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贺兰山地区中奥陶统樱桃沟组物源及构造背景分析①

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摘 要 鄂尔多斯盆地西缘贺兰山地区的樱桃沟组发育一套夹有碳酸盐滑塌重力流沉积的陆源碎屑岩。由于缺少可靠的物源数据,对早古生代鄂尔多斯盆地西缘的构造背景尚未有定论。本文对樱桃沟组碎屑岩进行了地球化学及岩石学分析,砂岩碎屑组分特征表明,该组源区大地构造背景为再旋回造山带。常量元素和微量元素地球化学特征表明樱桃沟组的物源呈现双物源的特点。更进一步,樱桃沟组的稀土元素配分模式对比表明了樱桃沟组碎屑岩的物源来自阿拉善古陆和/或北祁连造山带。综合分析砂岩的常量元素、微量元素和稀土元素的地球化学特征,经构造判别图解,认为樱桃沟组物源区主要为主动大陆边缘,也有来自被动大陆边缘的信息,表明贺兰山地区业已受到北祁连早古生代造山带的影响。樱桃沟组与研究区周缘造山带稀土元素配分模式对比研究显示,前者与其北西部阿拉善古陆和南西部北祁早古生代连造山带花岗岩露头稀土元素配分模式一致,均表现为轻稀土富集,重稀土亏损的右倾模式,具有轻微的Eu负异常和明显的Tm负异常,结合中奥陶世鄂尔多斯西缘古水流和碎屑锆石年龄分布特征,认为樱桃沟组的物源主要来自祁连造山带,部分来自阿拉善古陆。

关键词 鄂尔多斯盆地 贺兰山地区 樱桃沟组 构造背景 物源

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0 引言

分布于贺兰山阿拉善左旗地区的中奥陶统樱桃沟组发育一套夹有数套碳酸盐滑塌重力流沉积的陆源碎屑岩,前人[1~10]对该组的沉积学和古生物学研究颇多,但对其物源尚存不同认识:高振中等[7]依据浊积岩底面槽模、沟模、交错层理和少数砾屑灰岩中的叠瓦状构造判断贺兰山、胡基台(阿拉善左旗)一带的古流向,认为贺兰山海底扇的物源来自于其东部的鄂尔多斯古陆碳酸盐台地;林畅松等[3,6]、朱如凯等[5]、孟祥化等[8]、郭峰等[10]认为樱桃沟组为海底扇沉积,其物源来自阿拉善古陆。近来,对鄂尔多斯西缘北段(贺兰山西缘)与鄂尔多斯西缘中南段(牛首山、大罗山、小罗山)的米钵山组砂岩中碎屑锆石LA-ICP-MS U-Pb定年研究表明,其物源均来自阿拉善地块和北祁连造山带,且主要来自北祁连造山带[11,12]。

长期以来,由于缺少非常可靠的物源数据,对早古生代鄂尔多斯盆地西缘的构造背景尚未有定论,具体讨论见张进等[11]。本文对樱桃沟组碎屑岩进行了地球化学及岩石学分析,取得了可靠的物源数据,进而判断该出地层的源区,其结果与近来通过碎屑锆石及其沉积相分析得出的结论基本一致,进一步指出了阿拉善东缘的奥陶纪碎屑岩的物源是祁连山及其阿拉善本身,而没有来自华北板块的信息。在此基础上,对中奥陶世鄂尔多斯盆地的构造背景进行了分析和讨论。

1 区域地质概况

鄂尔多斯盆地位于华北克拉通的西部[13],是一个稳定沉降、凹陷迁移、扭动明显的多旋回克拉通含油气盆地[14],经历了复杂的构造和沉积演化历史[15~20]。鄂尔多斯盆地古生代处于大型稳定克拉通盆地发育阶段[19],发育了区域性的海相沉积。早古生代寒武纪—中奥陶世马家沟期鄂尔多斯盆地的古地理呈现“一隆三凹”的古构造格局,中奥陶世平凉期至晚奥陶世,呈现“一隆两凹”的古地理背景[21],即鄂尔多斯盆地的西缘和南缘在早古生代期间一直为沉积凹陷,与盆地内部存在较大差异,盆地西部和南部以较深水相的海槽沉积为主,而盆地内部则以碳酸盐台地相沉积为主[22]。鄂尔多斯盆地西缘奥陶系海底扇、等深流、浊积岩、内潮汐等沉积[3,5,7,9,23~28]发育,对周围构造事件响应突出,是研究鄂尔多斯盆地

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西缘构造体制的理想地区。

研究区位于鄂尔多斯盆地西缘北部的贺兰山西麓，其北西为阿拉善地块，南西以青铜峡—固原断裂为界与北祁连早古生代造山带相望，东临鄂尔多斯地块，南北分别为祁连海槽和兴蒙海槽，总体呈南宽北窄的楔形体，从北祁连地区向NNE方向楔入阿拉善地块与鄂尔多斯地块之间(图1)。

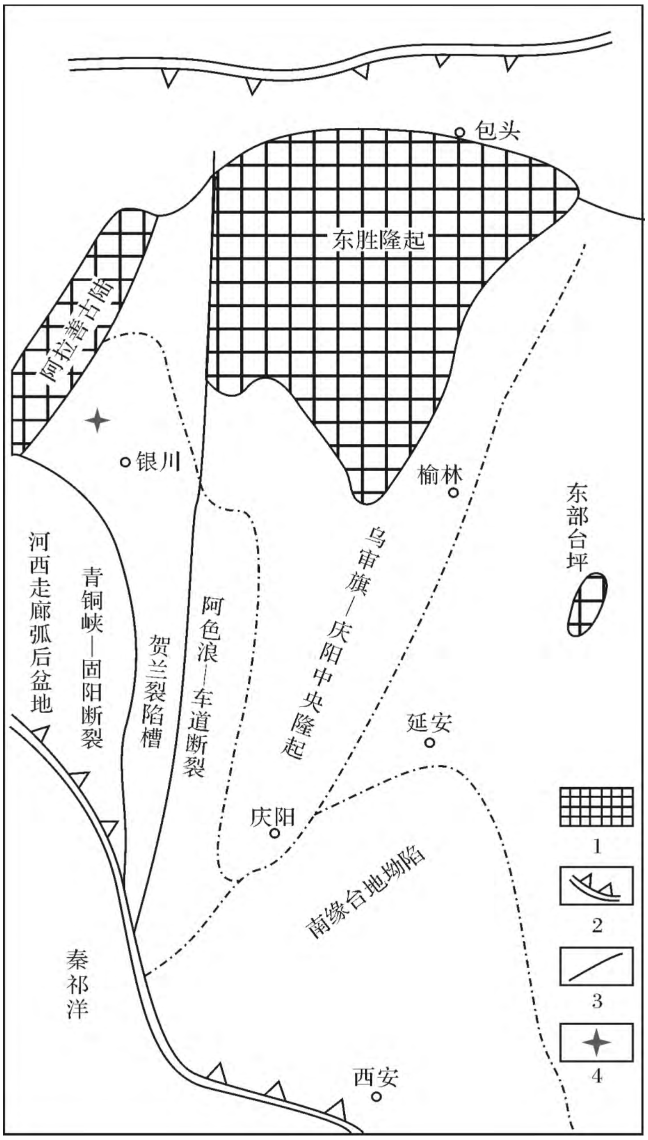


图1 鄂尔多斯盆地西缘早古生代构造略图
(据文献[29]简化)
1.古陆;2.俯冲带;3.断裂;4.研究区

Fig.1 Schematic geotectonic map and paleocurrent direction in western Ordos basin
(base map simplified from Zhang Hong, 1995)
1. ancient landmass; 2. subduction zone; 3. fault; 4. study area

2 樱桃沟组地层划分和沉积特征

樱桃沟组分布于贺兰山西麓的樱桃沟、胡基台等地，厚度及岩相变化剧烈，在樱桃沟厚141 m，向西至胡基台、方家田一带(相距15 km)，厚度增至1 771 m，岩性也随之变化，由薄层泥晶灰岩、砾屑灰岩夹黑色板岩、青灰色板岩与砂岩互层变为粒度更粗的砂、板岩不等厚互层、夹砾岩、砾屑灰岩、砂质灰岩等[4]。胡基台剖面与下伏中梁子祖整合接触，与上覆石炭系羊虎沟组不整合接触(图2A)。整体上，樱桃沟组为一套陆源碎屑浊流夹碳酸盐角砾岩沉积，主要岩性为灰绿色砂页岩夹数层厚度不等的角砾灰岩(图2B)。研究普遍认为樱桃沟组沉积于贺兰坳拉槽边缘斜坡带的深水—半深水环境[1~9]。

对樱桃沟组地层时代归属的认识前后存在一些变化。早期曾一度认为樱桃沟组为早奥陶世晚期沉积，例如葛梅钰等[30]对采自樱桃沟和胡基台剖面的笔石的研究。安太庠等[1]和郑昭昌等[2]认为该组发育的牙形石是混杂的牙形石动物群，根据牙形石序列和地层展布特征将其时代限定为牯牛潭期，可与华北腹地的上马家沟组对比(图2C)。宁夏回族自治区地质矿产局[31,32]认为樱桃沟组与中奥陶统米钵山组岩性相当、层位一致。综上，本文采用樱桃沟组沉积于达瑞威尔阶的认识。

3 樱桃沟组砂岩碎屑成分特征

根据砂岩的成分判断其物源区的构造性质，已经成为盆地分析的通用方法之一[33,34]。对该组48个薄片进行了碎屑统计分析，砂岩几乎全为长石岩屑砂岩，遂选取了10个典型薄片进行了碎屑颗粒百分含量统计分析(表1)。将统计结果投影到Qt-F-L、Qm-F-Lt图解(图3)[35,36]中，可以清楚的看到樱桃沟组源区的大地构造背景一致表现为再旋回造山带。

4 樱桃沟组砂岩地球化学特征

通过物源分析可了解物源区的气候条件和大地构造背景[37]。地球化学在物源及沉积背景分析中起着非常重要的作用，可以解决一些其他方法无法解决的难题[38]。笔者通过详细的室内岩石薄片鉴定，对其中的10个具有代表性的样品统一进行了常量元素、微量元素和稀土元素测试(表2,3,4)。

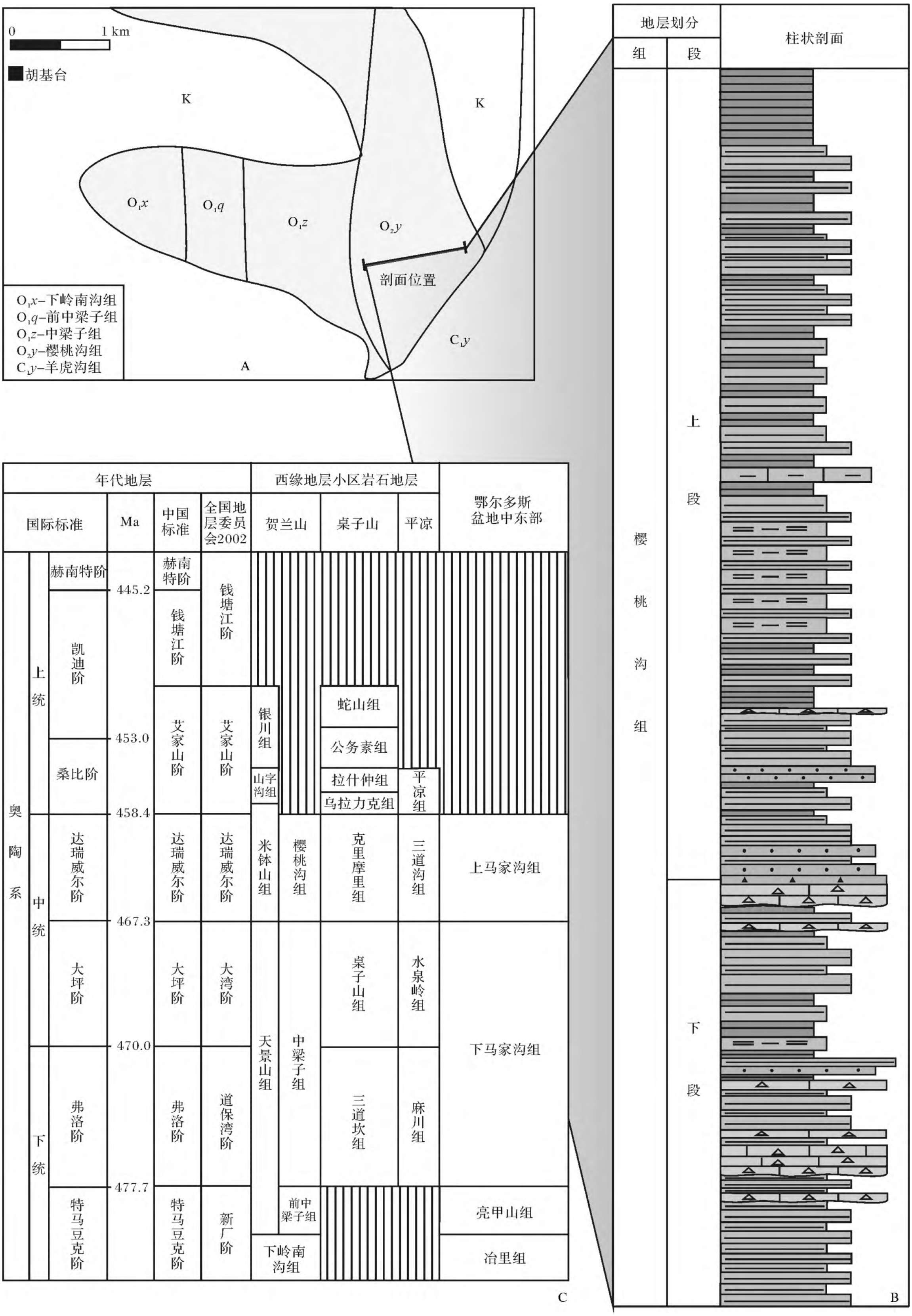


图 2　樱桃沟组剖面位置（A 据文献 [9]）、岩性特征（B）及其地层对比（C）

Fig.2　Location (A after literature [9]) and lithologic character (B) of Yingtaogou Formation and its stratigraphic correlation (C)

表1 樱桃沟组砂岩颗粒组成百分含量(%)

Table 1 Content(%) of the sandstone in the Yingtaogou Formation

样号	Qt-F-L			Qm-F-Lt		
	Qt	F	L	Qm	F	Lt
H-1-R-1	68	13	19	49	13	38
H-1-R-2	57	15	28	36	15	49
H-1-R-3	55	15	30	31	15	54
H-3-R-1	54	21	25	37	21	42
H-4-R-1	67	13	20	45	13	42
H-4-R-2	64	16	20	39	16	45
H-5-R-2	54	10	36	36	10	54
H-6-R-1	55	15	30	31	15	54
H-9-R-1	66	14	20	44	14	42
H-16-R-1	59	11	30	37	11	52

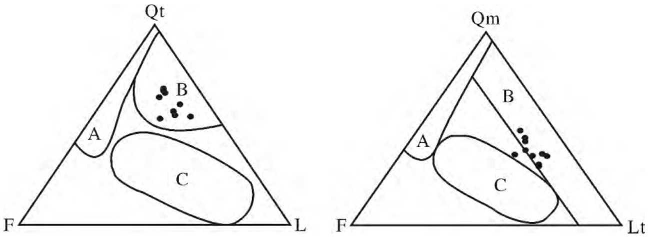


图3 樱桃沟组砂岩碎屑平均组分图解

A. 克拉通; B. 再旋回造山带; C. 岩浆弧

Fig.3 Diagram showing the average component of the sandstone of the Yingtaogou Formation

A. cratons; B. recycled orogenic belt; C. magmatic arc

4.1 常量元素特征

由 Fe$_2$O$_3$+MgO 百分含量分别与 TiO$_2$、Al$_2$O$_3$/SiO$_2$、K$_2$O/Na$_2$O、Al$_2$O$_3$/(CaO+Na$_2$O) 百分含量的关系和其构造环境判别图解(图4)[39]可以看出,研究区樱桃沟组砂岩常量元素与 Bhatia[39] 的数据相比,具有如下特征:①有较为正常的 Fe$_2$O$_3$+MgO 百分含量,变化范围在 2.82%~5.21%之间,平均值为3.72%;②有较低的 TiO$_2$、Al$_2$O$_3$/SiO$_2$百分含量,TiO$_2$百分含量变化范围在 0.37%~0.56%之间,平均值为0.44%;Al$_2$O$_3$/SiO$_2$百分含量变化范围在0.08%~1.14%之间,平均值为 0.1%;③有较高的 K$_2$O/Na$_2$O 百分含量和较低的 Al$_2$O$_3$/(CaO+Na$_2$O) 百分含量,K$_2$O/Na$_2$O 百分含量变化范围在 1.05%~3.21%之间,平均值为 2.25%;Al$_2$O$_3$/(CaO+Na$_2$O) 百分含量变化范围在 1.09%~3.05%之间,平均值为 1.91%;④Fe$_2$O$_3$+MgO 与 TiO$_2$的构造判别图上,1 个点落在大陆岛弧区域内,1 个落在被动大陆边缘范围内,其他 8 个点均落在了活动大陆边缘区域内;在 Fe$_2$O$_3$+MgO 和 Al$_2$O$_3$/SiO$_2$的构造判别图上,1 个点落在了活动大陆边缘区域内,7 个点落在了被动大陆边缘范围内;在 Fe$_2$O$_3$+MgO 和 K$_2$O/Na$_2$O 构造判别图上,1 个点落在被动大陆边缘区域内;在 Fe$_2$O$_3$+MgO 和 Al$_2$O$_3$/(CaO+Na$_2$O) 构造判别图上,有4个点落到了活动大陆边缘

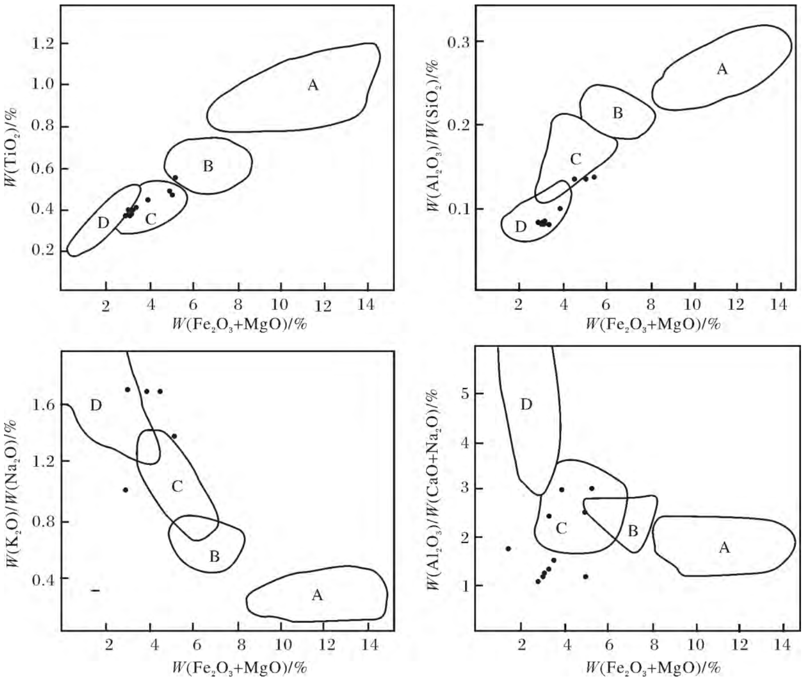


图4 常量元素构造环境判别图(底图据文献[39])

A. 大洋岛弧; B. 大陆岛弧; C. 活动大陆边缘; D. 被动大陆边缘; Fe$_2$O$_3$代表全铁

Fig.4 Diagram of major elements and tectonic setting

A. Oceanic island arc; B. Continental island arc; C. Active continental margin; D. Passive continental margin; Fe$_2$O$_3$ represents total iron

上。由以上数据可以看出，研究区中奥陶世樱桃沟组具有高的 K_2O 含量、低的 Al_2O_3 含量，高的 K_2O/Na_2O 比值和低的 $Al_2O_3/(CaO+Na_2O)$ 比值，其物源区总体成分主要与活动边缘和被动大陆边缘相关。

同时，根据 Roser[40] 对砂岩、泥岩套提出的 SiO_2-K_2O/Na_2O、TiO_2-SiO_2 图解(图 5)，可判断出被动大陆边缘和活动大陆边缘是樱桃沟组的主要物源区; 在 TiO_2-SiO_2 图解上，样品落入沉积岩区，说明樱桃沟组物质来源于正常沉积。

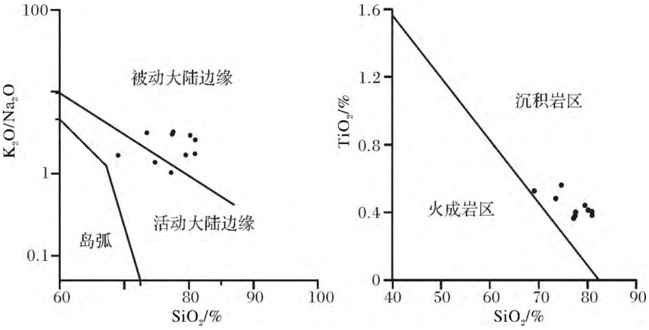


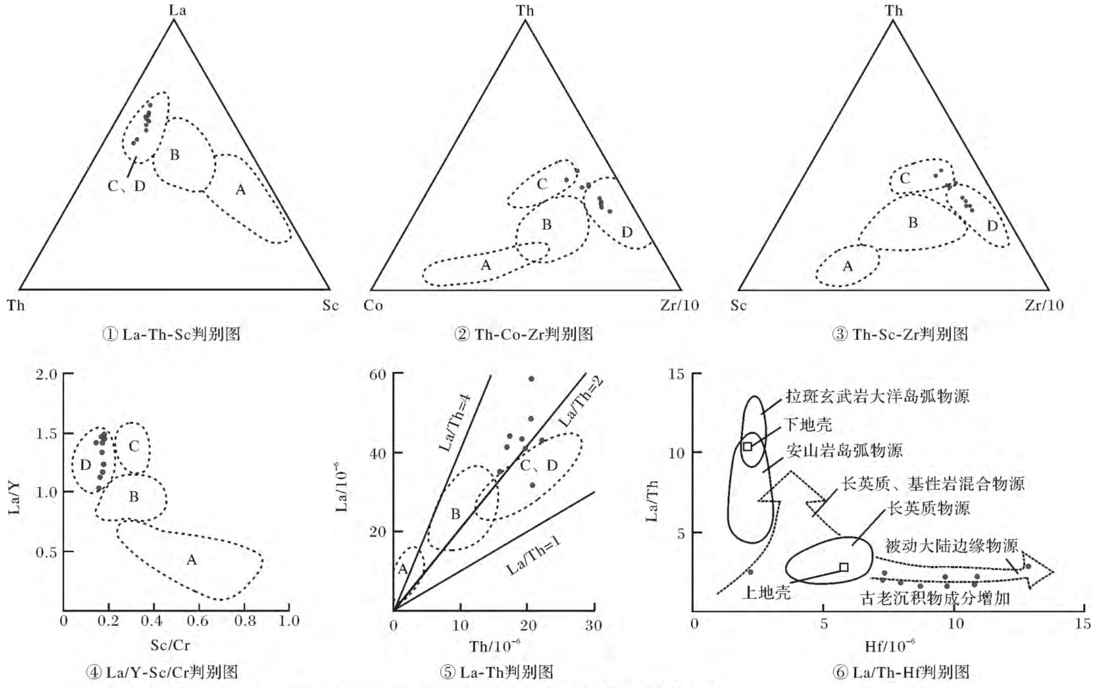
图 5　砂岩、粉砂岩常量元素源区构造背景判别图解

Fig.5　Major element ratios diagrams of sandstones and siltstones for tectonic setting

4.2　微量元素特征

陆源碎屑岩中的微量元素具有较大的稳定性，其含量变化与源区构造背景之间存在着必然联系。细粒沉积物中的微量元素已被广泛应用于沉积源区的确定和构造背景分析等研究中[41]。

对研究区实验测得的微量元素数据进行了 Th-Co-Zr/10、Th-Sc-Zr/10、La-Th-Sc 等 3 个判别图解[39,42]投点(图 6①-③)。La-Th-Sc 判别图解上，都落在了活动大陆边缘和被动大陆边缘区域内; Th-Co-Zr 判别图解上，1 个点落在了活动大陆边缘区域内，6 个点落在了被动大陆边缘区域内; Th-Sc-Zr 判别图解上，2 个点落在了活动大陆边缘区域内，6 个点落在了被动大陆边缘区域内。用樱桃沟组微量元素含量及比值与 Bhatia 等[42]总结的微量元素丰度相对比可知，Pb、Rb/Sr、Hf、Nb、Zr/Th、Ti、Sc、Co、Zn 等的平均值指示被动大陆边缘环境; Th 的平均值指示活动大陆边缘和被动大陆边缘环境。同时，对微量元素数据进行了 La/Th、La/Th-Hf 和 La/Y-Sc/Cr 源岩判别图解的投点分析。在 La/Y-Sc/Cr 判别图解(图 6④)上，完全落在了被动大陆边缘区域内; 在 La/Th 判别图解(图 6⑤)上，只有一个点落在了活动大陆边缘和被动大陆边缘范围内; La/Th-Hf 判别图解(图 6⑥)上表明有古老沉积物的混入。综合上述数据特征，研究区中奥陶世樱桃沟组源区表现为被动大陆边缘和活动大陆边缘构造特征。



注:A.大洋岛弧; B.大陆岛弧; C.主动大陆边缘; D.被动大陆边缘; 图中元素含量均指质量分数

图 6　砂岩微量元素构造环境判别图

A. 大洋岛弧; B. 大陆岛弧; C. 主动大陆边缘; D. 被动大陆边缘; 图中元素含量均指质量分数

Fig.6　Discrimination diagrams of tectonic setting based on trace elements of detrital rocks

4.3 稀土元素特征

碎屑岩的REE含量主要受控于其物源区岩石成分[43,44]，其配分模式从源岩到沉积物没有明显变化[41,45,46]，常被用作判别源区岩石的主要标志[47~49]。另外，通过研究区和疑似物源区稀土元素配分曲线位置的高低、倾斜程度、铕异常以及曲线总体形态的相互对比来分析研究区的物源[50~53]，也是目前物源分析中应用最广也最有效的手段之一。

研究区樱桃沟组∑REE的最小值为176.0 ppm，最大值为368.8 ppm，平均值为259.5 ppm; LREE/HREE最小值2.604，最大值为3.486，平均值为3.034，LREE富集，HREE亏损。δEu最小值为0.189，最大值为0.233，平均值为0.207，δEu轻度亏损; δTm最小值为0.154，最大值为0.160，平均值为0.158，δTm严重亏损。REE配分模式图中(图7A)，10个样品均为轻稀土富集型，δEu轻度亏损，δTm严重亏损，“谷”状明显，曲线展布特征、规律一致。上述REE特征值和配分曲线特征与活动大陆边缘模式曲线特征[48]较为一致。

在樱桃沟组砂岩稀土元素数据的基础上，笔者搜集并分析了前人在研究区周缘构造单元(阿拉善古陆、苏右旗—林西构造带、阴山造山带、北祁连造山带)岩石的稀土元素数据[54~57]，为方便对比研究，统一采取Boynton[58]推荐的球粒陨石平均值对其进行标准化(图7B—F)，结果显示后者仅与阿拉善古陆花岗岩和北祁连早古生代造山带花岗岩REE特征值和配分模式曲线一致，均为轻稀土富集型，δEu轻度亏损和δTm严重亏损，反应樱桃沟组的物源为阿拉善古陆和北祁连造山带，或者二者之一。

4.4 物源分析

中奥陶世，鄂尔多斯地块虽整体处于剥蚀状态，但其上为巨厚的碳酸盐岩覆盖，并不能提供大量的陆源碎屑，并且在研究区西部的巴彦浩特盆地亦发育与研究区樱桃沟组可对比的地层[4]，表明樱桃沟组砂岩物源基本与华北板块无关。樱桃沟组砂岩的常量元素和微量元素地球化学特征及构造判别图解，表明樱桃沟组的物源呈现双物源的特点，即砂岩主要与活动大陆边缘和被动大陆边缘有关，更进一步，樱桃沟组的稀土元素配分模式对比表明了樱桃沟组碎屑岩的物源来自阿拉善古陆和/或北祁连造山带。

北祁连造山带经由寒武纪裂谷盆地、奥陶纪初期成熟洋盆、奥陶纪中晚期北祁连活动大陆边缘[59~67]或奥陶纪多岛洋盆[66]、志留纪—早、中泥盆世碰撞造山过程[67]。可见，北祁连从新元古代开始裂陷，经过寒武纪的裂谷盆地、奥陶纪初期形成成熟的洋盆期间，其北侧的阿拉善地块南缘为离散型大陆边缘，于奥陶纪中晚期为北祁连弧后盆地构造背景，发育碎屑岩建造，以变质砂岩粉砂岩为主[65]。与樱桃沟期鄂尔多斯古陆发育碳酸盐岩不同，阿拉善陆块业已满足了为樱桃沟组提供物源的岩性条件，但其是否是物源区，还需要进一步的证据。

近来，碎屑锆石的研究为中奥陶世研究的物源提供了更为清晰的证据。中奥陶统米钵山组砂岩碎屑锆石LA-ICP-MS U-Pb年龄谱与区域岩浆热事件对比(图8)分析表明，鄂尔多斯西缘北段(贺兰山西缘)与鄂尔多斯西缘中南段(牛首山、大罗山、小罗山)的米钵山组物源均为阿拉善地块和北祁连造山带，且主要来自北祁连造山带[11,12]，即中奥陶世北祁连造山带物源业已影响到贺兰山地区。据此推测，同处阿拉善东缘、同时期的樱桃沟组其物源势必也与米钵山组相同。

需要注意的是，在上述各种判别图解中，砂岩图解均说明来自再旋回造山带，而其它图解大多数是指出樱桃沟组碎屑岩有一部分来自被动大陆边缘，结合上述分析，此部分理应来自阿拉善陆块，而那些显示来自再旋回造山带、活动大陆边缘的物源区对应了北祁连造山带。这同时也得到了以下研究的支持。Darby和Gehrels[68]认为桌子山地区元古宇和寒武系主要来自华北板块本身，而奥陶系物源则发生了很大变化。无独有偶，阿拉善东缘(贺兰山西侧)南部的白银地区(鄂尔多斯西缘南段)早奥陶世晚期以来沉积环境也发生了显著变化，物源从早期的阿拉善地区变为南侧的岛弧[69]。因此，在其后的中奥陶世，贺兰山地区的沉积响应反应来自阿拉善陆块及其南部的岛弧区(北祁连造山带)的这种双物源特点是极其合理的。

5 讨论

围绕奥陶纪鄂尔多斯盆地西缘的构造背景是“贺兰坳拉槽”[3,5,6,70~73]还是岛弧及弧后环境或弧后前陆盆地[11,74~76]，一直争议不断。传统观点认为，鄂尔多斯陆块西部的贺兰坳拉槽与其南部的秦祁海槽构成三叉裂谷系，“贺兰坳拉槽”为其中的衰亡支[14,70,71,73,77]，长期以来以坳拉槽构造体制作为鄂尔多斯盆地西缘沉积演化解释的依据[3,5~8,25,28]。然而，坳拉槽构造体制无法解决一些基本问题，诸如

(1) 中奥陶世鄂尔多斯盆地西缘南侧为岛弧环境[69]，而坳拉槽是大陆裂解阶段的产物，两者在构造性质上存在基本的矛盾; (2) 如果是坳拉槽为什么碎屑锆石没有发现来自华北的信息[11]？张进[76]还提出了早古生代“贺兰坳拉槽”并不存在的 4 个理由。除此以外，另有学者[78]从秦祁贺地区的构造形迹、航磁异常特征和地层分区等方面，对“贺兰坳拉槽”提出了质疑。

如上文所述，樱桃沟组砂岩的常量元、微量和稀土元素地球化学特征及构造判别图解和碎屑锆石综合研究均表明该组的物源来自北祁连造山带和阿拉善陆块，而与华北板块无关。这是用坳拉槽体制无法解释的。近年来，在鄂尔多斯盆地西缘奥陶系海底扇、等深流、浊积岩等沉积的相继发现[3,5,23~28]，使得对鄂尔多斯盆地西缘中奥陶统古流向的认识更趋全面。高振中等[24]认为在中奥陶世沿鄂尔多斯地区西

表 2　樱桃沟组主量元素分析结果(%)

Table 2　Major element analyses(%) of the Yingtaogou Formation

样品编号	岩性	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	MnO	P_2O_5	H_2O^+
H-1-R-3	细粒长石岩屑砂岩	69.03	9.03	0.53	1.41	1.65	6.25	1.39	2.25	1.34	0.047	0.198	2.18
H-9-R-1	中粒长石岩屑砂岩	80.16	6.49	0.41	1.13	1.22	3.47	1.00	2.09	0.71	0.027	0.160	1.47
H-13-R-1	细粒长石岩屑砂岩	73.47	9.72	0.48	1.82	1.58	2.75	1.59	3.05	0.97	0.036	0.155	2.33
H-16-R-1	细粒长石岩屑砂岩	77.54	6.52	0.40	1.23	1.05	4.26	0.94	2.42	0.76	0.040	0.154	1.69
H-20-R-2	细粒长石岩屑砂岩	77.42	6.36	0.38	1.16	0.91	4.67	0.93	2.11	0.70	0.048	0.146	1.62
K-1-R-1	含岩屑砂质砾岩	80.94	7.01	0.39	1.44	0.79	2.15	0.97	2.03	0.78	0.030	0.145	1.75
K-7-R-1	含长石岩屑粉砂岩	74.74	10.24	0.56	1.28	2.32	1.83	1.60	2.10	1.53	0.042	0.189	2.32
K-10-R-1	细粒长石岩屑砂岩	77.22	6.65	0.37	0.88	1.08	4.88	0.87	1.28	1.22	0.085	0.140	1.62
K-13-R-1	细粒含长石岩屑砂岩	79.52	8.14	0.44	1.28	1.46	1.66	1.17	1.80	1.06	0.033	0.158	2.05
K-17-R-2	细粒长石岩屑砂岩	80.90	6.55	0.40	1.14	0.98	2.77	0.93	1.58	0.91	0.042	0.152	1.61

表 3　樱桃沟组微量元素分析结果($\times10^{-6}$)

Table 3　Trace element analyses($\times10^{-6}$) of the Yingtaogou Formation

样品编号	Ba	Sr	V	Zn	Co	Zr	Cs	Pb	Rb	Sc	Th	U	Cu	Ni	Cr	Ta	Nb
H-1-R-3	240.1	63.6	39.7	38.8	7.16	399.6	2.46	14.8	79.2	6.67	20.39	3.05	11.8	15.8	39.6	0.97	10.77
H-9-R-1	258.1	45.1	37.7	30.8	4.95	372.2	1.92	14.5	70.5	6.01	17.47	2.56	13.2	13.2	36.8	0.77	8.83
H-13-R-1	383.7	51.7	53.5	50.8	8.69	226.4	3.91	18.0	112.3	7.98	21.71	2.52	21.0	20.2	49.1	0.98	11.40
H-16-R-1	384.0	66.5	38.1	32.5	5.33	341.6	2.04	17.7	83.5	6.26	19.13	2.50	11.7	13.7	39.9	0.64	9.25
H-20-R-2	266.3	52.9	32.7	28.6	4.94	289.2	2.10	16.7	72.0	5.65	15.36	2.28	9.4	13.0	35.2	0.65	8.43
K-1-R-1	305.1	40.8	37.8	32.0	5.38	270.4	2.34	15.6	78.6	5.50	21.13	1.98	9.5	14.5	39.0	0.72	8.91
K-7-R-1	266.8	59.3	53.5	60.8	7.51	299.9	2.77	18.7	92.3	8.37	29.73	3.50	23.6	20.8	53.3	1.10	12.95
K-10-R-1	169.1	118.4	36.9	34.5	4.58	225.1	2.15	18.6	58.4	5.72	16.94	2.58	16.2	14.3	35.1	0.71	8.73
K-13-R-1	240.5	66.2	43.2	37.5	6.53	249.8	2.46	27.1	74.9	6.90	19.43	2.76	15.7	17.1	42.2	0.82	10.17
K-17-R-2	214.5	83.6	39.3	28.6	5.58	341.5	1.93	19.3	66.9	6.41	20.40	2.39	13.2	14.3	34.2	0.83	9.56

表 4　樱桃沟组稀土元素分析结果($\times10^{-6}$)

Table 4　The REE analyses($\times10^{-6}$) of the Yingtaogou Formation

样品编号	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf
H-1-R-3	47.53	59.15	123.4	16.03	60.36	12.11	2.15	10.42	1.83	11.62	2.23	6.52	1.04	6.59	1.13	13.23
H-9-R-1	30.08	44.33	92.57	11.67	43.07	8.19	1.56	7.20	1.20	7.51	1.43	4.26	0.69	4.56	0.85	12.06
H-13-R-1	30.69	43.49	77.64	11.02	41.68	7.97	1.67	7.10	1.20	7.52	1.42	4.26	0.67	4.43	0.72	7.24
H-16-R-1	33.20	44.23	74.62	11.52	42.81	8.33	1.60	7.39	1.31	8.34	1.60	4.92	0.79	5.25	0.89	10.98
H-20-R-2	29.93	35.36	60.99	9.42	35.30	7.07	1.41	6.23	1.12	7.19	1.40	4.17	0.67	4.34	0.72	9.40
K-1-R-1	21.98	31.94	52.44	8.01	29.49	5.59	1.23	4.95	0.86	5.41	1.03	3.09	0.51	3.37	0.62	8.74
K-7-R-1	45.90	48.30	105.7	13.47	51.59	10.10	1.82	9.10	1.62	10.41	2.04	5.97	0.96	6.04	0.98	9.44
K-10-R-1	37.21	42.24	71.86	10.93	41.51	7.96	1.59	7.25	1.31	8.57	1.65	5.00	0.80	5.02	0.80	7.27
K-13-R-1	28.35	41.08	69.20	10.24	37.55	7.05	1.39	6.24	1.06	6.65	1.30	3.86	0.63	4.10	0.70	7.97
K-17-R-2	32.14	47.80	95.69	11.65	42.61	7.99	1.47	7.09	1.21	7.55	1.47	4.34	0.71	4.69	0.83	10.62

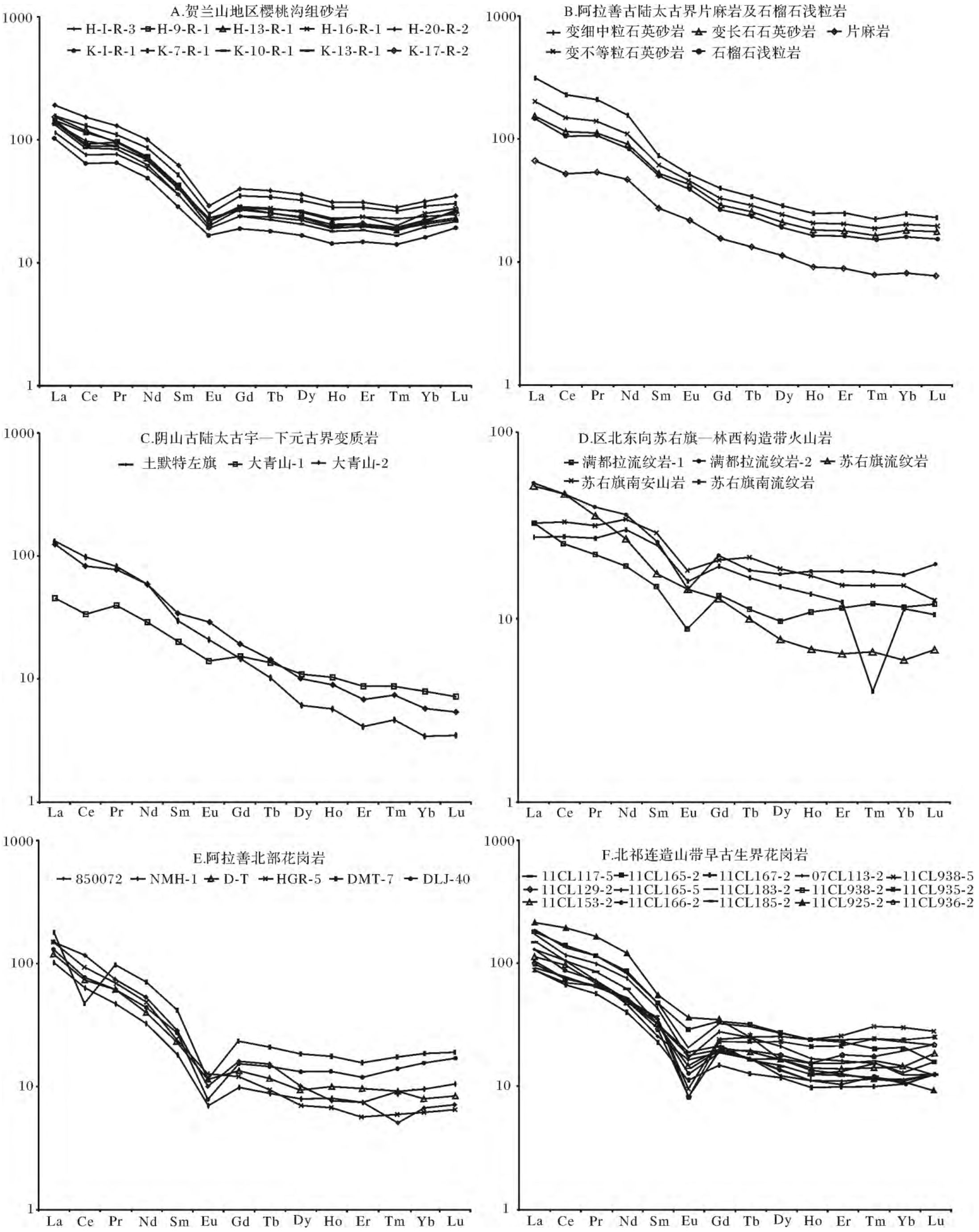


图7 研究区樱桃沟组与周缘造山带岩系 REE 配分模式

Fig.7 Distribution patterns of rare earth elements from Yingtaogou Formation in Helan Mountains region and rock series of peripheral orogenic belts

A 本文; B、C 据文献 [54]; D 据文献 [55]; E 据文献 [56]; F 据文献 [57]

缘斜坡带存在较强的自南而北的等深流流动体系; 丁海军等[28]依据在桌子山地区首次发现的克里摩里组等深流沉积,认为在鄂尔多斯西缘(靠近阿拉善古陆附近)其等深流方向为南西至北东方向。上述古流向为北祁连造山带物源供给提供了水动力条件,并且均暗示其物源来自北祁连地区,同时亦表明坳拉槽体制的矛盾之处。如若是坳拉槽,其顶部(桌子山地区)古流向是从北东向南西流才对!

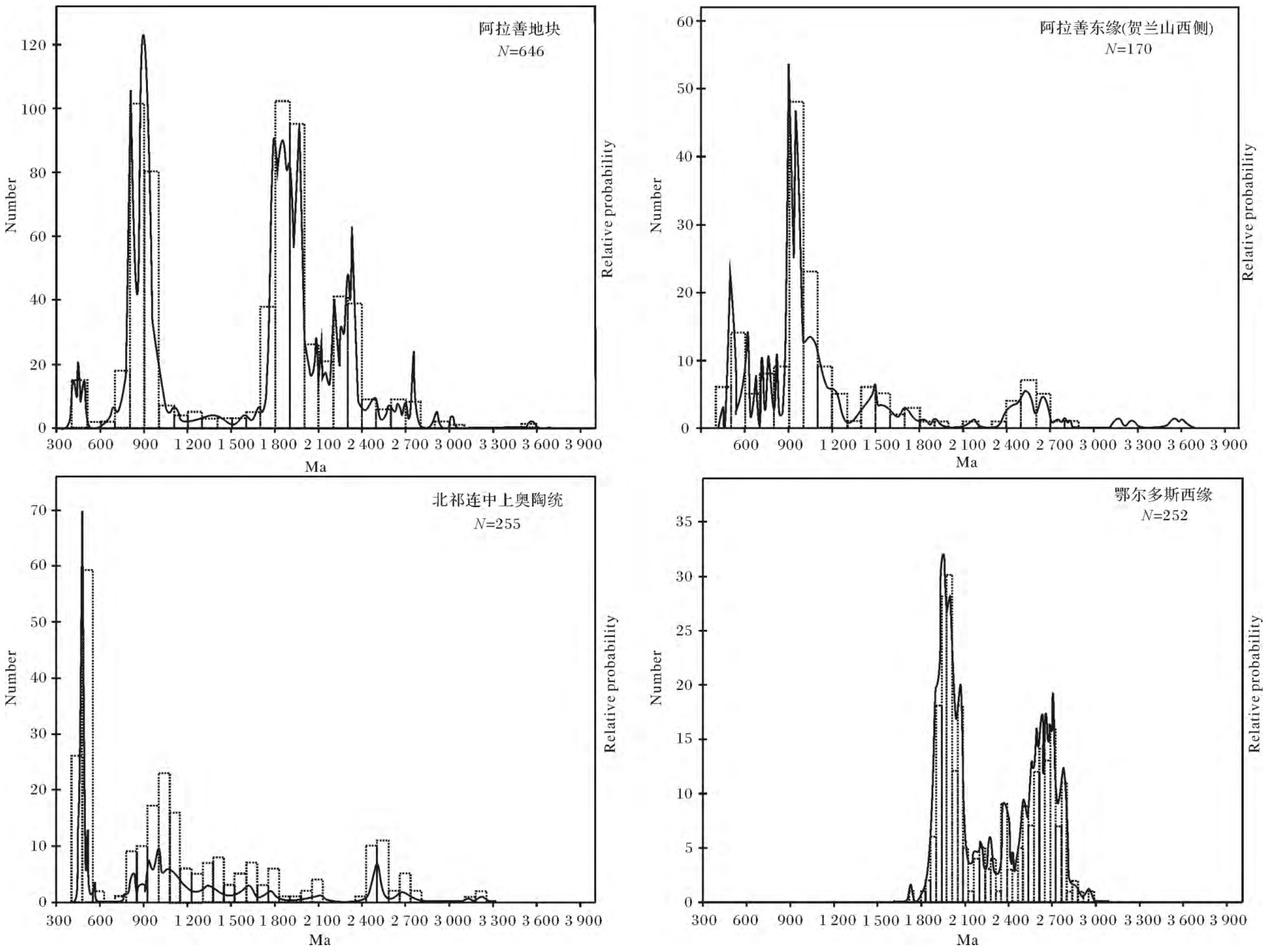


图 8　研究区周围奥陶系碎屑锆石年龄谱分布(据文献[11])

Fig.8　Relative age probability diagrams of the Ordovician strata in the Helan Mountains area and its vicinity (after reference [11])

6　结论

(1) 对贺兰山地区樱桃沟组的室内大量岩石薄片观察和砂岩碎屑颗粒特征统计分析表明,其大地构造背景主要为再旋回造山带;

(2) 研究区樱桃沟组砂岩的常量元素具有较高的 K_2O 含量、低的 Al_2O_3 含量,高的 K_2O/Na_2O 比值和低的 $Al_2O_3/(CaO+Na_2O)$ 比值及其 Fe_2O_3+MgO 百分含量分别与 TiO_2、Al_2O_3/SiO_2、K_2O/Na_2O、$Al_2O_3/(CaO+Na_2O)$ 百分含量的关系表明,中奥陶世研究区物源区具有主动大陆边缘和被动大陆边缘的性质,受到阿拉善古陆和北祁连造山带的双重影响。

(3) 研究区樱桃沟组与研究区周缘造山带的 REE 配分模式对比研究表明,其物源为阿拉善古陆和北祁连造山带。结合阿拉善东缘中奥陶统米钵山组碎屑锆石年龄分布特征、古流向特征,樱桃沟组物源主要来自北祁连造山带,部分来自阿拉善古陆。

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Provenance and Tectonic Settings Analysis of Yingtaogou Formation of Middle Ordovician in Helan Mountain Area

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Abstract: Yingtaogou Formation in the Helan Mountain area, located in the western margin of Ordos basin, consists of a set of terrigenous detrital rocks, with carbonate slump gravity flow deposits. The Early Paleozoic tectonic setting of Ordos basin is still in debate due to the lack of reliable material source data. In this paper, the petrologic and geochemical characteristics have been researched systematically. The characteristics of debris composition of sandstone show that Yingtaogou Formation comes from recycling orogeny area. The geochemical signatures of major and trace elements of sandstone from Yingtaogou Formation indicate its double provenance supply feature. More specifically, comparison study on REE distribution patterns shows clastic rocks from Yingtaogou Formation derive from Alashan and/or North Qilian orogenic belt. The geochemical signatures of major and trace elements and REEs, in Combination with the discrimination diagrams for tectonic settings have mirrored that the study area when Yingtaogou Formation deposited was surrounded by the active and passive continental margin, which means it is affected by both Helan aulacogen and North Qilian Early Paleozoic orogenic belt. REE patterns between Yingtaogou Formation and its adjacent areas display the former is in accordance with Alashan paleolandmass to the northwest and granite from North Qilian Early Paleozoic orogenic belt, and the REE distribution pattern show they are rich in LREE and lack of HREE and exhibit slightly Eu anomalies and marked negative Tm anomalies. After comprehensive consideration of the middle Ordovician palaeocurrents in the western Ordos and detrital zircon age features, this paper suggests that the provenance of Yingtaogou Formation was mainly the North Qilian orogenic belt and the Alashan paleolandmass as a minor one.

Key words: Ordos Basin; Helan Mountain area; Yingtaogou Formation; tectonic setting; provenance; North Qilian orogenic belt