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西秦岭凤太矿集区铅锌矿床硅钙面控矿作用 ——以铅硐山铅锌矿床为例

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摘要:【研究目的】西秦岭凤太矿集区是秦岭铅锌金多金属成矿带重要组成部分,但对矿集区铅锌矿的矿床类型和控矿因素一直存在争议。【研究方法】通过对凤太矿集区内具有代表性的铅硐山铅锌矿进行详细的野外调查和资料梳理,论述了该矿床的硅钙面控矿特征。【研究结果】认为作为凤太盆地铅锌矿底板的古道岭组灰岩,为偏碱性的Ca质岩石,顶板星红铺组千枚岩为Si质的岩石,形成了一个完美的Si/Ca界面。地层中初始富集的成矿物质在三叠纪岩浆热液作用下再次富集,并沿盆地内NWW向的一系列褶皱构造及同生断裂运移,在大型褶皱转折端、层间滑脱带等部位的Si/Ca界面聚集成矿。【结论】据此认为区域上复式背斜转折端附近和其翼部的层间滑脱带、复式背斜的鞍部、层间滑脱带是成矿的有利部位。同时西秦岭印支期铅锌矿成矿作用与大规模的构造–岩浆活动在空间和时间上相耦合,矿集区内铅锌矿床类型为与岩浆活动有关的热液矿床。

关键词: 铅锌矿床; 硅钙面; 热液矿床; 矿产勘查工程; 凤太矿集区; 西秦岭

创 新 点: 历年来凤太矿集区控矿特征争议较大,以典型矿床为例,利用硅钙面成矿理论,详细阐述了区内铅锌矿床的控矿特征。

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Characteristics of silicon–calcium surface ore–controlling in Fengtai ore–concentration areas, West Qinling Mountains: Examples from Qiandongshan Pb–Zn deposit

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Abstract: This paper is the result of mineral exploration engineering.

[Objective] The Fengtai ore-concentration area in the Western Qinling is an important part of the Qinling lead-zinc-gold polymetallic metallogenic belt. However, there has been a long running controversial debate about the type and ore-controlling factors of the lead-zinc ore-concentration area. **[Methods]** Based on the detailed field investigation and data combing of the representative Qiandongshan lead-zinc deposit in the Fengtai ore-concentration Area, the ore-controlling characteristics of the silicon-calcium surface of the deposit are discussed. **[Results]** It is considered that the bottom plate of the c in the Fengtai Basin is the limestone of the Gudaoling Formation, which is an alkaline calcareous rock, and the top plate is the phyllite of the Xinghongpu Formation, which is a siliceous rock. They form a perfect Si/Ca interface. The initially enriched ore-forming materials in the stratum were enriched again under the action of the Triassic magmatic hydrothermal fluid, and migrates along a series of NWW-strikefold structures and syngeneic faults in the basin, therefore, they concentrate to form deposits at the Si/Ca interface of the turning end of large folds, interlayer slip zone, etc. **[Conclusions]** Based on this, it is considered that the interlayer slip zone near the turning end of the compound anticline and its wings, the saddle portion of the interticle, and the interlayer slip zone in the area are favorable areas for mineralization. At the same time, the metallogenesis of the Indosinian lead-zinc deposit in the Western Qinling was coupled with large-scale tectonic-magmatic activities in space and time. And the types of lead-zinc deposits in the ore-concentrated area are hydrothermal deposits related to magmatic activities.

Key words: lead-zinc deposit; Si/Ca interface; hydrothermal deposit; mineral exploration engineering; Fengtai ore-concentration area; Western Qinling

Highlights: The ore-controlling characteristics of the Fengtai ore-concentration area is controversial over the years. Taking typical deposits as an example, the ore-controlling characteristics of lead-zinc deposits in the area expound in detail by using the theory of silicon-calcium surface mineralization and taking typical deposits as an example.

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1 引言

西秦岭凤县—太白(简称凤太)矿集区是中国铅锌矿的重要产地之一,是西秦岭铅锌金多金属成矿带的重要组成部分。矿集区内资源储量丰富,矿种主要有铅锌、金及少量的银,其中铅锌金属储量超过500万t(高卫宏,2013;陈明寿,2017),金的探明金属储量200余t(唐敏杰,2013)。区内铅锌矿床自20世纪60年代发现以来,对于矿床类型争议一直较大,主要存在以下认识:中低温热液矿床、层控型矿床(杨锦源和张四喜,1985)、沉积-区域变质作用末期变质活化热液就地改造型层控铅锌矿床(梁文艺等,1985)、构造动力热液矿床(杨兴科,1986)、海底喷气-沉积型(SEDEX)矿床(戴问天,1989;祁思敬等,1993;祁思敬和李英,1999;薛春纪等,2000)、热水喷流沉积(SEDEX)-改造(再造)型矿床(张复新和王俊发,1988,1991;隗合明和吕仁

生,1990;方维萱,1999;姚书振等,2002;王瑞廷等,2007)、后生流体充填交代型(王义天等,2009;胡青等,2011,2013)。随着综合研究的深入和找矿理论的创新,目前争论的焦点主要集中在同生沉积和后生热液成因的分歧。虽然有研究者曾提出凤太矿集区铅锌矿床具有硅钙面控矿特征(陈绍聪,2015;张革利,2018),其中张长青(2012)根据矿床形成机制和岩性条件的差异,将硅钙面分为3种形式,共4类,将铅硐山铅锌矿床归入第三种第一亚类,即碳酸盐岩与细碎屑岩岩性界面,但硅钙面对本区铅锌矿控矿特征、成矿机制的作用及二者岩性在显微镜下的差异等方面未进行深入研究。考虑到凤太矿集区铅锌矿床矿体空间形态、产出位置、控矿构造等特征十分相似,因此有必要选择典型矿床(铅硐山铅锌矿)进行示范研究,以期为本区铅锌矿床硅钙面控矿作用特征、矿床成因提供有价值的参考,进而对指导凤太矿集区深部及外围找矿

提供一定的理论基础。

2 区域地质概况

秦岭造山带以近东西向(北西西向)构造为特征,其主要是印支期华北板块与扬子板块碰撞拼贴的结果(图 1a)。凤太矿集区位于西秦岭商丹构造带南侧,在大地构造位置上归属于中秦岭弧前盆地(王宗起,2009)。

盆地内主要出露泥盆系,为一套浅变质强变形滨浅海碎屑岩和碳酸盐岩组合,从老至新分别为中泥盆统大枫沟组(D_{2d})中厚层状亮晶胶结的石英砂岩、变石英砂岩、长石石英砂岩、细粉砂岩;中泥盆统古道岭组(D_{2g})上部为中厚层状微晶灰岩、薄层生物碎屑灰岩、重结晶灰岩、少量内碎屑灰岩、局部可见生物礁灰岩,可见较丰富的腕足、珊瑚等化石,下部为薄层状变钙质粉砂岩、细粉砂岩、中厚层状

变长石石英砂岩夹中薄层粉砂质微晶灰岩、大理岩;上泥盆统星红铺组(D_{3x})底部为粉砂质千枚岩夹薄层微晶灰岩、生物碎屑灰岩,中部为薄层粉砂质绢云母千枚岩、灰绿色绿泥绢云千枚岩夹中薄层状微晶灰岩,上部为绢云母千枚岩、绿泥绢云千枚岩、微晶灰岩夹方解石千枚岩、粉砂质绿泥绢云千枚岩、变质粉砂岩、细砂岩;上泥盆统九里坪组(D_{3j})底部为变钙质长石石英砂岩、粉砂质千枚岩、粉砂质微晶灰岩,中部为绢云母千枚岩、微晶灰岩、粉砂质微晶灰岩、变钙质长石石英细砂岩,上部为绢云母千枚岩、方解石千枚岩、粉砂质微晶灰岩、变钙质长石石英细砂岩夹粉砂质千枚岩、泥灰岩。区内铅锌矿床主要产自中泥盆统古道岭组(D_{2g})和上泥盆统星红铺组(D_{3x})的接触面附近。前寒武系地层出露于矿集区北侧(图 1),为一套副变质岩、变火山岩及石英片岩(方维萱,2012)。西北部有石炭系浅变质

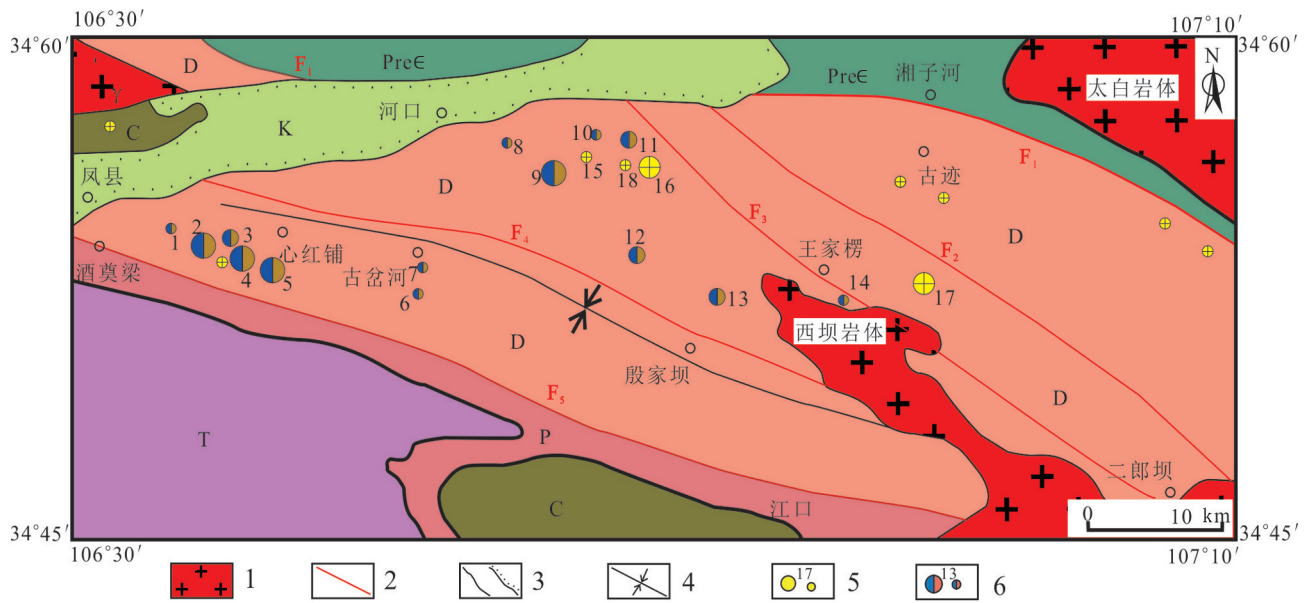


图 1 西秦岭凤太矿集区大地构造位置及地质简图(修改自 Dong et al., 2012; 杨朋涛等, 2013)

地层:K—白垩系;T—三叠系;P—二叠系;C—石炭系;D—泥盆系;S—志留系;PreC—前寒武系;断裂:F1—湘子河—黄柏源断裂(商丹缝合带);F2—修石岩—观音峡断裂;F3—王家楞—二郎坝断裂;F4—倒回沟—柘梨园断裂;F5—酒奠梁—江口断裂;铅锌矿床(点):1—谭家沟;2—银洞梁;3—峰崖;4—手搬崖;5—铅洞山;6—苇子坪—安沟;7—苇子坪—洞沟;8—尖端山;9—八方山—二里河;10—长沟;11—洞沟;12—银母寺;13—大黑沟;14—崖房湾;金矿床(点):15—司马岭;16—Baguamiao;17—Shuangwang;18—Chaima;其他:1—花岗岩;2—断裂;3—地质界线和不整合界线;4—向斜;5—金矿床(点)及编号;6—铅锌矿床(点)及编号

Fig.1 Geological sketch map of the Fengtai ore cluster, Western Qinling(modified from Dong et al., 2012; Yang et al., 2013)

Layers:K—Cretaceous;T—Triassic;P—Permian;C—Carboniferous;D—Devonian;S—Silurian; PreC—Precambrian;
Faults:F1—Xiangzihe—Huangbaiyuan fault(Shangdan suture zone number);F2—Xiushiyang—Guanyinxia fault; F3—Wangjialeng— Erlangba fault; F4— Daohuigou—Tuoliyuan fault; F5—Jiudianliang—Jiangkou fault; Lead-zinc deposits (points): 1—Tanjiagou; 2—Yindongliang; 3—Fengya; 4— Shoubanya; 5—Qiandongshan; 6—Weiziping—Angou; 7—Weiziping—Donggou; 8— Jianduanshan;9— Bafangshan—Erlihe; 10—Changgou; 11— Donggou; 12—Yinmushi; 13—Daheigou; 14—Yafangwan; Gold deposits(points): 15—Simaoling;16—Baguamiao;17—Shuangwang;18—Chaima; Other: 1—Granite; 2—Fault; 3—Geological boundary and unconformity boundary; 4—Syncline; 5—Gold deposits(points) and number; 6—Lead-zinc deposits (points) and number

千枚岩及含炭硅质岩、白垩系砾岩夹薄层页岩、石英砂岩出露;二叠系浅变质千枚岩加灰岩和中生代三叠系细碎屑岩夹碳酸盐岩产于盆地南侧。

古岔河—般家坝复式向斜构成该区基本构造格架,呈北西西向倾伏延伸,轴迹纵贯矿田东西。西倾伏端为区域不整合面所截断,东部起端为西坝岩体所侵吞,南北两翼分别被酒奠梁—狮子坝断裂、凤州—靖口关断裂纵向切断(图1b)。在复式向斜构造内,从南向北由9条平行相间排列的次一级褶皱构造组成,分别为水柏沟—谭家庄复式背斜、古岔河—般家河向斜、黑山—银母寺复式背斜、寺沟—东沟倒转向斜、尖端山—八方山复式背斜、苏家沟—空棺复式向斜、长沟—崖房湾复式背斜、庙沟—元坝子向斜及铅硐山复式褶皱。大致以 F_3 断裂为分界线,以北褶皱相对开阔,以南褶皱相对紧闭(王义天,2009),其中次级背斜构造多控制矿集区内铅锌矿体的空间形态特征。

凤太矿集区内矿产资源丰富,矿种主要为铅、锌、金及少量的银。各矿种分布具有明显的分带性,总体以古岔河—般家坝复向斜轴为界,分为南北两个成矿带(王义天,2009),南矿带以铅、锌为主,分布有铅硐山—东塘子超大型铅、锌矿床,手搬崖、峰崖大型铅、锌矿床,以及谭家沟、苇子坪—安沟、洞沟等小型铅、锌矿点。北矿带以金、铅、锌为主,分布有八卦庙、双王(超)大型金矿床,丝毛岭、小梨园、松树湾、沈家湾等小型金矿床(点),八方山—二里河大型铅、锌、铜矿床,银母寺、关门沟等中型铅、锌矿床,尖端山、银洞山、长沟、洞沟、大黑沟、崖房湾等小型铅、锌矿点。

3 铅硐山铅、锌矿床地质特征

3.1 矿区地质特征

矿区内出露的地层主要为中泥盆统古道岭组上岩性段(D_2g_2)和上泥盆统星红铺组下岩性段(D_3x_1),呈近E-W向条带状展布,岩性主要为浅变质细碎屑岩和碳酸盐岩,各层岩性特征如下:

古道岭组可以分为两个岩性段,在铅硐山铅、锌矿床内出露地层为上岩性段第三层(D_2g_3),岩性为薄—中厚层含炭生物微晶灰岩,含生物碎屑微晶灰岩,一般生物灰岩与微晶灰岩互层,层厚大于375 m;位于背斜的核部,为矿体的下部控矿地层。

星红铺组主要出露的是下岩性段(D_3x_1),该岩

性段(D_3x_1)又划分为3个岩性层:第一层($D_3x_1^1$)、第二层($D_3x_1^2$)和第三层($D_3x_1^3$),其中第一层($D_3x_1^1$):含炭质钙质绢云母千枚岩、钙质绢云母千枚岩夹薄层含炭灰岩、含炭生物灰岩,层厚1~60 m,为矿体顶部控矿地层,第二层($D_3x_1^2$):铁白云质绢云母千枚岩,其次为含铁白云石钙质粉砂质千枚岩及铁白云石石英粉砂岩,局部含少量绿泥铁白云质千枚岩,层厚120 m。

赋矿地层为中泥盆统古道岭组上岩性段第三层(D_2g_3)和上泥盆统星红铺组底部($D_3x_1^1$)二者的过渡层及附近10 m的范围内(陕西地矿第三地质队,2016)。

以铅硐山复式背斜轴迹为界(图2),两侧星红铺组地层对称产出,构成褶皱的南北两翼,核部为古道岭组地层。同时在复式褶皱轴两侧对称产出两个次级背斜,构成独特的“两背夹一向”褶皱特征。

3.2 矿体展布特征

矿区范围内目前共圈定5个矿体,即I m、I m-1、II m-1、II m-2、II m-3,其中II m-2、II m-3为盲矿体,赋存于中泥盆统古道组(D_2g_2)与上泥盆统星红铺组(D_3x_1)地层的界面及附近,呈近东西向展布,整体向西侧伏。矿体由西向东逐渐变薄、变贫(图2),次级背斜转折端附近为矿体厚大富集部位(图3)。

主矿体具体特征如下:

I m号矿体:位于背斜的北翼,整体向西倾伏,上部边界倾伏角 $35^\circ\sim 39^\circ$,下部边界倾伏角 $25^\circ\sim 45^\circ$ 。矿体呈层状—似层状,矿体长度为1326 m,Pb平均品位 1.33×10^{-2} ,Zn平均品位 3.92×10^{-2} ,矿体产状为 $255^\circ\sim 277^\circ/\text{NWW}-\text{NNE}65^\circ\sim 79^\circ$ 。顶板岩性为炭质千枚岩夹薄层灰岩,底板岩性为生物灰岩,矿体与围岩呈基本整合接触,且与围岩界限清晰。

I m-1号矿体:位于铅硐山背斜核部倾覆端,矿体形态呈囊状、鞍状,具分支复合特征,矿体长130 m,厚度4~19 m。矿体北侧产状为 $354^\circ\sim 7^\circ/\text{W}55^\circ\sim 79^\circ$;南侧产状 $280^\circ/\text{N}67^\circ\sim 70^\circ$ 。铅品位 1.64×10^{-2} ,锌品位 5.78×10^{-2} 。顶板岩性为炭质千枚岩,底板岩性为炭质灰岩夹薄层生物碎屑灰岩。

II m-1号矿体:位于背斜的南翼,整体向西侧伏,呈似层状、透镜体状,上部边界侧伏角

$37^\circ\sim 40^\circ$;下部边界受断层切割而曲折。矿体长度为827 m,Pb平均品位 1.56×10^{-2} ,Zn平均品位

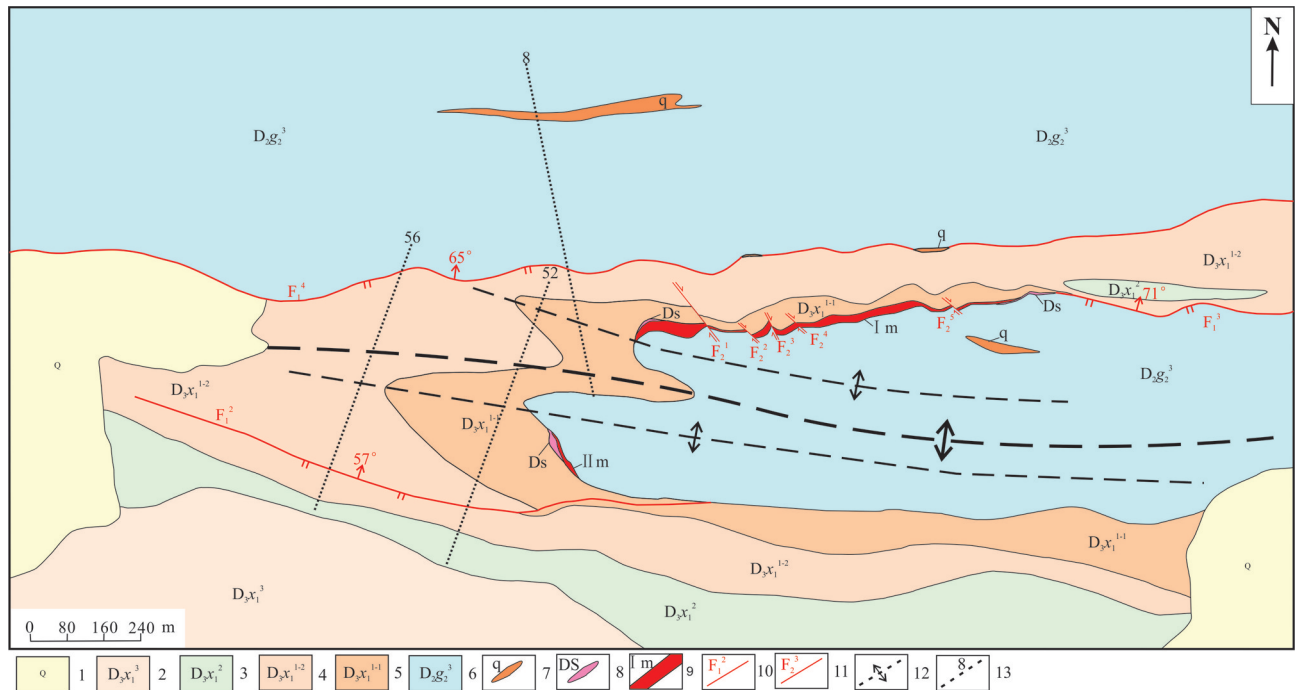


图2 铅硐山铅锌矿床地质简图(修编自吴军平等,2016)

1—第四系;2—上泥盆统星红铺组下段第三层;3—上泥盆统星红铺组下岩性段第二层;4—上泥盆统星红铺组下岩性段第一层第二小层;5—上泥盆统星红铺组下岩性段第一层第一小层;6—中泥盆统古道岭组上岩性段第三层;7—石英脉;8—硅化铁白云岩;9—矿体及编号;10—正断层及编号;11—走滑断层及编号;12—背斜;13—勘探线剖面位置及编号

Fig.2 Geological sketch map of Qiangongshan Lead-Zinc deposit(modified from Wu et al., 2016)

1— Quaternary;2— The third layer,lower section of the upper Devonian Xinghongpu Formation;3— The second layer,lower section of the upper Devonian Xinghongpu Formation;4— The first layer,lower section of the upper Devonian Xinghongpu Formation;5— The first small layer of first layer,lower section of the upper Devonian Xinghongpu Formation;6— The third layer, the upper lithological section of Middle Devonian Gudaoling Formation;7—Quartz vein;8— Iron silicide dolomite;9— Ore body and number;10— Normal fault and number;11— Strike-slip fault and number;12— Anticline;13— The position of prospecting sections and number

5.90×10^{-2} , 矿体产状为 $271^\circ \sim 286^\circ / N \sim NNE 77^\circ \sim 80^\circ$ 。矿体夹石主要为硅化铁白云岩、微石英岩、硅化灰岩或生物灰岩及后期岩脉等。

II m-2号矿体:为一盲矿体,产于II m-1号矿体下盘5~15 m的灰岩中,呈似层状。矿体走向倾斜大体与矿体II m-1号矿体一致。厚度0.97~19.00 m,平均厚度6.00 m。矿体产状 $270^\circ \sim 310^\circ / S 69^\circ \sim 85^\circ$,且自上向下矿体倾角总体变陡。矿体与围岩呈整合接触,顶、底板岩性均为灰岩。见少量硅化灰岩夹石。

II m-3号矿体:为一盲矿体,呈似层状产出,与围岩呈整合接触,顶板岩性主要为炭质灰岩,底板岩性为炭质千枚岩。

3.3 矿石组成及结构构造

矿石矿物主要有闪锌矿、方铅矿,其次为黄铁矿、黄铜矿、磁黄铁矿、菱锌矿、白铅矿、褐铁矿、孔雀石等。脉石矿物主要有方解石、白云石、石英、绢

云母等,发育方解石脉体切割条带状铅锌矿。

矿石结构主要为他形粒状结构,其次为骸晶结构、包含结构、格状结构等。矿石构造最常见类型为浸染状,其次为脉状构造、块状构造、条带状构造、蜂窝状构造等,其中浸染状最多,各类型之间均有过渡现象(应该有主要矿床类型的镜下照片及解释,以支撑硅钙面思想中矿体主要分布于钙质岩石中)。

综上所述,根据铅硐山铅锌矿体的宏观形态、产状变化、空间延伸和产出位置,可将矿区控矿构造分为2级: I级为铅硐山复式背斜,控制着矿体的宏观形态、空间延伸和产状; II级为层间破碎带和岩性界面,控制矿体的具体产出位置。

4 岩性界面控矿特征

在西秦岭地区,铅锌矿受岩性界面控制表现尤为明显,在西成矿集区产出的代表性铅锌矿,如厂坝铅

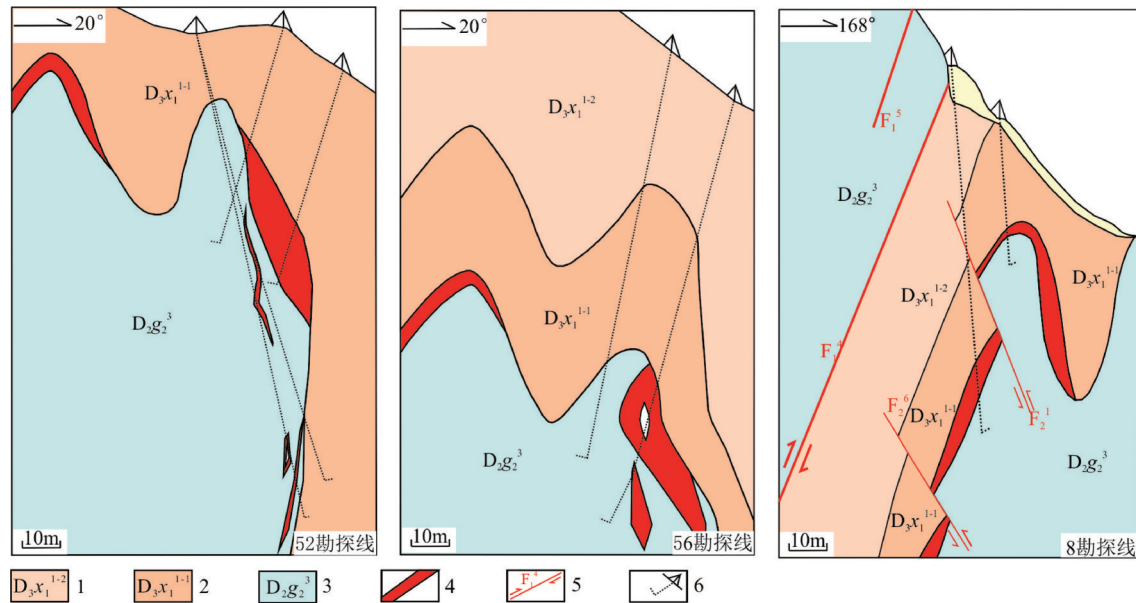


图3 铅硐山铅锌矿床勘探线剖面(据吴军平等,2016 修改)

1—上泥盆统星红铺组下岩性段第一层第二小层;2—上泥盆统星红铺组下岩性段第一层第一小层;3—中泥盆统古道岭组上岩性段第三层;
4—矿体;5—钻孔位置

Fig.3 Prospecting sections in Qiantongshan Lead-Zinc Deposit (modified from Wu et al., 2016)

1— The second Lower Layer of Lower First Lithology Section Upper Devonian Xinghongpu Formation;2—The first Lower Layer of Lower First Lithology Section Upper Devonian Xinghongpu Formation;3—The third layer the upper lithological section of Middle Devonian Gudaoling Formation;4—Ore body;5— Drilling position

锌矿、毕家山铅锌矿、邓家山铅锌矿的主矿体亦赋存于以钙质为主的碳酸盐岩(结晶灰岩、亮晶灰岩、生物碎屑灰岩和大理岩)和以硅质为主的碎屑岩(石英片岩、千枚岩)接触界面,局部亦偏碳酸盐岩一侧。在凤太矿集区产出的大型—超大型铅锌矿,如八方山—二里河铅锌矿、银母寺—关门沟铅锌矿、铅硐山铅锌矿的主矿体均产于以钙质为主的碳酸盐岩(硅质灰岩、生物碎屑灰岩和炭质灰岩等)(图4a)和以硅质为主的碎屑岩(粉砂质千枚岩、绢云粉砂质千枚岩)(图4b)接触界面,局部偏碳酸盐岩一侧;碳酸盐岩与碎屑岩的接触界面是非常明显的突变界面,该界面亦是前文所述的重要成矿流体地球化学界面之一。由矿体的地表产出特征(图5)及各中段剖面图(图6)可以看出,铅锌矿体主要沿层间或层内破碎带和一定层位(中泥盆统古道岭组和上泥盆统星红铺组)呈较规则的层状、似层状、透镜状和囊状产出。赋矿位置受构造控制明显,控矿构造主要为层间、层内破碎带、岩性界面和褶皱。

通过对铅硐山铅锌矿床各中段实地勘察,对各勘探线剖面分析研究,发现铅锌矿体主要产于中泥盆统古道岭组(碳酸盐岩)和上泥盆统星红铺组

(细碎屑岩)的岩性界面,偏古道岭组一侧(图7),在其上覆地层星红铺组可见细脉状方铅矿化沿裂隙充填,但不成规模。在八方山—二里河铅锌矿床和银母寺—关门沟铅锌矿床中(表1),矿体主要产于细碎屑岩+碳酸盐岩岩性界面处,这也是凤太矿集区铅锌矿床共有的普遍特征。

5 讨论

5.1 硅钙面控矿探讨

“相带”及“相带”界面对研究矿床的形成、探讨成矿规律和指导找矿预测有着重要作用(程裕淇等,1979,1983),地质体的不连续界面或不同地质体的分界面(如断裂、不整合、侵入接触面等)表现为地质体连续性的突然中断,同时伴有物质成分及其物理和化学属性的变化,成矿界面既是地质构造界面、岩石物理界面,也是元素聚散物理化学界面,是有利的成矿部位,成矿流体在界面附近停积而发生矿石沉淀、富集成矿之所在(赵鹏大等,1991;吴淦国等,1999;叶天竺等,2007)。

硅钙(Si/Ca)面是指含硅酸盐类岩石(Si)与含碳酸盐类岩石(Ca)之间形成的岩性界面(张长青

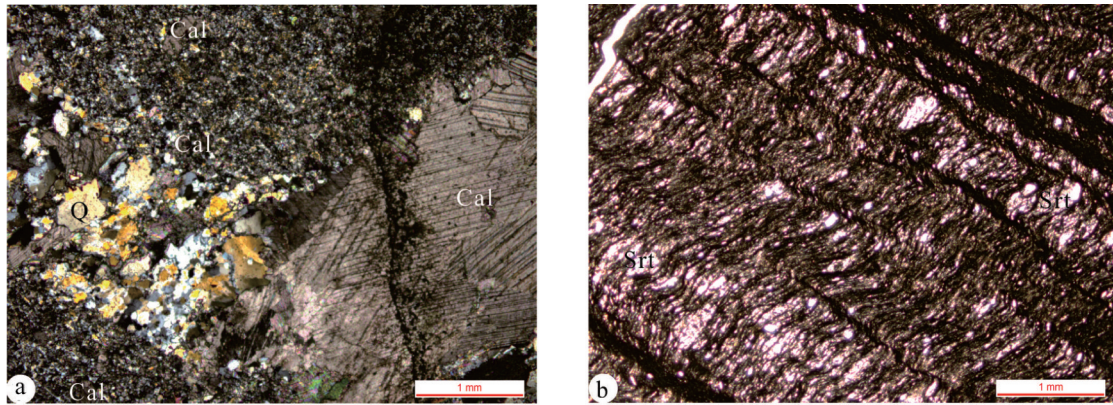


图4 铅硐山铅锌矿床赋矿围岩显微特征

a—硅质灰岩,石英呈微细粒,并交代细粒方解石;b—绢云母千枚岩,绢云母定向排列,石英呈微细颗粒;Srt—绢云母;Q—石英;Cal—方解石

Fig.4 Microscopic characteristics of the ore-forming surrounding rocks in Qiandongshan Lead-Zinc Deposit

a—Siliceous limestone, fine particles of quartz, and replaced with fine-grained calcite; b— Sericite phyllite, Oriented sericite, fine particles of quartz; Srt—Sericite; Q—Quartz; Cal—Calcite

等,2012),在不同成因类型的铅锌矿床中,都能找到发育Si/Ca面的实例(戴自希等,2005;张长青等,2009),许多铅锌矿床的形成都具有Si/Ca“界面成矿”的特征,如江苏栖霞山铅锌矿床的主矿体产于石炭系黄龙组灰岩与泥盆系五通组、石炭系高丽山组砂岩的接触界面上,主要在石炭系黄龙组灰岩一侧的构造破碎带内(张明超等,2014);云南金顶铅

锌矿床产于三合洞组灰岩与云龙组粉砂岩、泥岩接触带内(张长青等,2012);新疆彩霞山铅锌矿床主矿体产于青白口系卡瓦布拉克组第一岩性段碎屑岩+碳酸盐岩组合之中(张明超等,2014);青海锡铁山铅锌矿床主矿体产于奥陶系滩间山群b岩性段变质的灰黑色碳硅泥质沉积岩+碳酸盐岩组合中(张德全等,2005)等。由此可以看出,硅钙面控矿具有

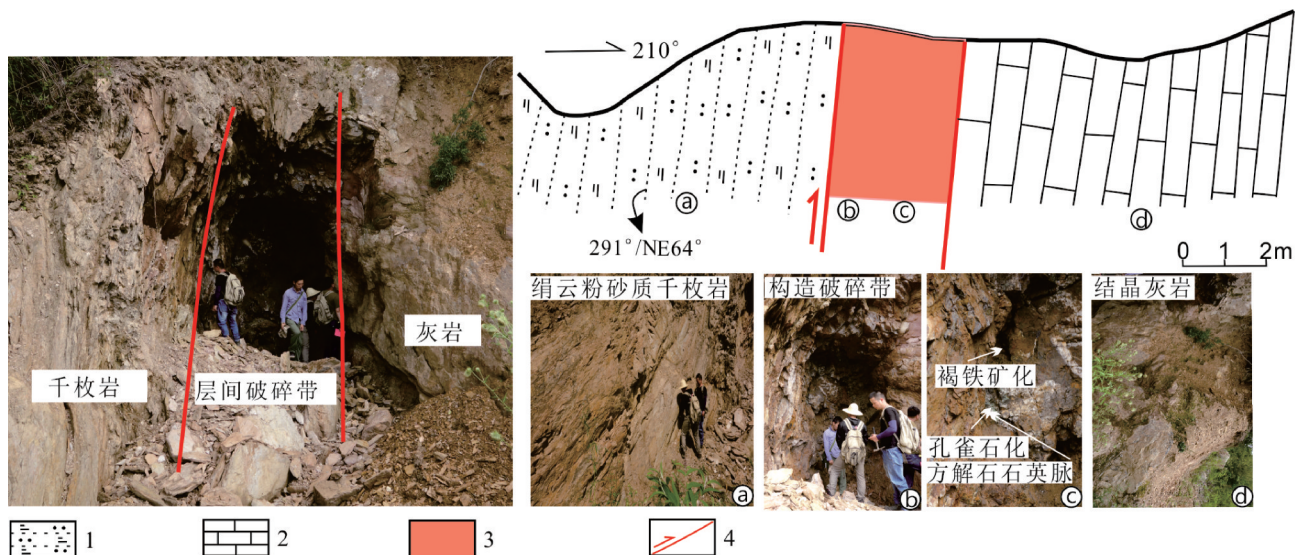


图5 铅硐山铅锌矿床矿化蚀变带地表产出特征

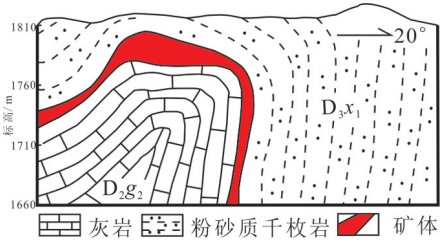
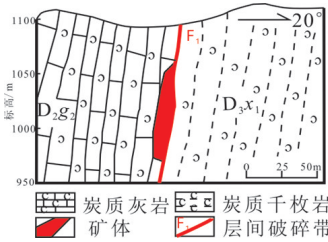
a—绢云粉砂质千枚岩宏观特征;b—层间构造破碎带特征;c—破碎带内矿化特征;d—结晶灰岩宏观特征;1—绢云粉砂质千枚岩;2—结晶灰岩;3—蚀变带;4—压性断裂

Fig.5 Surface output characteristics of mineralized alteration zone of Pb-Zn deposit

a—Macro characteristics of seric silt phyllite; b—Characteristics of interlayer structural fracture zone; c—Mineralization characteristics in the fracture zone;d— Macro characteristics of crystalline limestone;

1— Seric silt phyllite;2— Crystalline limestone;3— Alteration zone;4— Compressive fault

表1 凤太矿集区典型铅锌矿床地质特征

Table1 Geological characteristics of typical lead-zinc deposits in the Fengtai Fengtai Ore-concentration area		
矿床名称	八方山—二里河铅锌矿床	银母寺—关门沟铅锌矿床
矿床规模	超大型	大型
赋矿围岩	主矿体产于古道岭组(D ₂ g ₂)灰岩与星红铺组(D ₃ x ₁)千枚岩接触面	主矿体产于古道岭组(D ₂ g ₂)灰岩与星红铺组(D ₃ x ₁)千枚岩接触面和古道岭组(D ₂ g ₂)灰岩层内破碎带内
剖面特征		
控矿构造	八方山铅锌矿床105勘探线剖面简图 I级为八方山—二里河短轴背斜,控制矿体的宏观形态、产状和空间延伸 II级为层间、层内破碎带和岩性界面,控制矿体的具体产出位置	大黑沟铅锌矿床45勘探线剖面简图 I级为银母寺—大黑沟背斜,控制矿体的宏观形态、产状和空间延伸
矿体形态	地表矿化带围绕背斜核部结晶灰岩呈不规则的环状,环内为古道岭组灰岩,环外为星红铺组千枚岩,深部向四周扩大,在剖面上呈“八字型”或“抛物线型”两种形态	呈似层状、透镜状、网脉状、不规则脉状产于背斜北翼
矿石品位	Pb: 1.38%、Zn: 4.89%	Pb: 2.92%、Zn: 7.86%
矿石矿物	以方铅矿、闪锌矿为主,局部伴有黄铜矿、黄铁矿	以方铅矿、闪锌矿为主,少量黄铜矿、黄铁矿及毒砂
脉石矿物	石英及其他碳酸盐矿物	以石英、方解石为主,次为绢云母、白云母、绿泥石等
矿石结构	交代生物假象结构、重结晶结构、交代-溶蚀结构、共边结构、压力影结构、碎裂结构、揉皱结构	交代、溶蚀和镶嵌结构
矿石构造	条带状构造、浸染状构造、块状-团块状构造、细脉-网脉状构造	以块状、脉状为主,次为浸染状、碎裂状
围岩蚀变	矿体底板灰岩的硅化、褪色化、石墨化,矿体顶板千枚岩的硅化、绢云母化及叶腊石化	以硅化、碳酸盐化为主,次为绢云母化
岩浆岩	地表未见大的岩体,但侵入岩脉较发育,包括闪长玢岩脉、花岗斑岩脉以及煌斑岩脉,沿NW向顺层充填或沿NE向裂隙充填	发育沿NE向裂隙产出的闪长玢岩脉
资料来源	王集磊等,1996;田民民等,2004;王义天等,2013;唐敏杰等,2013;胡乔青,2015;陈绍聪,2015;本研究	

普遍性。

张长青等(2012)将Si/Ca面划分为3种表现形式,分别为:(1)侵入接触界面,即碳酸盐岩与中—酸性岩的界面;(2)火山—沉积界面,即碳酸盐岩与火山岩的界面;(3)沉积界面,即碳酸盐岩与硅质沉积岩(碎屑岩)及其变质岩(片岩、板岩、千枚岩、石英岩等)的界面,西秦岭地区铅锌矿的Si/Ca面大部分为这种类型。

根据矿体的控矿特征和矿体的产出状态,本次研究认为铅硐山铅锌矿床的矿体的就位空间并非受具体的层位控制,而是受硅钙面控制,由脆性断裂(层间或层内断裂)上下盘形成的硅钙面,上盘地

层为上泥盆统星红铺组,岩性以千枚岩、砂岩为主,该套地层具硅质含量高、性软、渗透性差的特征(图4b),为一套较好的屏蔽层,对含矿热液起到屏蔽作用;下盘地层为中泥盆统古道岭组,岩性以灰岩为主,该套地层具钙质含量高、性脆、渗透性好、化学活动性强的特征(图4a),在二者接触界面,由于压力、温度、Eh、渗透率等物理化学性质的变化,构成了良好的地球化学障,易于含矿热液的充填和沉淀。(应该从宏观及显微的角度了解不同层的结构特征,以证明屏蔽层及成矿层差异性,而非定性描述。)因此,主矿体以层间和层内破碎带为运移通道,赋存于上泥盆统星红铺组和中泥盆统古道岭组

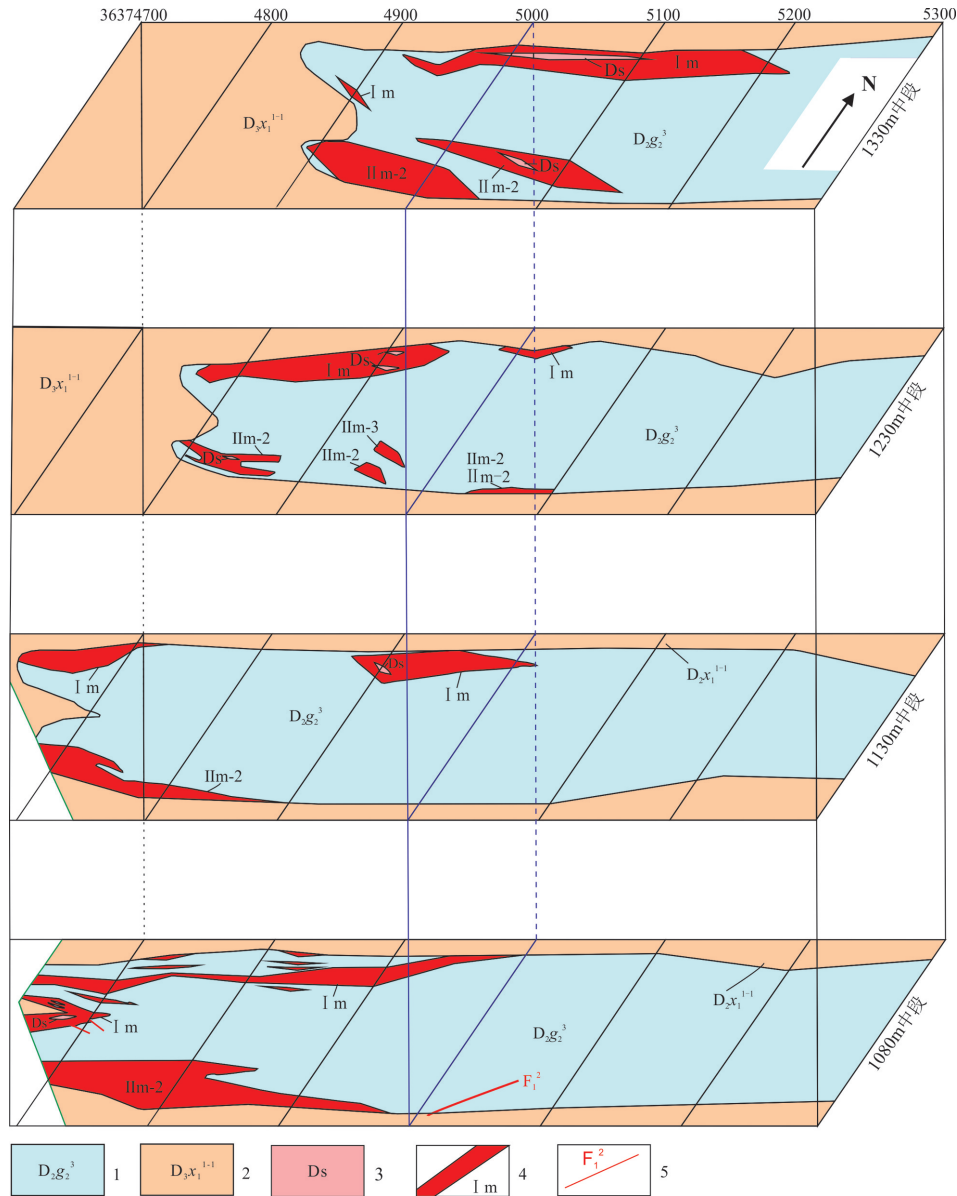


图6 铅硐山铅锌矿床主矿体立体示意图(修编自吴军平等,2016)

1—中泥盆统古道岭组上岩性段第三层;2—上泥盆统星红铺组下岩性段第一层第一小层;3—硅质铁白云岩;4—矿体及编号;5—断裂及编号

Fig.6 Sampling plan map of Qiantongshan Lead-Zinc Deposit(modified from Wu et al., 2016)

1-The third layer, the upper lithological section of Middle Devonian Gudaoling Formation;2-The first Lower Layer, Lower First Lithology Section of Upper Devonian Xinghongpu Formation;3-Iron silicide dolomite;4-Ore body and number;5-Fault and number

的岩性界面,偏古道岭组灰岩一侧。

凤太盆地在泥盆纪为活动大陆边缘沉积环境,铅锌矿的底板古道岭组灰岩为偏碱性的Ca质岩石,顶板星红铺组千枚岩代表了Si质的岩石,形成了一个“完美”的Si/Ca界面,大量的稳定同位素研究显示,成矿物质在地层中的初始富集是最终成矿的基础(王集磊等,1996;王相等,1996;李强等,2007;任鹏等,2013;胡乔青,2015)。胡乔青(2012)对二里

河铅锌矿顶板千枚岩中绢云母⁴⁰Ar-³⁹Ar测年,获得其年龄分别为(215.9±2)Ma、(217.3±2)Ma、(220.4±2)Ma和(219.3±2)Ma,可将本区变质-变形时代限制为晚三叠世,说明进入晚三叠世,凤太盆地所处的南秦岭构造带发生碰撞造山作用,地层发生强烈的构造变形,同时形成盆地内NWW向的一系列褶皱构造及同生断裂,为区内铅锌金等多金属成矿奠定了良好的地质基础,至早侏罗世190 Ma,进入后

碰撞环境(Dong et al.,2010;汪欢,2012;Zhang et al.,2012),大规模岩浆热液进一步活化迁移了地层中的Pb、Zn等物质。凤太矿集区的矿产多为三叠纪大规模成矿作用的产物,其形成环境与碰撞造山或后碰撞环境相关(毛景文,2012;王义天,2018),故在之前已经“准备”好的大型褶皱转折端、层间滑脱带等部位成矿,例如在凤太矿集区内,铅硐山铅锌矿赋存于铅硐山复式背斜转折端附近和其翼部的层间滑脱带;八方山—二里河铅锌矿主矿体产于八方山—二里河短轴背斜的鞍部;银母寺铅锌矿产于磨沟—田竹园背斜的层间滑脱带中。

综合来说,中泥盆统古道岭组灰岩和上泥盆统星红铺组千枚岩、砂岩构成的硅钙面,就是矿体就位于钙质岩石与硅质岩石的接触面界面,且沿硅钙面延伸,因此硅钙面成矿应该是凤太矿集区铅锌矿资源勘查的重要依据。

5.2 矿床成因探讨

在西秦岭地区铅锌矿中,Si/Ca面普遍发育,如厂坝铅锌矿,矿床类型为SEDEX型铅锌矿(邓海军,2010;张长青等,2013;张腾姣,2015;祝建东等,2016;

翟玉林等,2017),矿体赋存于泥盆系安家岔组大理岩与石英片岩接触面处,矿体与围岩产状基本一致,呈层状、似层状和透镜状产出;毕家山铅锌矿受毕家山背斜控制,矿体产出于中泥盆统安家岔组结晶灰岩与千枚岩的接触界面,局部偏灰岩一侧;邓家山铅锌矿产于中泥盆统西水汉组中,矿体底部围岩为中厚层状灰岩(生物碎屑灰岩、结晶灰岩、亮晶灰岩和内碎屑粉晶灰岩等),顶板围岩为千枚岩。

硅钙面在铅锌成矿过程中的重要作用与他们的地球化学性质密不可分,Si为亲氧元素,与O有极强的亲和力,在自然界中主要以[SiO₄]⁴⁻四面体形式形成各种硅酸盐矿物。Ca为金属元素,它与强负电性的元素O、F结合,可形成以离子键为主的化合物,Ca在矿物中的类质同象多以Ca-Na和Ca-Mg以及Ca-稀土元素形式存在。Pb和Zn为亲硫元素,具有形成硫化物及其类似化合物的强烈倾向,常成为原子晶格或金属晶格,是构成金属矿床的主要成矿元素。

由于Pb、Zn元素的离子半径较大,而能量系数和晶格能较小,在岩浆结晶的早期,往往以类质同象的形式存在于造岩矿物中,很难以方铅矿或闪锌矿的形

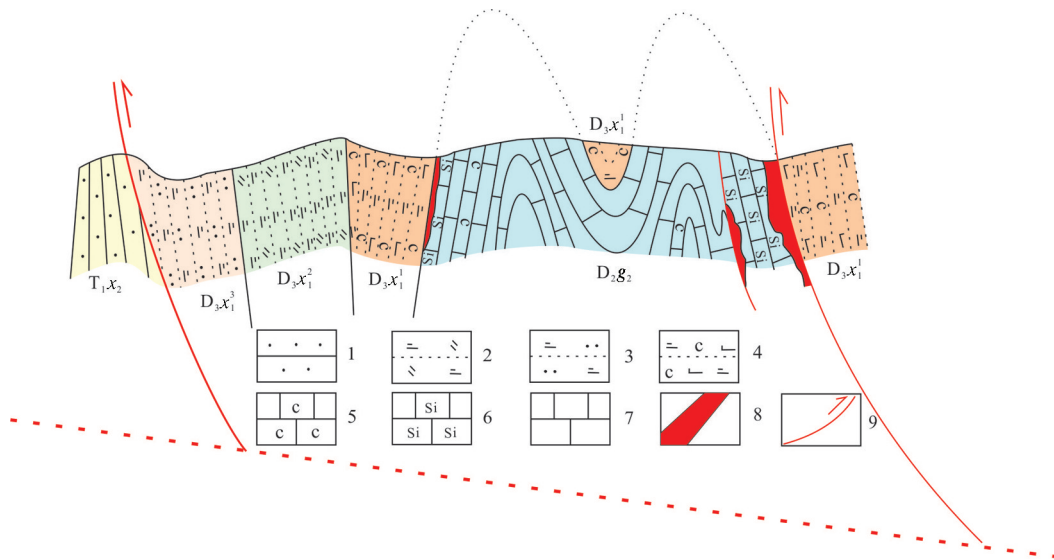


图7 铅硐山铅锌矿床综合剖面示意图

1—细砂岩;2—白云质绢云千枚岩;3—粉砂质绢云千枚岩;4—含炭钙质绢云千枚岩;5—炭质灰岩;6—硅质灰岩;7—结晶灰岩;8—Pb-Zn矿体;9—压性断裂;T_{1x2}—下三叠统西河组;D_{3x1}³—上泥盆统星红铺组下岩性段第三岩性层;D_{3x1}²—上泥盆统星红铺组下岩性段第二岩性层;D_{3x1}¹—上泥盆统星红铺组下岩性段第一岩性层;D_{2g2}—中泥盆统古道岭组上岩性段

Fig.7 The comprehensive section of Qiangongshan Lead-Zinc Deposit

1—Fine sandstone;2—Dolomite-sericite phyllite;3—Silty-sericite phyllite;4—Carbon-containing calcium sericite phyllite;5—Carbon Limestone;6—silicified limestone;7—Crystalline limestone;8—Pb-Zn ore body;9—Compressive fault; T_{1x2}—Lower Triassic Xihe formation; D_{3x1}³—The third lithology, lower lithology section of upper Devonian Xinghongpu Formation; D_{3x1}²—The second lithology, lower lithology section of upper Devonian Xinghongpu Formation; D_{3x1}¹—The first lithology, lower lithology section of upper Devonian Xinghongpu Formation; D_{2g2}—Upper lithological section of Middle Devonian Gudaoling Formation

式“独立”出来形成工业矿体(王育民,1984),只有当热液中气相组分的 S^{2-} 或 HS^- 聚集时,Pb、Zn才可能发生大规模的沉淀成矿。碳酸盐岩的化学性质十分活泼,易于溶解,岩石的孔隙度及渗透率都会增加,为成矿物质的活化迁移和富集沉淀提供了有利环境(王文斌,1983)。此外,由于Pb、Zn组成的硫化物一般为低温矿物,在构造活动不太强烈(即温压条件不是很高)的情况下即可发生活化,二次富集,因此,铅锌矿多沉淀于碳酸盐岩地层中。

除了Pb、Zn本身的地球化学性质之外,Si/Ca面构成异相定位空间和形成的地球化学障也是Pb、Zn成矿的重要方面(张长青等,2012)。在Si/Ca面中,钙质岩石具有硬度小、性脆、遇酸易溶解的物理性质,当含矿的热液流体进入到碳酸盐岩地层时,在地层内产生破碎、溶解、扩容等现象,从而为矿质的沉淀提供空间。硅质岩石则具有硬度大、可塑性大、化学性质稳定的特点,含矿热液遇到硅质岩石后,很难发生像钙质岩石那样的溶解、破碎、扩容的作用,而是对含矿热液的流通起到“阻隔”作用,通常成为矿化热液流动的“屏障”,为矿体定位提供了“盖层”条件,从而导致矿体聚集于盖层界面之下。Si/Ca面往往反映了外界条件的改变,物理环境的变化(岩石成分、岩石渗透率、压力、温度)必然导致成矿流体化学性质的变化(氧化还原电位、pH值、氧逸度、溶解度等),导致在流体中原来稳定存在的某些元素溶解能力下降,沉淀形成矿体。

5.3 岩浆作用与成矿时代

如前所述,目前对于凤太矿集区内铅锌矿床成因争论的根源在于是否有岩浆活动的参与。虽然在区内单个矿床内未发现大规模岩体的产出,仅有少量中基性岩脉产出,但纵观整个矿集区,岩浆活动较为发育(图8),西坝岩体是区内最大的花岗岩体,产于矿集区中东部,其中发育细粒闪长质包体。其锆石U-Pb年龄为215~219 Ma(汪欢,2012;张帆,2009),闪长岩包体的年龄为214 Ma(Zhang et al.,2012),二者基本一致,其地球化学结果显示,其形成于华北板块与扬子板块沿勉略缝合带俯冲的后碰撞环境,为晚印支期的产物。区内另一规模较大的岩体为花红树坪岩体,出露于矿集区中北部,其长轴方向与西坝岩体近乎平行,沿NWW向延伸,陈绍聪(2015)对该岩体中的花岗闪长岩LA-ICP-MS锆石U-Pb测年,获得其

加权平均年龄为(225.9±1.2)Ma和(225.1±1.5)Ma,指示其形成于印支晚期。脉岩作为判别隐伏岩体存在的重要标志之一,在凤太矿集区产出的各铅锌矿床虽未见岩体产出,但在各矿区地表及钻孔中均可见到数量较多的脉岩产出(陈绍聪,2018),因此推测在矿床深部可能有隐伏岩体存在。说明南秦岭微陆块在印支期构造-岩浆活动强烈。

前人对矿集区内典型矿床同位素测年结果显示,八方山—二里河铅锌矿床黄铁矿Re-Os年龄为(226±17)Ma(Zhang et al.,2011)、闪锌矿Rb-Sr等时线年龄为(220.7±7.3)Ma(胡乔青等,2012),铅硐山—东塘子铅锌矿床和银洞山铅锌矿床硫化物Rb-Sr同位素年龄分别为(211.6±2.6)Ma和(215.3±3.2)Ma(胡乔青等,2015),柴玛金矿床中闪锌矿Rb-Sr等时线年龄为(210.8±2.4)Ma(王义天等,2018),可以看出,矿集区内铅锌矿体形成于210~220 Ma,为印支晚期的产物。南秦岭中生代的构造-岩浆活动与凤太矿集区成矿作用在时间和空间上相耦合。

张革利(2018)对矿集区内东塘子铅锌矿体中的黄铁矿(该矿床为铅硐山铅锌矿体西延伸段)的H-O同位素年龄、微量元素等研究,结果显示其为热液成因,暗示铅锌矿床的形成与热液有关;铅锌矿矿石稀土特征与正常海水热沉积成因的特征并不一致,认为成矿作用与岩浆热液活动有关,伴有后期地层建造水的加入。王可新(2012)通过对区内稳定同位素研究发现,成矿物质具深源热液特征,其成矿流体主要来源于岩浆热液。

综上所述,本文认为区内产出的铅锌矿床可能是受硅钙面控制与岩浆热液有关的矿床,成矿地质体为深部隐伏的侵入体。

6 结 论

(1)西秦岭凤太矿集区铅锌矿体定位受硅钙面的控制,赋矿围岩为上泥盆统星红铺组碎屑岩(硅质岩石)和中泥盆统古道岭组碳酸盐岩(钙质岩石)组合。

(2)西秦岭印支期大规模的构造-岩浆活动与铅锌矿成矿作用在空间和时间上相耦合。构造运动过程中形成一系列层间、层内破碎带,为深部含矿热液提供上升通道,而碎屑岩+碳酸岩岩这套“脆-软-硬”地层组合,提供了良好的地球化学障,

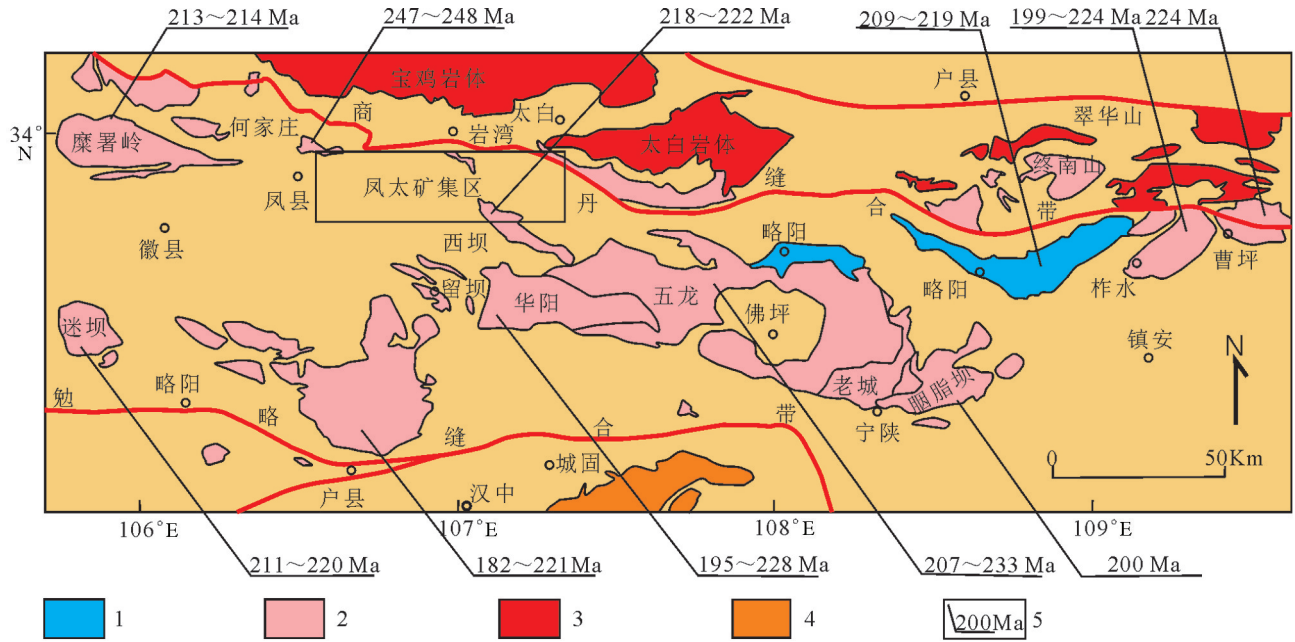


图8 南秦岭中生代花岗岩类的时空分布图(底图修编自孟旭阳等,2013)

1—中生代闪长岩;2—中生代花岗岩;3—古生代花岗岩;4—元古代花岗岩;5—岩体年龄

Fig.8 Emporal and Spatial distribution of Mesozoic granites in the Southern Qinling Mountains (modified from Meng et al., 2013)

1—Mesozoic diorite;2— Mesozoic granite;3—Paleozoic granite;4—Proterozoic granite;5—Rock age

为含矿热液的沉淀富集提供了有利场所,矿集区内铅锌矿床类型为受硅钙面控制的与岩浆活动有关的热液矿床。

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