, 36(1): 1-28.
潘桂棠, 王立全, 李荣社, 等, 2012. 多岛弧盆系构造模式: 认识大陆地质的关键[J]. 沉积与特提斯地质, 32(3): 1-20.
潘桂棠, 王立全, 耿全如, 等, 2021. 班公湖-双湖-怒江-昌宁-孟连对接带时空结构——特提斯大洋地质及演化问题[J]. 沉积与特提斯地质, 40(3): 1-19.
吴福元, 万博, 赵亮, 等, 2020. 特提斯地球动力学[J]. 岩石学报, 36(6): 1627-1674.
袁四化, 潘桂棠, 王立全, 等, 2009a. 大陆边缘增生造山作用[J]. 地学前缘, 16(3): 31-48.
袁四化, 王立全, 江新胜, 等, 2009b. 多岛海(洋)及多岛弧盆系造山模式解析造山带演化的研究进展[J]. 地质科技情报, 28(5): 1-11.
袁四化, 刘永江, Neubauer F, 等, 2020. 东阿尔卑斯原-古特提斯构造演化[J]. 岩石学报, 36(8): 2357-2382.

A brief review on the tectonic evolution of the west Tethysides

YUAN Sihua[1,5], LIU Yongjiang[2,3], CHANG Ruihong[4], NEUBAUER Franz[4], GENSER Johann[4], GUAN Qingbing[2,3], HUANG Qianwen[2,3]
(1. *College of Earth Sciences*, *Institute of Disaster Prevention*, *Sanhe* 065201, *Hebei*, *China*; 2. *Frontiers Science Center for Deep Ocean Multispheres and Earth System*, *Key Lab of Submarine Geosciences and Prospecting Techniques*, *MOE*, *College of Marine Geosciences*, *Ocean University of China*, *Qingdao* 266100, *Shandong*, *China*; 3. *Laboratory for Marine Mineral Resources*, *Qingdao National Laboratory for Marine Science and Technology*, *Qingdao* 266237, *Shandong*, *China*; 4. *Paris-Lodron-University of Salzburg*, *Department of Geography and Geology*, *Geology Division*, *Hellbrunnerstraße* 34, 5020 *Salzburg*, *Austria*; 5. *Hebei Key Laboratory of Earthquake Dynamics*, *Sanhe* 065201, *Hebei*, *China*)

Abstract: The research progress of the main suture zones in the west Tethysides and the development characteristics of the oceanic basin represented by them are reviewed. We propose the potential location of the Paleo-Tethys suture and summarize a brief evolution of the Paleo-Tethyan Ocean. Combining with regional geological data, this paper discusses the tectonic framework of the west Tethysides during the latest Paleozoic to the Mesozoic. The similar tectonic evolution is also found within the Paleo-Tethys which can be compared between the east and west parts. From the latest Paleozoic onward, the west Tethysides realm was mainly affected by double-sided subduction of the Paleo-Tethys. The Neo-Tethys was characterised by archipelagic arc-basin system during the Mesozoic, which succeed the Permian rifts in the aftermath of the Paleo-Tethys subduction. The west Tethysides was mainly manifested by the orogenesis of collaped back-arc basin.

Key words: composite arc-basin system; Tethysides; suture zone; oceanic plate geology