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甘肃省厂坝矿集区十里铺幅和黄渚关幅 1∶50 000 地球化学数据集

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摘要：甘肃省厂坝地区位于厂坝—页水河华力西、印支期铅锌金银成矿带，在中国地质调查局发展研究中心“甘肃省厂坝矿集区找矿预测”项目实施过程中，深化处理了已有地质、物探、化探、遥感及矿产分布和找矿标志数据，重点在十里铺幅和黄渚关幅开展 1∶50 000 构造地球化学测量工作。共采集 8 694 件样品，为 2 911 件构造地球化学测量样品做了含量分析，主要采样介质为构造充填物与蚀变岩石，平均采样密度 13.02 个/km^2。应用电感耦合等离子质谱仪 (ICP–MS)、原子荧光光谱法 (AFS)、垂直电极–发射光谱法 (ES) 分析了 19 种元素 (Au、Ag、Cu、Pb、Zn、As、Sb、Bi、Hg、W、Sn、Mo、Cd、Cr、Co、Ni、Mn、Ba、B)，总体查明了主成矿元素铅锌金及伴生元素的分布规律，确定了元素与地层、构造的关系，提出了 3 个找矿远景区，最终形成 1∶50 000 甘肃十里铺幅、黄渚关幅地球化学数据集。数据集包含有 2 911 件样品、每件样品 19 种元素的原始分析数据表 1 个，图集 1 套 (含有 1 张采样点位图、19 张元素地球化学图、5 张元素组合异常图、1 张综合异常图和 1 张推断解释图)。区内共新发现单元素地球化学异常 344 处，综合异常 24 处。结合地质、矿产、物探、化探、遥感等信息圈出金矿找矿靶区 1 处、铅锌找矿靶区 2 处。该数据集为矿产地质调查提供了地球化学信息，对厂坝及周边地区深部找矿预测和基础地质研究都具有重要的参考价值。

关键词：十里铺幅；黄渚关幅；构造地球化学测量；数据集；地质调查工程；甘肃

数据服务系统网址：http://dcc.cgs.gov.cn

1　引言

甘肃省厂坝矿集区位于秦–祁–昆造山系秦岭弧盆系中秦岭陆缘盆地 (潘桂棠等，2009)，属于厂坝—页水河华力西、印支期铅锌金银成矿带 (张新虎等，2013)，该区以往开展了大量矿产勘查工作，取得了显著找矿成果，区域找矿潜力巨大 (张长青等，2013)。区内已探明 (超) 大型铅锌矿 3 处 (厂坝—李家沟、毕家山、页水河—邓家山);

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大、中型铅锌矿 3 处 (向阳山、庙沟、尖崖沟)；小型铅锌矿点数十处 (戴问天，1987；杨松年和缪远兴，1986；祝新友等，2006)。这些矿床 (点) 基本可以归为与碳酸盐岩和碎屑岩沉积建造有关的层控型铅锌矿成矿系列 (孙矿生和彭德启，2004)，是受岩相、断裂构造、侵入活动和区域变质作用等多方面控制的多元复合成因矿床 (李实，1989；王锦涛，2019)。近年在厂坝矿集区东部郭家沟一带深部发现厚大铅锌矿体 (王孝国等，2014；张世新等，2019)。此外，区内已发现金矿 10 余处，一般规模较小，典型的有三洋坝金矿及小沟里中型金矿床。这些金矿大部分是受构造控制的热液型矿床 (冯建忠等，2003；俞中辉等，2008)。目前累计探明铅锌资源量 1 700 多万吨，金资源量近百吨 (张世新等，2019；卢杰，2016)。除勘查工作外，前人在该区还做了大量基础科研工作 (祁思敬等，1993；祁思敬和李英，1993；马国良等，1996；张旺定，2001；姚书振等，2006；王义天等，2013)，但成矿认识局限于以往的传统思维，没有结合现代成矿理论及矿集区找矿方法新思路进行研究。同时该区进入隐伏矿找矿阶段，需要根据“勘查区成矿地质体找矿预测理论”(叶天竺等, 2014, 2017)，在厂坝矿集区内重点勘查区开展成矿地质体、成矿结构面、成矿作用特征标志调查，进一步认识总结本区的铅锌、金等多金属成矿规律，圈定找矿靶区。

甘肃省厂坝矿集区的铅锌矿成矿时代主要为早泥盆世，金矿成矿时代一般为晚三叠世，矿床受构造控制明显。矿集区工作程度较高，常规的找矿方法已经很难奏效。本次研究在矿产专项地质填图基础上对十里铺幅 (I48E013014)、黄渚关幅 (I48E013015) 进一步开展构造地球化学方法找矿研究，采用矿床原生地球化学晕分带特征分析方法确定矿体的剥蚀程度和赋矿深度，结合控矿构造研究，为实施深部工程验证提供依据。构造地球化学研究对由构造控制的隐伏矿床进行定位预测和评价是有效技术方法，在危机矿山深部及外围找矿中具有重要作用 (钱建平，1999；韩润生，2005；韩润生，2013；宋明春等，2020)。最早的构造地球化学研究思想是“经受着变形的岩石可以发生化学变化”(Sorby, 1863)。涂光炽 (1984) 认为“构造地球化学是探求构造与地球化学的内在联系”，是研究地质构造作用与地壳中化学元素的分配和迁移、分散和富集等关系的学科。构造地球化学找矿在弱化一些无矿的干扰因素的同时，能增强与成矿有关的信息，具有实用、高效、经济的特点 (韩润生等，2001；陈楠，2013)。

十里铺幅、黄渚关幅属陇南山区，海拔一般为 1 500～2 300 m，相对高差 500～800 m，地形切割属中等，沟谷发育，山势险峻，多为悬崖、峡谷及“V”字形谷地。该区地层以泥盆系西汉水群为主，侵入岩零星分布 (图 1)，地质构造复杂，成矿地质条件优越。

本次调查工作从 2016 年 7 月开始至 2018 年 12 月结束，累计完成十里铺幅、黄渚关幅 667.85 km^2 范围的 1：50 000 构造地球化学测量，形成本文的地球化学数据集 (夏云等，2020；表 1)。

2 数据采集及处理方法

2.1 野外定点

根据调查区的特点以及区内地球化学条件，结合前人地质及地球化学资料，采用 1：50 000 标准图幅地形图为底图布设构造地球化学测量点位。

以 1 km^2 为基本采样单元，采样单元编号按由左至右自上而下顺序编排。将每个基本采样单元平均划分为 4 个小格 (0.25 km^2)，由左至右、自上而下分别标注为 a、b、c、d，

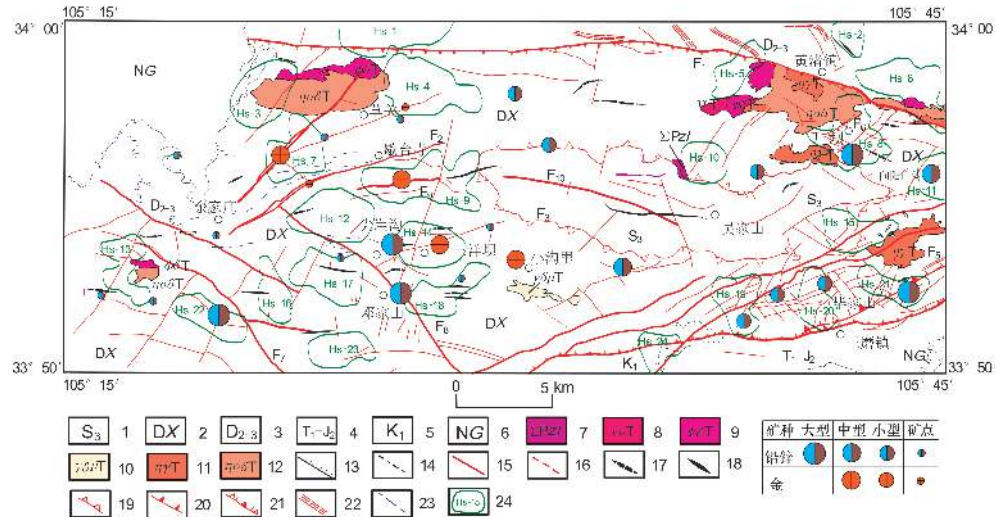

图 1　甘肃省厂坝矿集区十里铺—黄渚关幅构造纲要图

1—晚志留世吴家山岩组、海酒山岩组；2—泥盆纪西汉水群；3—泥盆纪中统–上统；4—三叠系、侏罗系；5—白垩系；6—新近系甘肃群；7—超基性岩体；8—三叠纪辉长岩；9—三叠纪辉石闪长岩；10—三叠纪花岗闪长玢岩；11—三叠纪二长花岗岩；12—三叠纪石英二长闪长岩；13—角度不整合；14—涌动接触；15—实测断裂；16—推测断裂；17—向斜构造；18—背斜构造；19—剥离断层；20—区域控盆断裂构造；21—同生断裂；22—韧性剪切带；23—相变界线；24—本次工作圈定综合异常

表 1　数据库 (集) 元数据简表

条目	描述
数据库(集)名称	甘肃省厂坝矿集区十里铺幅和黄渚关幅1∶50 000地球化学数据集
数据库(集)作者	夏　云，甘肃省地质矿产勘查开发局第一地质矿产勘查院 贾祥祥，甘肃省地质矿产勘查开发局第一地质矿产勘查院 邴明明，甘肃省地质矿产勘查开发局第一地质矿产勘查院
数据时间范围	2016.7—2018.12
地理区域	位于西秦岭南麓，属甘肃1∶50 000十里铺幅-黄渚关幅，面积约667.85 km^2。地理坐标：东经105°15′00″ ~ 100°15′45″，北纬33°50′00″ ~ 34°00′00″
数据格式	*.xls, *.mpj, *.wt, *.wl, *.wp
数据量	275 MB
数据服务系统网址	http://dcc.cgs.gov.cn
基金项目	中国地质调查局地质调查项目“全国重要矿集区找矿预测”(DD20160052)子项目“甘肃省厂坝矿集区找矿预测”(DD2016005214)
语种	中文
数据库(集)组成	包括1个Excel表格，含有2 911件样品、每件19种元素的原始分析数据; 1套图集，含有1张采样点位图、19张元素地球化学图、5张元素组合异常图、1张综合异常图和1张推断解释图

并在其后标注阿拉伯数字顺序号，如 a1、b1 等。

构造地球化学分析的采集样品及采集次序为：蚀变矿化岩 (A)(或矿化岩石 (M))>构造充填物 (C)>构造破碎带岩石 (F)>普通岩石 (G)。

采样点编号：采样单元编号+小格编号+顺序号+样品类型+顺序号。

2.2　采样密度

本次工作共采集 8 694 件样品，样品密度为 13.02 件/km^2。本次工作最终采集样品的物质主要为构造充填物 (C) 及蚀变岩石 (A)。采集样品中蚀变矿化岩 (A)(或矿化岩石

(M))+构造充填物 (C)+构造破碎带 (F) 类样品共计 7 436 件，占总样品数的 85.53%。

2.3 采样方法

在 0.25 km^2 小格内，采用“之”字形、S 形采样路线，尽可能寻找构造露头，一般采集 3 ~ 6 个点。详细记录每个采样点构造特点、地质体产状、矿化特征等信息。每个采样点采集样品重量 50 ~ 350 g。

2.4 样品加工

将每个小格内采集的所有样品等量组合为 1 个分析样，样品编号为小格号。剩余样品作独立副样长期保存。分析样运送至甘肃省地质矿产勘查开发局第一地质矿产勘查院实验测试中心进行 Au、Ag、Cu、Pb、Zn、As、Sb、Bi、Hg、W、Sn、Mo、Cd、Cr、Co、Ni、Mn、Ba、B 共 19 种元素含量分析，副样由甘肃省地质矿产勘查开发局第一地质矿产勘查院长期保存。

2.5 数据处理

2.5.1 数据处理

本次数据处理软件采用软件“中大比例尺化探数据一体化处理系统”(Geochem Studio 1.5) 及 MapGIS6.7。

对调查区内的 19 种元素的原始数据集，以 ($\bar{x}\pm 3S$) 进行循环叠代剔除离群数据，直到无离群数值可剔除为止，形成背景数据集，以剔除离群全域均值 ($\bar{x}$) 和标准离差 (S) 为依据计算异常下限 (T)，计算方法为 $T=\bar{x}+2S$，最终确定异常下限值。

2.5.2 数据网格化

网格距为 250 m×250 m，搜索半径 1 250 m，采用幂指数加权模型的参数进行数据网格处理。

2.5.3 图件绘制

(1) 元素地球化学图

在数据网格化的基础上，应用“中大比例尺化探数据一体化处理系统”(GeoChem Studio1.5)，按累频 0.5%、1.2%、2%、3%、4.5%、8%、15%、25%、40%、60%、75%、85%、92%、95.5%、97%、98%、98.8%、99.5%、100% 生成地球化学等值线和等值区。等值区按照《地球化学普查规范 (1：50 000)》(DZ/T 0011—2015) 对不同分级含量由低到高采用蓝—绿—黄—红的过渡色表示 (图 2)。

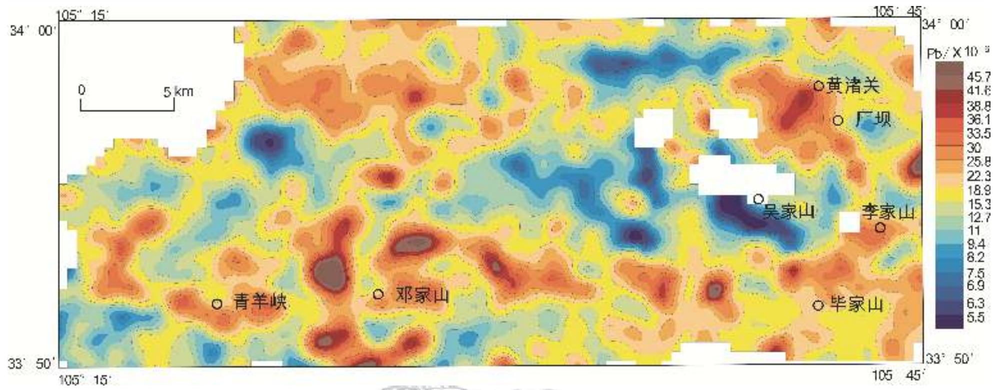

图 2 十里铺—黄渚关幅铅元素地球化学图

(2) 组合异常图

将 19 种元素，按照高、中、低温元素组合及各元素异常分布关系编制组合异常图。一般情况下出现 3 ~ 5 种元素套合在一起，即确定为组合异常。对主元素 (Au、Zn) 标出浓度分带，其余则只圈出异常范围。

(3) 综合异常图

在 19 种元素异常叠合图上，根据各元素异常分布关系，以包含公共面积的最大范围确定综合异常范围。多种元素套合在一起，确定为综合异常。共确定综合异常 24 个，图上用单圈表示，并将元素组合标于线上。

(4) 推断解释图

以建造构造图为底图，用 As、Sb、Hg 和 F 等元素的地球化学图来推测本区隐伏断裂构造，以浓度梯度带作为划分断裂的主要依据，结合建造构造图来划分。用 Li、Be、U、Th 和 W、Sn、Mo 等元素的地球化学图结合建造构造图来推断本区的隐伏岩体。

3 数据样本描述

3.1 数据特征

甘肃十里铺幅和黄渚关幅地球化学数据集元素地球化学分析数据类型为字符型与浮点型 (表 2)；分析元素为 Au、Ag、Cu、Pb、Zn、As、Sb、Bi、Hg、W、Sn、Mo、Cd、Cr、Co、Ni、Mn、Ba、B 共 19 种元素。

表 2 十里铺—黄渚关幅元素地球化学分析数据表

序号	字符名称	数据类型	示例	序号	字符名称	数据类型	示例
1	分析批号	字符型	CSZX–2016–1 217	12	Pb	浮点型	17.4
2	实验室编号	字符型	S1	13	Zn	浮点型	45.6
3	样品号	字符型	45a1	14	Ba	浮点型	1 047
4	As	浮点型	12.6	15	Co	浮点型	10.2
5	Sb	浮点型	1.1	16	Cr	浮点型	44.5
6	Hg	浮点型	23	17	Mn	浮点型	967
7	Au	浮点型	17.6	18	Ni	浮点型	19.7
8	W	浮点型	3.1	19	Ag	浮点型	167
9	Bi	浮点型	0.65	20	Sn	浮点型	1.5
10	Cd	浮点型	0.13	21	Mo	浮点型	2.9
11	Cu	浮点型	21.1	22	B	浮点型	42.6

注：Au、Hg量纲为$\times10^{-9}$，其余元素为$\times10^{-6}$。

(1) 元素的集中

由表 3 看出：该区元素背景含量与地壳 (黎彤，1976) 丰度比较，其浓集克拉克值 (*C*) 大于 1 的有 Bi、Pb、As、B、W、Au、Sb、Ag、Cd、Mo、Sn、Zn，这些元素在该区富集；浓集克拉克值接近 1 的有 Ba；浓集克拉克值小于 1 的有 Hg、Mn、Cr、Co、Cu、Ni，显示这些元素在该区贫化。

表 3　区域元素分布特征参数表

元素	X	S	Cv	Xo	So	Cvo	D	地壳丰度	陇南平均值	C	Kk	Kko
Ag/10^{-6}	0.22	1.57	7.01	0.09	0.05	0.58	76.76	0.08	0.07	2.75	3.14	1.29
As/10^{-6}	11.19	17.82	1.59	6.03	4.71	0.78	7.02	2.2	11.34	5.09	0.99	0.53
Au/10^{-9}	14.87	140.37	9.44	1.88	1.05	0.56	1 057.4	4	1.58	3.72	9.41	1.19
B/10^{-6}	34.53	52.57	1.52	28.29	29.19	1.03	2.20	7.6	56.67	4.54	0.61	0.50
Ba/10^{-6}	445.53	4 917.33	11.04	231.46	216.96	0.94	43.63	390	486.17	1.14	0.92	0.48
Bi/10^{-6}	0.41	4.84	11.88	0.20	0.07	0.37	141.74	0.004	0.33	102.50	1.24	0.61
Cd/10^{-6}	0.53	8.17	15.28	0.13	0.06	0.50	555.14	0.2	0.125	2.65	4.24	1.04
Co/10^{-6}	9.35	8.16	0.87	8.69	4.82	0.56	1.82	25	13.85	0.37	0.68	0.63
Cr/10^{-6}	44.93	77.36	1.72	39.00	33.05	0.85	2.70	110	69.72	0.41	0.64	0.56
Cu/10^{-6}	21.19	99.28	4.69	14.12	10.94	0.78	13.62	63	24.7	0.34	0.86	0.57
Hg/10^{-9}	50.15	292.89	5.84	15.02	5.70	0.38	171.57	80	26.75	0.63	1.87	0.56
Mn/10^{-6}	650.15	593.90	0.91	544.01	318.87	0.59	2.23	1 300	695.6	0.50	0.93	0.78
Mo/10^{-6}	2.98	2.84	0.95	2.59	2.04	0.79	1.60	1.3	0.62	2.29	4.81	4.18
Ni/10^{-6}	21.95	70.15	3.20	17.37	13.34	0.77	6.65	89	30.25	0.25	0.73	0.57
Pb/10^{-6}	174.3	5 451.5	31.3	14.90	8.18	0.55	7 794.18	12	21.81	14.52	7.99	0.68
Sb/10^{-6}	1.88	5.83	3.10	1.02	0.35	0.34	30.70	0.6	0.82	3.13	2.29	1.24
Sn/10^{-6}	2.44	2.62	1.08	2.28	1.13	0.50	2.48	1.7	3.01	1.44	0.81	0.76
W/10^{-6}	4.70	114.08	24.3	0.87	0.52	0.60	1 185.2	1.1	1.84	4.27	2.55	0.47
Zn/10^{-6}	132.0	1 423.1	10.8	41.37	31.54	0.76	143.99	94	73.89	1.40	1.79	0.56

注：X、S、Cv为剔除离群数据前的平均值、标准离差、变异系数，Xo、So、Cvo为剔除离群数据后的平均值、标准离差、变异系数；D为叠加值，$D=(X\cdot S)/(Xo\cdot So)$；地壳丰度据黎彤(1976), C为浓集克拉克值，$C=X$/地壳丰度；陇南平均值据李通国和金治鹏(2009)；Kk(浓集系数)=调查区元素平均含量/陇南地区元素平均值，Kk为剔除离群数据前的浓集系数，Kk0为剔除离群数据后的浓集系数。

该区元素背景含量与陇南地区平均值比较，浓集系数 (Kk) 大于 1 的有 Au、Pb、Mo、Cd、Ag、W、Sb、Hg、Zn；浓集系数接近 1 的 Bi、As；浓集系数小于 1 的有 Mn、Ba、Cu、Sn、Ni、Co、Cr、B，显示这些元素在该区贫化。

元素叠加值 $D\geq 100$ 表明元素具极强的后生叠加作用，成矿可能性较大，而 $D=10\sim100$ 表明元素具强叠加性，具有一定的成矿能力。本区元素叠加值大于 100 的元素有 Pb、W、Au、Cd、Hg、Zn、Bi，分别为 7794.18、1185.2、1057.4、555.14、171.57、143.99、141.74。因此，本区具成矿可能性的元素有 Pb、W、Au、Cd、Hg、Zn、Bi。

(2) 元素的分异

元素含量标准离差、变异系数较大的有 Pb、Ba、Zn、Au、Hg 等，反映了他们的含量变化均匀性较差，在全区分布不均匀，在局部有利地段有可能富集成矿。

由表 3 看出：构造地球化学测量中分异强的元素 ($Cv\geq 2$) 有 Pb、W、Cd、Bi、Ba、Zn、Au、Ag、Hg、Cu、Ni，说明它们在地层中分布极不均匀，成矿可能性较大；分异较强的元素 ($Cv=1\sim2$) 有 Cr、As、B、Sn，它们在地层中分布较不均匀，具有一定的成矿可能。显然，元素含量分布愈不均匀的元素，局部富集成矿的可能性愈大；分布愈均匀的元素，反映受成岩作用控制愈明显，富集成矿的可能性愈小。

综上所述，Pb、Zn、Au、W、Bi 等元素分异程度强、离散性高，后生叠加作用强烈，成矿可能性大。与本区已知矿产分布基本对应。

(3) 成矿元素分析

元素浓集系数 (*K*k) 反映了区中所分析元素含量相对于全区的富集程度，浓集系数越大说明元素含量越高，越有利于富集成矿。元素的变异系数 (*C*v) 反映了区中元素相对的分异程度，变异系数越大说明元素分异越明显，越易于局部富集，越利于成矿。

为了便于比较，使用参数“元素地球化学成矿有利度 (简称成矿有利度)”表示一个元素成矿可能性的大小。成矿有利度与元素浓集系数和元素变异系数均成正比，即:

成矿有利度 (*Z*)=元素浓集系数 (*K*k)×元素变异系数 (*C*v)

依据以上公式计算出区内 19 种元素的成矿有利度，排序结果如表 4 所示，Pb 元素成矿有利度最大，为 249.93，Co 元素成矿有利度最小，为 0.59。由表 4 可知，调查区内有利成矿元素为 Pb、Zn、Cd、Au、Ag、W。

表 4　调查区元素成矿有利度表

元素	Pb	Au	Cd	W	Ag	Zn	Bi	Hg	Ba	Sb
成矿有利度(*Z*)	249.93	88.83	64.79	61.89	22.01	19.3	14.73	10.92	10.16	7.1
元素	Mo	Cu	Ni	As	Cr	B	Sn	Mn	Co	–
成矿有利度(*Z*)	4.57	4.03	2.34	1.57	1.1	0.93	0.87	0.85	0.59	–

(4) 元素组合特征

利用全区构造地球化学测量 19 种元素分析值作 R 型因子分析。由于正交旋转因子负载矩阵比初始因子负载矩阵所反映的元素组合更具合理性和可解释性，因此采用了正交旋转因子负载矩阵来划分元素组合，确定了下列 6 个因子:

F1 因子：由 Ba、Pb、Hg、Zn、Cd 元素组成，与喷流沉积型铅锌矿有关，表明 Pb、Zn 矿化与 Ba、Hg、Cd 密切相关。

F2 因子：由 As、Sb、Ag、Au 元素组成，与岩浆期后热液活动有关，表明 Au 矿化与 As、Sb、Ag 关系密切。

F3 因子：由 Co、Cr、Ni 元素组成，与高温热液活动有关，异常一般由岩浆活动所引起。

F4 因子：Ag；F5 因子：B；F6 因子：Cd。

因子分析显示本区具有多个成矿阶段叠加；F4 因子、F5 因子、F6 因子主成分为单一因子，因此最终确定前 3 个因子分别代表的工作区的 3 种元素组合类型。

3.2　元素地球化学特征

统计了调查区和各地质子区的各元素参数特征值，以此反映调查区元素在不同地质单元中的分布特征及与地质成矿有关的地球化学过程 (表 5)。

从表 5 可以看出，严家河花岗闪长玢岩 ($\gamma\delta\mu$T) 地质单元样本数量较少 (*N*=6)，不具明显的统计学意义，其余 11 个地质单元的地球化学特征为:

(1) 上志留统吴家山岩组 (S_3w) 富集 Au(*K*=10.44)、Cr、Ni；分异性强的元素有 Au (*C*v=5.07)、Cr、Ni；具后生强叠加的元素有 Au(*D*=965.18)、Ni。上述特征表明该地层中 Au 容易富集成矿。

(2) 上志留统海酒山岩组 (S_3h) 富集 Ag、Cd、Cu、W；分异性强的元素有 W、Cu、

表 5 元素在各地质单元中参数

单元	参数	Au	Ag	Sn	Mo	B	Cd	W	Bi	Ba	Co	Cr	Cu	Mn	Ni	Pb	Zn	As	Sb	Hg
K_1js	*N*	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63
	X	8.28	0.11	2.01	3.75	44.70	0.21	3.82	0.22	249.60	9.57	43.35	17.90	723.60	19.58	18.24	49.71	12.46	1.30	42.48
	M	2.70	0.10	1.70	3.50	43.00	0.21	1.29	0.21	233.00	9.90	42.50	16.10	729.00	18.80	16.30	49.20	11.40	1.20	31.00
	S	16.38	0.07	2.19	1.95	45.36	0.09	16.72	0.08	181.45	3.25	21.49	9.71	279.32	10.48	8.19	27.68	7.08	0.39	37.23
	Cv	1.98	0.65	1.09	0.52	1.02	0.44	4.38	0.36	0.73	0.34	0.50	0.54	0.39	0.54	0.45	0.56	0.57	0.30	0.88
	X_{max}	88.80	0.52	18.20	8.97	344.00	0.44	133.50	0.51	1 233.00	16.70	86.40	41.40	1 499.00	41.90	48.90	141.20	32.40	2.39	202.00
	X_{min}	1.00	0.03	0.40	0.58	3.00	0.03	0.21	0.10	22.00	3.50	5.60	2.60	160.00	3.20	4.50	5.80	0.40	0.64	10.00
	Xo	2.44	0.11	1.75	3.75	39.87	0.21	1.24	0.22	233.74	9.57	43.35	17.90	723.60	19.58	17.75	48.24	12.46	1.30	35.27
	So	1.03	0.05	0.70	1.95	24.47	0.09	0.70	0.07	131.74	3.25	21.49	9.71	279.32	10.48	7.25	25.29	7.08	0.39	23.99
	Cvo	0.42	0.50	0.40	0.52	0.61	0.44	0.56	0.33	0.56	0.34	0.50	0.54	0.39	0.54	0.41	0.52	0.57	0.30	0.68
	K	4.40	1.30	0.88	1.45	1.58	1.66	4.40	1.14	1.08	1.10	1.11	1.27	1.33	1.13	1.22	1.20	2.07	1.27	2.83
	D	54.01	1.46	3.58	1.00	2.08	1.00	73.37	1.15	1.47	1.00	1.00	1.00	1.00	1.00	1.16	1.13	1.00	1.00	1.87
T*l*	*N*	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93
	X	3.58	0.09	1.81	2.47	42.22	0.58	1.01	0.22	240.33	10.12	39.79	13.17	657.59	17.62	29.57	145.49	11.23	1.35	136.94
	M	2.30	0.06	1.70	1.98	38.00	0.17	0.89	0.20	192.00	10.40	36.50	12.20	597.00	17.70	18.20	48.30	7.60	1.05	69.00
	S	4.53	0.14	0.95	1.80	30.00	3.73	0.54	0.09	248.81	3.63	25.48	7.31	325.51	7.42	66.43	927.08	13.82	0.78	511.65
	Cv	1.27	1.51	0.52	0.73	0.71	6.48	0.54	0.39	1.04	0.36	0.64	0.56	0.50	0.42	2.25	6.37	1.23	0.58	3.74
	X_{max}	29.20	1.32	5.00	9.96	185.00	36.10	3.67	0.66	2 196.00	21.60	203.50	42.00	1 812.00	40.40	571.70	8 986.40	113.00	4.58	4 950.00
	X_{min}	1.00	0.03	0.40	0.25	3.00	0.03	0.09	0.12	35.00	2.80	4.40	2.80	69.00	3.20	5.60	7.30	1.60	0.50	9.00
	Xo	2.42	0.07	1.78	2.38	39.75	0.17	0.94	0.21	196.91	9.99	38.01	12.08	595.29	17.37	18.16	47.86	8.09	1.23	66.55
	So	1.17	0.03	0.89	1.63	24.76	0.06	0.35	0.05	93.23	3.44	18.94	5.15	225.15	7.06	5.46	21.15	4.06	0.52	39.56
	Cvo	0.49	0.44	0.50	0.69	0.62	0.38	0.37	0.24	0.47	0.34	0.50	0.43	0.38	0.41	0.30	0.44	0.50	0.43	0.59
	K	1.91	1.06	0.80	0.95	1.49	4.46	1.16	1.13	1.04	1.16	1.02	0.93	1.21	1.01	1.98	3.52	1.86	1.32	9.12
	D	5.72	6.13	1.08	1.14	1.29	206.16	1.68	1.89	3.26	1.07	1.41	1.55	1.6	1.07	19.81	133.27	4.72	1.64	26.61

续表 5

单元	参数	Au	Ag	Sn	Mo	B	Cd	W	Bi	Ba	Co	Cr	Cu	Mn	Ni	Pb	Zn	As	Sb	Hg
D_3sl	N	882	882	882	882	882	882	882	882	882	882	882	882	882	882	882	882	882	882	882
	X	11.78	0.22	2.35	2.96	34.68	0.20	3.93	0.50	420.59	9.55	41.37	21.58	720.24	19.11	90.49	66.69	10.32	1.85	37.64
	M	1.80	0.07	2.10	2.34	15.00	0.11	0.67	0.18	107.50	7.60	26.65	10.40	579.50	12.40	13.90	26.30	5.15	0.96	14.00
	S	93.95	1.54	1.51	2.61	53.69	1.08	83.90	7.64	5 981.00	7.21	36.53	113.44	566.56	16.46	1 666.00	398.20	17.02	6.28	207.35
	Cv	7.98	6.93	0.64	0.88	1.55	5.32	21.35	15.38	14.22	0.76	0.88	5.26	0.79	0.86	18.42	5.97	1.65	3.40	5.51
	X_{max}	1 912.00	40.16	26.20	16.01	795.00	29.08	2 492.03	226.92	177 712.00	118.40	213.10	3 208.40	5 383.00	187.20	49 088.60	10 055.60	160.70	132.60	4 185.00
	X_{min}	0.20	0.03	0.40	0.25	3.00	0.03	0.05	0.09	8.00	2.00	0.20	1.90	20.00	2.30	2.60	2.70	0.30	0.38	6.00
	Xo	1.68	0.07	2.28	2.54	29.09	0.12	0.83	0.20	201.37	9.00	40.88	14.56	612.37	18.60	13.94	39.62	5.44	1.02	13.77
	So	0.88	0.04	1.17	1.86	30.98	0.06	0.52	0.08	202.76	4.93	35.57	11.62	349.07	14.90	7.56	33.72	4.01	0.33	4.45
	Cvo	0.53	0.58	0.51	0.73	1.07	0.51	0.63	0.40	1.01	0.55	0.87	0.80	0.57	0.80	0.54	0.85	0.74	0.33	0.32
	K	6.27	2.52	1.03	1.14	1.23	1.58	4.53	2.52	1.82	1.10	1.06	1.53	1.32	1.10	6.07	1.61	1.71	1.81	2.51
	D	751.78	109.93	1.33	1.64	2.07	30.15	771.15	237.19	61.62	1.55	1.04	14.47	1.91	1.13	1 430.00	19.88	8.05	34.00	127.33
$D_{2-3}hl$	N	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155
	X	6.05	0.18	3.02	2.08	21.56	0.23	0.82	0.18	178.63	6.84	25.57	17.37	558.73	13.09	64.82	97.65	10.86	1.68	59.42
	M	1.40	0.10	2.30	1.07	4.00	0.10	0.53	0.14	66.00	5.30	10.90	5.40	453.00	7.90	14.30	21.10	5.60	1.11	17.00
	S	24.90	0.51	7.91	2.42	31.20	0.99	1.04	0.13	387.71	4.80	30.51	73.90	496.62	13.49	314.91	557.92	15.67	2.20	226.89
	Cv	4.12	2.80	2.62	1.16	1.45	4.24	1.27	0.70	2.17	0.70	1.19	4.26	0.89	1.03	4.86	5.71	1.44	1.31	3.82
	X_{max}	271.50	6.02	99.40	11.49	134.00	12.10	9.04	1.11	4 374.00	27.70	117.80	917.30	3 567.00	66.30	2 956.70	6 586.00	104.80	20.09	2 400.00
	X_{min}	0.10	0.03	0.40	0.25	3.00	0.04	0.12	0.10	16.00	2.00	4.60	2.40	47.00	1.90	3.90	4.50	0.50	0.52	8.00
	Xo	1.55	0.10	2.30	1.79	3.52	0.11	0.60	0.16	138.01	6.51	11.49	8.33	446.32	7.98	13.23	32.74	5.95	1.17	18.28
	So	1.00	0.06	1.06	1.92	0.66	0.05	0.34	0.05	162.29	4.19	8.98	7.22	276.22	5.11	4.63	29.46	4.83	0.48	8.58
	Cvo	0.64	0.53	0.46	1.08	0.19	0.49	0.56	0.31	1.18	0.64	0.78	0.87	0.62	0.64	0.35	0.90	0.81	0.41	0.47
	K	3.22	2.07	1.33	0.80	0.76	1.81	0.95	0.93	0.77	0.79	0.66	1.23	1.03	0.75	4.35	2.36	1.80	1.65	3.96
	D	97.97	16.23	9.76	1.47	290.16	39.89	4.19	2.89	3.09	1.20	7.57	21.35	2.25	4.33	333.12	56.50	5.93	6.60	85.90

续表 5

单元	参数	Au	Ag	Sn	Mo	B	Cd	W	Bi	Ba	Co	Cr	Cu	Mn	Ni	Pb	Zn	As	Sb	Hg
D_2h	N	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735
	X	11.99	0.25	2.37	2.86	35.92	0.44	1.69	0.35	428.09	9.52	44.25	25.27	727.51	20.36	467.34	170.45	14.58	2.17	52.99
	M	2.10	0.07	2.20	2.17	21.00	0.13	0.85	0.20	183.00	8.20	31.20	14.00	584.00	15.60	13.90	40.00	8.30	1.10	15.00
	S	89.55	2.14	1.36	2.51	37.10	3.92	15.21	2.42	4 468.00	5.38	36.32	123.39	603.93	15.60	10 168.00	1 900.00	18.99	6.92	350.68
	Cv	7.47	8.42	0.57	0.88	1.03	8.84	9.03	6.90	10.44	0.57	0.82	4.88	0.83	0.77	21.76	11.14	1.30	3.19	6.62
	X_{max}	2 018.60	53.30	13.80	18.07	305.00	85.60	412.48	65.37	121 192.00	45.40	230.20	3 111.50	6 039.00	113.00	272 844.00	43 935.10	150.50	96.88	6 604.00
	X_{min}	0.10	0.03	0.40	0.25	3.00	0.01	0.09	0.10	17.00	1.60	2.70	1.00	25.00	2.30	2.30	4.20	0.60	0.53	6.00
	Xo	2.19	0.08	2.29	2.59	33.82	0.13	0.99	0.22	245.99	9.35	43.83	16.68	603.39	19.90	15.24	46.83	9.04	1.12	15.75
	So	1.25	0.05	1.13	1.99	32.67	0.06	0.58	0.08	210.00	5.00	35.43	11.93	337.35	14.74	8.67	33.74	6.67	0.38	6.44
	Cvo	0.57	0.58	0.50	0.77	0.97	0.47	0.59	0.38	0.85	0.54	0.81	0.72	0.56	0.74	0.57	0.72	0.74	0.34	0.41
	K	6.38	2.89	1.04	1.10	1.27	3.44	1.94	1.78	1.85	1.09	1.13	1.79	1.34	1.17	31.36	4.12	2.42	2.13	3.53
	D	391.25	134.75	1.24	1.39	1.21	226.80	44.51	47.39	37.03	1.09	1.04	15.68	2.16	1.08	35 995.00	204.89	4.59	35.00	183.11
D_1a	N	318	318	318	318	318	318	318	318	318	318	318	318	318	318	318	318	318	318	318
	X	45.39	0.34	2.38	2.71	24.98	2.25	4.00	0.51	726.21	8.41	32.51	15.24	498.65	18.28	51.29	357.96	12.00	2.35	88.17
	M	1.90	0.12	2.20	1.45	8.00	0.12	0.70	0.18	105.00	6.50	16.75	8.35	373.50	10.40	14.20	28.00	3.85	0.88	17.00
	S	339.29	1.74	1.28	3.77	39.90	22.55	46.97	3.92	7 434.00	12.37	69.23	22.75	564.57	56.53	264.03	2 755.00	24.60	6.87	450.24
	Cv	7.48	5.11	0.54	1.39	1.60	10.00	11.75	7.75	10.24	1.47	2.13	1.49	1.13	3.09	5.15	7.70	2.05	2.92	5.11
	X_{max}	5 288.00	26.23	9.90	41.06	363.00	377.89	827.80	69.65	131 771.00	203.70	1 078.80	254.20	7 281.00	932.50	3 413.80	41 654.10	156.60	67.67	6 019.00
	X_{min}	0.10	0.03	0.40	0.25	3.00	0.01	0.16	0.10	9.00	1.70	2.30	2.40	21.00	2.30	3.00	5.00	0.10	0.44	6.00
	Xo	1.72	0.12	2.32	1.80	14.78	0.13	0.75	0.17	138.41	7.27	25.54	11.44	415.77	13.20	14.03	32.74	3.85	0.89	16.04
	So	0.93	0.06	1.13	1.73	17.16	0.07	0.42	0.06	136.14	4.33	24.23	9.37	275.08	10.04	6.80	24.14	2.74	0.27	5.74
	Cvo	0.54	0.52	0.49	0.96	1.16	0.53	0.55	0.32	0.98	0.60	0.95	0.82	0.66	0.76	0.48	0.74	0.71	0.30	0.36
	K	24.14	3.86	1.05	1.04	0.88	17.47	4.61	2.57	3.14	0.97	0.83	1.08	0.92	1.05	3.44	8.65	1.99	2.31	5.87
	D	9 652.00	85.64	1.17	3.27	3.93	5 974.00	604.90	207.16	286.53	3.31	3.64	3.24	2.46	7.80	141.97	1 248.00	27.95	68.00	431.24

续表 5

单元	参数	Au	Ag	Sn	Mo	B	Cd	W	Bi	Ba	Co	Cr	Cu	Mn	Ni	Pb	Zn	As	Sb	Hg
S_3h	N	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106
	X	2.97	0.18	2.61	2.87	36.47	0.33	2.44	0.22	284.59	8.72	47.9	33.42	531.86	33.19	12.37	45.81	5.78	1.62	27.76
	M	1.7	0.14	2.55	1.84	6	0.12	0.62	0.16	95.5	4.85	16.45	6.25	315.5	9.9	11.25	14.1	2.35	0.88	17
	S	3.94	0.17	1.37	3.77	71.69	0.8	15.41	0.21	342.17	14.12	140.82	149.38	1 193.14	121.64	7.52	94.92	13.85	3.22	41.9
	Cv	1.33	0.95	0.52	1.31	1.97	2.46	6.33	0.94	1.2	1.62	2.94	4.47	2.24	3.67	0.61	2.07	2.4	1.99	1.51
	X_{max}	31.7	1.275	7.3	20.83	364	5.872	159.15	1.54	1 354	110.1	1 362.2	1 504.8	1 2 024	1 120.7	50.4	794.1	125.1	24.84	398
	X_{min}	0.3	0.031	0.4	0.25	3	0.021	0.16	0.09	4	1.6	4.6	2	23	2.4	4.1	5.4	0.1	0.45	9
	Xo	2.12	0.14	2.53	2.13	7.23	0.14	0.72	0.15	274.41	5.55	25.02	9.72	383.28	11.08	11.23	28.93	2.78	0.89	18.32
	So	1.58	0.08	1.23	2.03	6.22	0.09	0.48	0.03	327.27	3.54	24.88	10.36	323.09	8.47	4.53	26.86	2.38	0.24	7.8
	Cvo	0.74	0.57	0.49	0.95	0.86	0.62	0.67	0.19	1.19	0.64	0.99	1.07	0.84	0.77	0.4	0.93	0.86	0.27	0.43
	K	1.58	2.01	1.15	1.11	1.29	2.52	2.81	1.11	1.23	1	1.23	2.37	0.98	1.91	0.83	1.11	0.96	1.59	1.85
	D	3.5	2.59	1.15	2.5	58.16	20.99	107.81	9.78	1.08	6.27	10.84	49.57	5.12	43.05	1.83	5.6	12.11	25	8.13
S_3w	N	129	129	129	129	129	129	129	129	129	129	129	129	129	129	129	129	129	129	129
	X	19.63	0.10	1.96	4.23	39.57	0.20	0.84	0.25	461.66	9.51	78.61	17.75	434.62	55.41	9.25	34.95	4.09	0.88	16.81
	M	2.10	0.06	1.90	3.57	31.00	0.16	0.64	0.18	377.00	7.40	41.70	10.00	369.00	16.00	7.10	28.70	1.80	0.73	12.00
	S	99.47	0.08	1.21	2.89	48.60	0.15	0.67	0.39	509.25	12.75	237.48	22.27	289.46	272.01	6.13	26.32	5.98	0.38	16.59
	Cv	5.07	0.86	0.62	0.68	1.23	0.73	0.79	1.55	1.10	1.34	3.02	1.25	0.67	4.91	0.66	0.75	1.46	0.43	0.99
	X_{max}	879.70	0.53	10.50	14.50	393.00	0.93	5.72	4.32	4 723.00	114.60	2 129.60	148.60	2 319.00	2 603.10	38.20	168.30	44.10	3.52	156.00
	X_{min}	0.50	0.03	0.40	0.28	3.00	0.02	0.24	0.10	19.00	2.20	2.30	2.70	23.00	2.70	1.90	4.40	0.20	0.53	9.00
	Xo	2.04	0.08	1.83	4.15	29.99	0.17	0.70	0.17	400.50	7.38	43.66	11.16	384.83	15.58	8.43	30.83	2.06	0.83	12.33
	So	0.99	0.05	0.82	2.76	21.34	0.09	0.31	0.05	293.90	2.48	23.06	7.73	177.34	7.50	4.51	15.98	1.46	0.24	2.72
	Cvo	0.49	0.62	0.45	0.66	0.71	0.53	0.44	0.29	0.73	0.34	0.53	0.69	0.46	0.48	0.54	0.52	0.71	0.29	0.22
	K	10.44	1.10	0.86	1.63	1.40	1.54	0.97	1.26	1.99	1.09	2.02	1.26	0.80	3.19	0.62	0.84	0.68	0.87	1.12
	D	965.18	1.99	1.58	1.07	3.00	1.89	2.60	11.08	2.00	6.63	18.55	4.58	1.84	128.99	1.49	1.87	8.14	1.73	8.33

续表 5

单元	参数	Au	Ag	Sn	Mo	B	Cd	W	Bi	Ba	Co	Cr	Cu	Mn	Ni	Pb	Zn	As	Sb	Hg
$\eta\gamma$T	N	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
	X	2.49	0.09	3.52	5.56	17.22	0.23	194.31	0.67	508.52	5.36	19.36	10.76	333.22	7.87	26.84	68.77	3.97	0.78	21.04
	M	1.20	0.08	3.20	4.49	9.00	0.17	0.89	0.22	457.00	4.80	14.20	6.70	319.00	5.20	27.50	46.30	3.60	0.72	17.00
	S	2.35	0.06	1.61	4.53	18.43	0.25	1 004.00	1.92	324.71	3.01	17.63	8.43	112.32	7.20	11.73	126.93	3.10	0.19	17.06
	Cv	0.95	0.60	0.46	0.81	1.07	1.10	5.17	2.85	0.64	0.56	0.91	0.78	0.34	0.92	0.44	1.85	0.78	0.25	0.81
	X_{max}	9.30	0.33	7.40	18.34	81.00	1.45	5 222.00	10.18	1 103.00	14.80	86.30	28.90	641.00	35.00	45.70	699.00	14.10	1.37	98.00
	X_{min}	0.80	0.04	1.50	0.56	3.00	0.10	0.40	0.14	93.00	2.00	5.40	3.50	193.00	2.70	4.10	7.90	0.30	0.54	10.00
	Xo	2.49	0.09	3.52	5.56	11.42	0.17	0.94	0.23	508.52	4.67	15.22	10.76	333.22	5.70	26.84	44.53	3.58	0.75	17.12
	So	2.35	0.03	1.61	4.53	6.87	0.05	0.51	0.07	324.71	1.75	8.72	8.43	112.32	2.65	11.73	16.05	2.40	0.15	5.84
	Cvo	0.95	0.38	0.46	0.81	0.60	0.29	0.54	0.32	0.64	0.38	0.57	0.78	0.34	0.47	0.44	0.36	0.67	0.20	0.34
	K	1.32	1.07	1.55	2.15	0.61	1.79	223.86	3.42	2.20	0.62	0.50	0.76	0.61	0.45	1.80	1.66	0.66	0.76	1.40
	D	1.00	1.97	1.00	1.00	4.05	6.65	405 610.00	75.70	1.00	1.97	2.57	1.00	1.00	3.75	1.00	12.22	1.44	1.29	3.59
$\eta o\delta$T	N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
	X	7.72	0.16	4.03	3.88	57.92	0.15	2.39	0.67	689.48	10.82	78.08	16.48	487.08	24.59	26.51	55.11	10.39	2.21	15.87
	M	1.80	0.10	2.70	3.28	25.50	0.12	1.12	0.21	722.50	10.15	58.50	10.60	438.50	16.95	25.95	54.90	4.85	0.80	11.00
	S	33.22	0.28	6.09	2.39	128.29	0.10	4.53	3.37	310.85	5.60	54.89	17.14	444.35	18.96	10.88	34.24	14.90	5.49	20.31
	Cv	4.30	1.76	1.51	0.62	2.22	0.69	1.90	5.01	0.45	0.52	0.70	1.04	0.91	0.77	0.41	0.62	1.43	2.48	1.28
	X_{max}	312.80	2.53	44.10	11.63	1 035.00	0.66	34.49	31.99	1 839.00	35.40	267.60	132.40	3 431.00	80.10	56.60	312.50	80.40	43.42	182.00
	X_{min}	0.40	0.03	0.50	0.26	3.00	0.05	0.29	0.12	18.00	2.20	4.70	3.00	106.00	3.50	4.70	7.20	0.10	0.51	9.00
	Xo	2.13	0.10	2.88	3.48	24.69	0.12	1.17	0.21	676.56	10.55	75.95	13.05	424.02	24.59	26.51	52.22	5.65	0.80	10.65
	So	1.45	0.04	1.12	1.80	15.76	0.04	0.65	0.06	287.30	4.98	51.33	7.77	142.64	18.96	10.88	20.61	3.80	0.20	1.21
	Cvo	0.68	0.42	0.39	0.52	0.64	0.36	0.55	0.29	0.43	0.47	0.68	0.60	0.34	0.77	0.41	0.40	0.67	0.25	0.11
	K	4.11	1.81	1.77	1.50	2.05	1.16	2.75	3.41	2.98	1.25	2.00	1.17	0.90	1.42	1.78	1.33	1.72	2.17	1.06
	D	83.14	10.97	7.60	1.48	19.10	2.84	14.35	179.47	1.10	1.15	1.10	2.79	3.58	1.00	1.00	1.75	7.21	75.80	24.96

续表 5

单元	参数	Au	Ag	Sn	Mo	B	Cd	W	Bi	Ba	Co	Cr	Cu	Mn	Ni	Pb	Zn	As	Sb	Hg
$\gamma\delta\mu$T	N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	X	2.33	0.42	2.30	1.95	9.33	0.14	17.24	2.49	575.17	5.45	17.67	6.32	332.83	6.83	33.72	34.72	6.20	0.92	13.83
	M	2.30	0.12	2.40	2.39	9.50	0.15	2.22	0.27	588.00	4.60	15.75	6.10	271.50	5.00	26.30	40.90	6.10	0.93	14.00
	S	1.50	0.76	0.58	1.27	3.78	0.03	37.43	5.45	274.68	2.38	11.19	2.33	143.44	5.25	22.71	15.35	3.63	0.23	1.60
	Cv	0.64	1.80	0.25	0.65	0.41	0.21	2.17	2.19	0.48	0.44	0.63	0.37	0.43	0.77	0.67	0.44	0.59	0.25	0.12
	X_{max}	4.70	1.98	2.90	3.56	14.00	0.18	93.63	13.60	911.00	10.10	35.50	10.20	556.00	17.40	78.10	47.60	10.50	1.19	16.00
	X_{min}	0.50	0.06	1.60	0.37	3.00	0.10	1.14	0.13	106.00	3.70	4.80	4.00	210.00	3.70	19.00	12.20	1.80	0.67	12.00
	Xo	2.33	0.42	2.30	1.95	9.33	0.14	17.24	2.49	575.17	5.45	17.67	6.32	332.83	6.83	33.72	34.72	6.20	0.92	13.83
	So	1.50	0.76	0.58	1.27	3.78	0.03	37.43	5.45	274.68	2.38	11.19	2.33	143.44	5.25	22.71	15.35	3.63	0.23	1.60
	Cvo	0.64	1.80	0.25	0.65	0.41	0.21	2.17	2.19	0.48	0.44	0.63	0.37	0.43	0.77	0.67	0.44	0.59	0.25	0.12
	K	1.24	4.81	1.01	0.75	0.33	1.11	19.86	12.61	2.48	0.63	0.45	0.45	0.61	0.39	2.26	0.84	1.03	0.90	0.92
	D	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
$\varphi\delta$T	N	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37
	X	6.26	0.12	2.67	3.59	39.32	0.14	1.18	0.23	685.78	18.68	163.18	22.36	753.57	62.28	23.08	68.96	4.92	0.76	11.97
	M	1.60	0.11	2.20	2.75	16.00	0.13	0.87	0.20	707.00	16.90	112.40	21.10	605.00	41.60	19.90	70.80	3.20	0.70	11.00
	S	18.49	0.05	1.35	3.24	109.58	0.05	0.91	0.11	269.70	11.51	198.52	11.21	699.14	76.16	10.29	29.75	5.95	0.20	2.71
	Cv	2.95	0.43	0.51	0.90	2.79	0.35	0.77	0.48	0.39	0.62	1.22	0.50	0.93	1.22	0.45	0.43	1.21	0.27	0.23
	X_{max}	108.70	0.24	7.50	18.61	680.00	0.29	5.46	0.65	1 311.00	59.90	1 107.00	47.20	4 371.00	427.60	53.70	128.10	32.40	1.38	20.00
	X_{min}	0.70	0.04	1.00	0.45	3.00	0.06	0.34	0.12	49.00	4.10	5.00	2.80	107.00	3.60	9.50	9.10	1.00	0.47	9.00
	Xo	1.63	0.12	2.53	3.17	19.51	0.14	1.06	0.21	685.78	16.64	125.44	22.36	570.67	44.31	23.08	68.96	3.67	0.74	11.97
	So	0.77	0.05	1.09	2.04	12.51	0.05	0.55	0.07	269.70	7.67	99.37	11.21	210.14	32.06	10.29	29.75	2.45	0.18	2.71
	Cvo	0.47	0.43	0.43	0.65	0.64	0.35	0.52	0.33	0.39	0.46	0.79	0.50	0.37	0.72	0.45	0.43	0.67	0.24	0.23
	K	3.33	1.32	1.17	1.38	1.39	1.12	1.35	1.15	2.96	2.15	4.18	1.58	1.39	3.59	1.55	1.67	0.82	0.74	0.80
	D	92.56	1.00	1.31	1.79	17.66	1.00	1.83	1.76	1.00	1.68	2.60	1.00	4.39	3.34	1.00	1.00	3.25	1.18	1.00

注：Au、Hg量纲为10^{-9}，其余元素为10^{-6}；N：样品数；X、S、Cv为剔除离群数据前的算术平均值、标准离差、变异系数，Xo、So、Cvo为剔除离群数据后的算术平均值、标准离差、变异系数；M：中位数；K：浓集系数，K=X/调查区元素平均含量(详见表3)；D：叠加值，D=(X·S)/(Xo·So)。

Ni、Cr、Cd、As、Mn、Zn；具后生强叠加的元素有 W。上述特征表明该地层中 W 容易富集成矿。

(3) 下泥盆统安家岔组 (D_1a) 富集 Au(K=24.14)、Cd、Zn(K=8.65)、Hg、W、Ag、Pb(K =3.44)、Ba、Bi、Sb；分异性强的元素有 W、Ba、Cd、Bi、Zn(Cv=7.70)、Au(Cv=7.48)、Pb(C v=5.15)、Ag、Hg、Ni、Sb、Cr、As；具后生强叠加的元素有 Au(D=9652.00)、Cd、Zn(D =1248.00)、W、Hg、Ba、Bi、Pb(D=1419.70)。上述特征表明该地层中 Au、Pb、Zn 等容易富集成矿。

(4) 中泥盆统黄家沟组 (D_2h) 富集 Pb(K=31.36)、Au(K=6.38)、Zn(K=4.12)、Hg、Cd、Ag、As、Sb；分异性强的元素有 Pb(Cv=21.76)、Zn(Cv=11.14)、Ba、W、Cd、Ag、Au(Cv=7.47)、Bi、Hg、Cu、Sb；具后生强叠加的元素有 Pb(D=35995.00)、Au(D=391.25)、Cd、Zn(D =204.89)、Hg、Ag。上述特征表明该地层中 Au、Pb、Zn 等容易富集成矿。

(5) 中–上泥盆统红岭山组 ($D_{2-3}hl$) 富集 Pb、Hg、Au、Zn、Ag；分异性强的元素有 Zn、Pb、Cu、Cd、Au、Hg、Ag、Sn、Ba；具后生强叠加的元素有 Pb、B。上述特征表明该地层中 Pb、Au、Ag 容易富集成矿。

(6) 上泥盆统双狼沟组 (D_3sl) 富集 Au、Pb、W、Bi、Ag、Hg；分异性强的元素有 W、Pb、Bi、Ba、Au、Ag、Zn、Hg、Cd、Cu、Sb；具后生强叠加的元素有 Pb、W、Au、Bi、Hg、Ag。上述特征表明该地层中 Pb、W、Au 等容易富集成矿。

(7) 三叠系隆务河组 (Tl) 富集 Hg、Cd、Zn，分异性强的元素有 Cd、Zn、Hg、Pb；具后生强叠加的元素有 Cd、Zn。上述特征表明该地层中 Zn、Cd 等容易富集成矿。

(8) 下白垩统鸡山组 (K_1js) 富集 As、Au、Hg、W，分异性强的元素有 W。上述特征表明该地层中 W 等容易富集成矿。

(9) 厂坝黑云二长花岗岩 ($\eta\gamma$T) 富集 W、Bi、Ba、Mo，分异性强的元素有 W、Bi；具后生强叠加的元素有 W。上述特征表明该岩体中 W 等容易富集成矿。

(10) 黄渚关石英二长闪长岩 ($\eta o\delta$T) 富集 Au、Ba、Bi、W、Sb、B，分异性强的元素有 Bi、Au、Sb、B；具后生强叠加的元素有 Bi、Au。上述特征表明该岩体中 Bi、Au、Sb 等容易富集成矿。岩体主要成矿元素高、中、低温元素都有，说明在岩浆侵入各阶段，有用元素均有不同程度的富集，尤以 Au、Sb、Bi 为最，说明岩浆侵入各个时期均可能成矿。所以，应着重在岩体内、外接触带附近寻找 Au、Sb、Bi 等矿产。

(11) 挖泉山细粒辉石闪长岩 ($\varphi\delta$T) 富集 Cr、Ni、Au、Ba、Co，分异性强的元素有 Au、B。上述特征表明该岩体中 Au 等容易富集成矿。

4 数据质量控制和评估

4.1 原始数据质量

19 种元素分析测试由甘肃省地质矿产勘查开发局第一地质矿产勘查院实验测试中心承担。分析方法以电感耦合等离子体质谱法 (ICP–MS) 为主，辅助以原子荧光光谱法 (AFS)、垂直电极–发射光谱法 (ES)。每一种元素的分析方法、分析方法的检出限、《地球化学普查规范 (1∶50 000)》(DZ/T 0011—2015) 要求的检出限、报出率等见表 6。

在本次样品的分析过程中，所有元素均采用国家一级标样进行监控。样品分析共加入国家一级标样 68 样次，总测试项目 1 224 项，合格 1 224 项，合格率达 100%。Au 标

表 6 分析方法的检出限及分析元素报出率

分析元素	分析方法	实际检出限/10^{-6}	要求检出限/10^{-6}	报出率/%
As	原子荧光光谱法	0.2	1.0	99.57
Sb	原子荧光光谱法	0.05	0.2	100
Hg	冷原子荧光光谱法	0.0003	0.0005	100
Au	电感耦合等离子质谱法	0.0001	0.0003	99.94
W	电感耦合等离子质谱法	0.2	0.5	99.39
Bi	电感耦合等离子质谱法	0.05	0.1	100
Cd	电感耦合等离子质谱法	0.05	0.1	96.59
Cu	X–荧光光谱法	0.9	1.5	100
Pb	X–荧光光谱法	2.0	5.0	99.94
Zn	X–荧光光谱法	1.0	15	100
Ba	X–荧光光谱法	18	50	98.72
Co	X–荧光光谱法	0.8	1.0	100
Cr	X–荧光光谱法	2.5	15	99.82
Mn	X–荧光光谱法	10	30	100
Ni	X–荧光光谱法	1.0	3.0	100
Ag	垂直电极–发射光谱法	0.02	0.03	100
Sn	垂直电极–发射光谱法	0.6	1	95.01
Mo	垂直电极–发射光谱法	0.2	0.5	100
B	垂直电极–发射光谱法	1	5	100

样的 RE 值：−35.24%≤RE≤52.27%，符合规范要求。

内检样品及异常点质量监控：内检样品按样品总数的 5% 随机抽取样品进行重复性密码分析，计算基本分析值与重复性密码分析值的相对偏差。共加入重复性密码样品 82 个，密码样品总测试项目 1 476 项，合格率>95%。

初次检测完成后，按 3%～5% 比例抽取异常样品，以密码形式下达分析室，并计算相对偏差，合格率>95%。

为了保证分析质量，实验室按 100 件样品为一小批以密码的形式加入国家一级标样，与样品同时分析，计算 ΔLgC、$\Delta\lambda$，用以衡量各批次间的分析偏差及本批次样品分析的准确度、精密度，并绘制日常质量监控图，以达到控制分析质量的目的。

综上所述，从分析数据的实际应用情况来看，由甘肃省地质矿产勘查开发局第一地质矿产勘查院实验测试中心提供的构造地球化学测量样品分析结果数据真实、可靠。其分析质量完全满足《地球化学普查规范 (1∶50 000)》(DZ/T 0011—2015) 的要求。

4.2 数据集建设质量

十里铺 (I48E013014)、黄渚关幅 (I48E013015)2 幅图 1∶50 000 构造地球化学测量成果数据集为甘肃省厂坝矿集区找矿预测成果资料数据库中的一部分，按照地球化学勘查数据模型，利用 GeoMapBM V2.5 软件 (该软件是由自然资源部矿产勘查技术指导中心发起、由中国地质大学 (武汉) 数学地质遥感地质研究所于 2018 年开发的) 进行编图与建库，其属性按照《矿集区找矿预测数据模型基本数据表结构及填写规定》❶ 进行填写，数据完整、逻辑一致、空间定位准确、属性数据正确、编图说明书及元数据文件齐

全。甘肃省厂坝矿集区找矿预测成果资料数据库经中国地质调查局发展研究中心专家评审验收，综合得分 90 分，数据质量等级评定为“优秀级”，已完成相关数据库汇交工作。

5 异常圈定及特征

5.1 地球化学异常圈定

根据研究对象的元素组合特征，分为 5 类地球化学组合异常：Cu、Pb、Zn、Ag、Cd 组合异常；Au、As、Sb、Hg 组合异常；Ba、Mn、B 组合异常；W、Sn、Bi、Mo 组合异常；Co、Cr、Ni 组合异常。

根据 19 种元素异常组合、面积、强度、地质环境因素等进行筛选，将在地质环境、成因及空间等有明显联系的一组异常叠加部分圈定为异常。对异常元素组合及成矿地质条件差的异常，进行选择性的经验剔除；对个别分布面积较大的单元素异常，综合考虑地质条件、元素组合边界，并在相互连接薄弱处对其进行人为分割，构成综合异常。

全区共圈定综合异常 24 个（图 1）。

5.2 异常总体特征

元素异常的空间展布总体与区域构造线有密切的关系，局部与岩体基本一致:

(1) 吴家山背斜北厂坝—黄渚关—晒经乡一带：分布元素为 Ag、Au、B、Bi、Cd、Cu、Mn、Mo、Pb、Zn 等，形态大致呈长条带状，展布方向为北西—南东向，与区域构造线一致，可能反映一组与喷流沉积型铅锌矿有关的元素组合。

(2) 吴家山背斜轴部官店—安家岔一带：分布元素为 Ag、Au、B、Ba、Cd、Cu、Mo、Zn 等，形态大致呈长条带状，展布方向为北西西向，与区域构造线基本一致，可能反映一组与岩浆期后热液型金矿有关的元素组合。

(3) 吴家山背斜南毕家山—青阳峡一带：分布元素为 Ag、As、Au、B、Cd、Cu、Hg、Mn、Pb、Sb、Zn 等，形态大致呈长条带状，展布方向为东西向，与区域构造线大致一致。可能反映一组与喷流沉积型铅锌矿及岩浆期后热液型金矿有关的元素组合。

(4) 黄渚关岩体外接触带：分布元素为 As、Au、B、Ba、Bi、Co、Cr、Cu、Mo、Ni、Pb、Sn、W、Zn 等，反映一组与高、中、低温热液有关的元素组合，形态上呈弧形环绕黄渚关岩体分布。

(5) 草关岩体外接触带：分布元素为 Ag、As、Au、B、Ba、Bi、Co、Cr、Cu、Mo、Ni、Pb、Sb、Sn、W、Zn 等，反映一组与高、中、低温热液有关的元素组合，元素基本沿岩体接触带分布，形态上呈弧形。

6 结论

甘肃省厂坝地区十里铺幅、黄渚关幅 1∶50 000 地球化学数据集工作通过开展 1∶50 000 构造地球化学测量，获得了第一手地球化学测量数据，并以此为基础编制形成地球化学图集。数据集的建立为该区域矿产地质调查提供了地球化学信息，能最大限度地满足相关科研人员对该区构造地球化学测量信息的查询需求，为实现信息资源共享创造了条件。新发现单元素地球化学异常 344 处，综合异常 24 处，其中甲类综合异常 14 处，乙类综合异常 9 处。结合地质、矿产、物探、化探、遥感等信息圈出金矿找矿靶区 1 处、铅锌找矿靶区 2 处，进一步扩大了区内寻找金、铅锌的找矿远景，为调查区

及周边矿山企业提供了资源找寻信息。

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1∶50 000 Geochemical Dataset of Shilipu and Huangzhuguan Map-sheets, Changba Ore Concentration Area, Gansu Province

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Abstract: Changba area, Gansu Province is located in Changba-Yeshuiheariscan and Indosinian Pb-Zn-Ag-Au metallogenic zone. During the implementation of the project titled *Prospecting Prediction of Changba Ore Concentration Area*, *Gansu Province* initiated by the Development and Research Center of China Geological Survey, the existing data on geology, geophysics, geochemistry, remote sensing, mineral distribution, and prospecting indicators of Changba area, were further processed. Most importantly, a 1∶50 000 tectonic-geochemical survey of Shilipu and Huangzhuguan Map-sheets was carried out. A total of 8694 samples were mainly collected from altered rocks and fillings in structures, with a mean sampling density of 13.02 samples per km^2. Among them, 2911 samples were used for tectonic-geochemical analysis. Nineteen elements (i.e. Au, Ag, Cu, Pb, Zn, As, Sb, Bi, Hg, W, Sn, Mo, Cd, Cr, Co, Ni, Mn, Ba, and B) were analyzed using the inductively coupled plasma-mass spectrometer (ICP–MS), atomic fluorescence spectroscopy (AFS) and perpendicular electrode-emission spectrometry (ES). As a result, the distribution regularity of major metallogenic elements (i.e. Pb, Zn, and Au) and their associated elements were generally ascertained, the relations of these elements with stratum and structures were identified, and three prospecting areas were proposed. Based on this, a 1∶50 000 geochemical dataset of Shilipu and Huangzhuguan Map-sheets, Gansu Province (also referred to as the Dataset) was finally developed. It consists of one data table and an atlas. The former is composed of the primary analysis data of 19 elements for 2911 samples and the later includes one sampling point bitmap, 19 element geochemical maps, five element-association anomaly maps, one integrated anomaly map, and one interference and interpretation map. A total of 344 single-element geochemical anomalies and 24 integrated anomalies were newly discovered in Changba area.

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Meanwhile, Combining with the information on geology, minerals, geophysical prospecting, geochemical prospecting and remote sensing, one Au prospecting target and two Pb-Zn prospecting targets were delineated. The Dataset could provide geochemical information for mineral geological surveys and serves as an important reference for deep mineral prospecting prediction and basic geological research of Changba and its surrounding areas.
Key words: Shilipu Map-sheet; Huangzhuguan Map-sheet; tectonic-geochemical survey; Dataset; geological survey engineering; Gansu
Data service system URL: http://dcc.cgs.gov.cn

1 Introduction

Changba Ore Concentration Area, Gansu Province lies in the middle Qinling epicontinental basin, Qinling arc-basin system, Kunlun–Qilian–Qinling orogenic system (Pan GT et al., 2009). It is a part of Changba–Yeshuihe Variscan and Indosinian Pb-Zn-Ag-Au metallogenic zone (Zhang XH et al., 2013). A large number of mineral surveys have been carried out in the area, obtaining significant prospecting outcomes and revealing great potential in mineral prospecting (Zhang CQ et al., 2013). Many lead–zinc deposits/ore occurrences have been identified in the area, including three (super-) large deposits (Changba−Lijiagou, Bijiashan, and Yeshuihe−Dengjiashan), three large/medium-sized deposits (Xiangyangshan, Miaogou, and Jianyagou), and dozens of small ore occurrences (Dai WT, 1987; Yang SN and Miu YX, 1986; Zhu XY et al., 2006). Generally, these deposits (ore occurrences) can be classified as the strata-bound lead–zinc metallogenic series associated with sedimentary suites of carbonate rocks and clastic rocks (Sun KS and Peng DQ, 2004). They are polygenetic compound deposits under control of lithofacies, fault structures, intrusive activities, and regional metamorphism (Li S, 1989; Wang JT, 2019). In recent years, large and thick lead–zinc ore bodies have been found in the deep part of Guojiagou area in the eastern part of the Changba Ore Concentration Area (Wang XG et al., 2014; Zhang SX et al., 2019). In addition, ten gold deposits were discovered in the area. They are small-sized in general and the typical ones include medium-sized Sanyangba and Xiaogouli gold deposits. Most of these deposits are hydrothermal ones controlled by structures (Feng JZ et al., 2003; Yu ZH et al., 2008). To date, the accumulative measured resources of lead–zinc and gold are more than 17 million tonnes and nearly 100 tonnes, respectively (Zhang SX et al., 2019; Lu J, 2016). Aside from surveys, a lot of fundamental researches have been conducted previously for the area (Qi SJ et al., 1993; Qi SJ and Li Y, 1993; Ma GL et al., 1996; Zhang WD, 2001; Yao SZ et al., 2006; Wang YT et al., 2013). However, previous understanding of metallogenesis in the area is limited by previous traditional ideas, and modern metallogenic theories and new ideas of mineral prospecting based on ore concentration areas are yet to be combined. Meanwhile, as the area enters the prospecting stage of concealed deposits, it is necessary to follow the "prospecting prediction theory of metallogenic geologic blocks in mineral exploration areas" (Ye TZ et al., 2014, 2017) to investigate the metallogenic geologic blocks, metallogenic structural planes, and features/indicators of metallogenesis in key exploration areas of the area. The purpose is to further understand and summarize metallogenic regularity of polymetallic minerals (e.g., Pb-Zn and Au) and delineate prospecting targets.

The lead–zinc deposits and gold deposits in the Changba Ore Concentration Area mainly occurred in Early Devonian and Late Triassic, respectively. Meanwhile, the gold deposits in the area are apparently controlled by structures. Conventional prospecting approaches do not work well in the area due to its high exploration level. In this study, tectonic-geochemical techniques were employed for the prospecting of Shilipu (I48E013014) and Huangzhuguan (I48E013015) Map-sheets based on the mineral-specific geological mapping. Meanwhile, the zoning characteristic analysis method of primary geochemical halos of deposits was applied to determine the denudation degree and ore-bearing depth of ore bodies. All these together with research on ore-controlling structures were conducted to provide the basis for deep engineering verification. Tectonic-geochemical research is an effective technology in the positioning, prediction, and evaluation of concealed deposits controlled by structures and thus plays a critical role in prospecting of the deep parts and peripheral areas of mines with resource crisis (Qian JP, 1999; Han RS, 2005, 2013; Song MC et al., 2020). The tectonic-geochemical research was initially built on the idea that “rocks undergoing deformation may suffer chemical changes” (Sorby, 1863). Tu GZ (1984) argued that “tectonic-geochemistry is to explore the inherent relations between structures and geochemistry” and is a science aiming to study the relations of geological tectonism with the distribution, migration, dispersion, and enrichment of chemical elements in the crust. Prospecting using tectonic-geochemistry can augment information related to metallogenesis while attenuating some interference factors unrelated to metallogenesis, and thus are practical, efficient, and economical (Han RS et al., 2001; Chen N, 2013).

The Shilipu and Huangzhuguan Map-sheets are located in the mountainous area of Longnan, Gansu Province, with an elevation of 1 500–2 300 m and a relative elevation difference of 500–800 m. Besides, they have medium terrain slicing, developed ravines, and precipitous mountains, and are mostly covered by cliffs, canyons and V-shaped valleys. The strata in the two map-sheets mainly include Devonian Xihanshui Group and sparsely distributed intrusive rocks (Fig. 1), with complex geological structures and favorable metallogenic geological conditions.

The 1：50 000 tectonic-geochemical survey in this study started in July 2016 and ended in December 2018, covering an area of 667.85 km^2 of the Shilipu and Huangzhuguan Map-sheets, and as a result, the geochemical dataset was formed (Xia Y et al., 2020; Table 1).

2 Methods for Data Acquisition and Processing

2.1 Determination of Field Sampling Points

Based on the characteristics of the study area and the geochemical conditions of landscapes in the study area, as well as previous geological and geochemical data, the tectonic-geochemical survey points were deployed by taking 1：50 000 topographic maps of standard map-sheets as the base map.

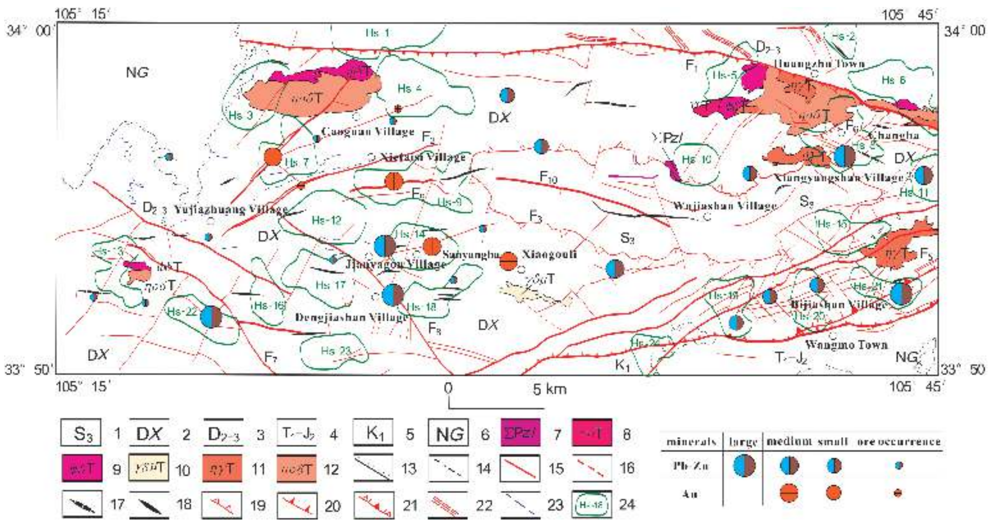

Fig. 1 Geological structure outline map of the Shilipu and Huangzhuguan Map-sheets in Changba Ore Concentration Area, Gansu Province

1—Late Silurian Wujiashan and Haijiushan formations; 2—Devonian Xihanshui Group; 3—Middle–Upper Devonian; 4—Triassic and Jurassic; 5—Cretaceous; 6—Neogene Gansu Group; 7—Ultramafic pluton; 8—Triassic gabbro; 9—Triassic pyroxene diorite; 10—Triassic granodiorite porphyrite; 11—Triassic monzonitic granite; 12—Triassic quartz monzodiorite; 13—angular unconformity; 14—surging intrusive contact; 15—measured fault; 16—inferred fault; 17—syncline structure; 18—anticline structure; 19—denudational fault; 20—regional basin-controlled fault; 21—syngenetic fault; 22—ductile shear zone; 23—lithofacies transition boundary; 24—delineated integrated anomalies through this study

The basic sampling units are set to 1 km^2 each. Each basic sampling unit was evenly divided into four cells (0.25 km^2 each) and numbered as a, b, c, and d from left to right and from top to bottom. Furthermore, behind each number, a serial number in Arabic was marked, such as a1, b1.

Tectonic-geochemical samples were taken from the following materials in the following order: altered mineralized rocks (A) (or mineralized rocks (M)) > fillings in structures (C) > rocks in tectonic fractured zones (F) > common rocks (G).

Each sampling point was numbered as “sample unit no. + cell no. + serial number + sample type + serial number”.

2.2 Sampling Density

A total of 8 694 samples were collected in this study, with a sampling density of 13.02 samples per km^2. They were mainly taken from fillings in structures (C) and altered rocks (A). Among them, 7 436 samples were collected from altered mineralized rocks (A) (or mineralized rocks (M)) + fillings in structures (C) + rocks in tectonic fractured zones, amounting for 85.53% of the total samples.

2.3 Sampling Method

In general, three to six sampling points were sampled in each cell with an area of 0.25 km^2 by seeking outcrops as many as possible along Z- and S-shaped sampling routes. The tectonic features, attitude of geologic blocks, and mineralization features of each sampling point were recorded. Samples weighing 50–350 g were collected from each sampling point.

Table 1 Metadata Table of Database (Dataset)

Items	Description
Database (dataset) name	1：50 000 Geochemical Dataset of the Shilipu and Huangzhuguan Map-Sheets, Changba Ore Concentration Area, Gansu Province
Database (dataset) authors	Xia Yun, The First Geological Mineral Exploration Institute of Gansu Provincial Geology and Mineral Bureau Jia Xiangxiang, The First Geological Mineral Exploration Institute of Gansu Provincial Geology and Mineral Bureau Bing Mingming, The First Geological Mineral Exploration Institute of Gansu Provincial Geology and Mineral Bureau
Data acquisition time	July 2016–December 2018
Geographical area	The survey area lies in the southern foot of western Qinling area and is a part of 1：50 000 Shilipu and Huangzhuguan Map-sheets, Gansu Province, covering an area of 667.85 km^2. Coordinates: 105°15′00″−100°15′45″E; 33°50′00″−34°00′00″N
Data format	*.xls, *.mpj; *.wt, *.wl, *.wp
Data size	275 MB
Data service system URL	http://dcc.cgs.gov.cn
Fund project	The project titled *Prospecting Prediction of Changba Ore Concentration Area*, *Gansu Province* (No.: DD2016005214), which is a subproject of the geological survey project titled *Prospecting Predication of Nationwide Major Integrated Exploration Areas in China* (No.: DD20160052) initiated by the China Geological Survey
Language	Chinese
Database (dataset) composition	The Dataset consists of one data table in Excel format and an atlas in MapGIS format. The former is composed of the primary analysis data of 19 elements for 2911 samples, and the latter includes one sampling point bitmap, 19 element geochemical maps, five element-association anomaly maps, one integrated anomaly map, and one interference and interpretation map

2.4 Sample Processing

All samples of equal amounts taken within one cell were combined into one analysis sample, which was numbered as the cell no.

The remaining samples were long kept as independent duplicate samples.

The analysis samples were sent to the experimental and testing center of The First Geological Mineral Exploration Institute of Gansu Provincial Geology and Mineral Bureau for content analysis of 19 elements (i.e. Au, Ag, Cu, Pb, Zn, As, Sb, Bi, Hg, W, Sn, Mo, Cd, Cr, Co, Ni, Mn, Ba, and B), while the duplicate samples were long kept in The First Geological Mineral Exploration Institute of Gansu Provincial Geology and Mineral Bureau.

2.5 Data processing

2.5.1 Data Processing

Relevant data were processed using the software "Integrated Data Processing System for Middle-large Scale Geochemical Surveys" (Geochem Studio 1.5) and MapGIS6.7.

For the primary dataset of the 19 elements in the survey area, loop-iteration was applied to eliminate data lying outside 3S of the mean ($\bar{x}$) in the normal distribution until no data can be eliminated. As a result, the background dataset was formed. The threshold (T) was calculated using the mean of all the data ($\bar{x}$) and the standard deviation (S) according to the formula $T=\bar{x}+2S$.

2.5.2 Data Griding

The data were grided using parameters from a weighted power-exponent model, with a grid spacing set to 250 m × 250 m and a search radius set to 1 250 m.

2.5.3 Map Preparation

(1) Element geochemical maps

On the basis of grided data, GeoChem Studio 1.5 was applied to generate geochemical isolines and equivalence regions at the cumulative frequencies of 0.5%, 1.2%, 2%, 3%, 4.5%, 8%, 15%, 25%, 40%, 60%, 75%, 85%, 92%, 95.5%, 97%, 98%, 98.8%, 99.5%, and 100%. The equivalence regions were presented with blue-green-yellow-red transitional colors from low to high content grades (Fig. 2) according to the *Specification of Geochemical Reconnaissance Survey* (1：50 000) (DZ/T0011- 2015; also referred to as the *Specification*).

(2) Composite anomaly maps

The composite anomaly maps of the 19 elements were developed based on the associations of elements with high/mid/low metallogenic temperature and the anomaly distribution relations of the elements. Generally, 3−5 types of elements overlapping together were determined to be a composite anomaly. Concentration zoning was marked for main elements (Au and Zn), while anomaly scopes were delineated for other elements.

(3) Integrated anomaly maps

On the anomaly overlapping map of the 19 elements, the scope comprising the maximum public area was determined to be the scope of an integrated anomaly based on the anomaly distribution relation of the elements. Many types of elements overlapping together were determined to be an integrated anomaly. A total of 24 integrated anomalies were determined. They were denoted using a single circle, with the element association marked on circle edge.

(4) Inference and interpretation maps

With the suite-tectonic map as the base map, the concealed fault structures in the Area were inferred from the geochemical maps of the elements such as As, Sb, Hg, and F.

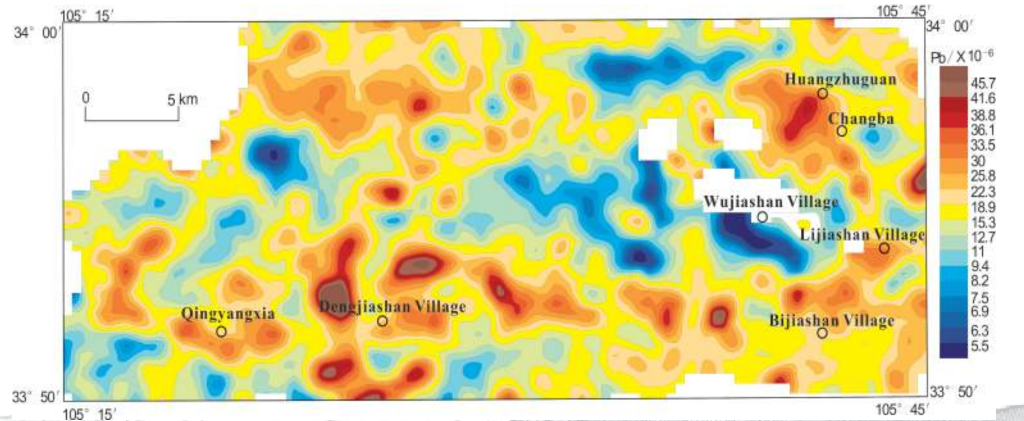

Fig. 2 Element geochemical map of Pb in the Shilipu and Huangzhuguan Map-sheets

Meanwhile, the faults were divided mainly on the basis of concentration gradient zones along with the suite-tectonic maps. The concealed plutons in the Area were inferred from geochemical maps of elements such as Li, Be, U, Th, W, Sn and Mo as well as the suite-tectonic maps.

3 Description of Data Samples

3.1 Data Characteristics

The data for element geochemical analysis in the Dataset are of two types: char and float (Table 2). Nineteen elements were analyzed, namely Au, Ag, Cu, Pb, Zn, As, Sb, Bi, Hg, W, Sn, Mo, Cd, Cr, Co, Ni, Mn, Ba, and B.

(1) Enrichment of elements

The enrichment of elements is shown in Table 3. According to comparison between the geological background of the study area with crustal abundance (Li T, 1976), the elements with Clarke of concentration (*C*) greater than 1 include Bi, Pb, As, B, W, Au, Sb, Ag, Cd, Mo, Sn, and Zn, and they are enriched in the Area; those with *C* near 1 are Ba; those with *C* less than 1 include Hg, Mn, Cr, Co, Cu, and Ni, and they are depleted in the Area.

According to comparison between the geological background of the study area with the content averages of Longnan area, Gansu Province, the elements in the Area with concentration coefficient (*K*k) greater than 1 include Au, Pb, Mo, Cd, Ag, W, Sb, Hg, and Zn; those with *K*k near 1 include Bi and As; those with *K*k less than 1 include Mn, Ba, Cu, Sn, Ni, Co, Cr, and B, and they are depleted in the Area.

An element with superposition strength coefficient $D \geqslant 100$ indicates that the element suffered very strong epigenetic superposition and has great metallogenic potential. An element with D = 10−100 means that the element suffered strong superposition and has a certain metallogenic potential. The elements with superposition strength coefficientt $D \geqslant 100$ in the

Table 2 Geochemical analytical data table of elements in the Shilipu and Huangzhuguan Map-sheets

No.	Field name	Data type	Example	No.	Field name	Data type	Example
1	Analysis lot no.	char	CSZX–2016–1 217	12	Pb	float	17.4
2	Lab. no.	char	S1	13	Zn	float	45.6
3	Sample no.	char	45a1	14	Ba	float	1 047
4	As	float	12.6	15	Co	float	10.2
5	Sb	float	1.1	16	Cr	float	44.5
6	Hg	float	23	17	Mn	float	967
7	Au	float	17.6	18	Ni	float	19.7
8	W	float	3.1	19	Ag	float	167
9	Bi	float	0.65	20	Sn	float	1.5
10	Cd	float	0.13	21	Mo	float	2.9
11	Cu	float	21.1	22	B	float	42.6

Notes: the dimension is 10^{-9} for Au and Hg, and 10^{-6} for other elements.

Table 3 Characteristic parameter values of regional element distribution

Element	*X*	*S*	*C*v	*X*o	*S*o	*C*vo	*D*	Crust abundance	Means in Longnan area	*C*	*K*k	*K*ko
Ag/10^{-6}	0.22	1.57	7.01	0.09	0.05	0.58	76.76	0.08	0.07	2.75	3.14	1.29
As/10^{-6}	11.19	17.82	1.59	6.03	4.71	0.78	7.02	2.2	11.34	5.09	0.99	0.53
Au/10^{-9}	14.87	140.37	9.44	1.88	1.05	0.56	1057.4	4	1.58	3.72	9.41	1.19
B/10^{-6}	34.53	52.57	1.52	28.29	29.19	1.03	2.20	7.6	56.67	4.54	0.61	0.50
Ba/10^{-6}	445.53	4917.33	11.04	231.46	216.96	0.94	43.63	390	486.17	1.14	0.92	0.48
Bi/10^{-6}	0.41	4.84	11.88	0.20	0.07	0.37	141.74	0.004	0.33	102.50	1.24	0.61
Cd/10^{-6}	0.53	8.17	15.28	0.13	0.06	0.50	555.14	0.2	0.125	2.65	4.24	1.04
Co/10^{-6}	9.35	8.16	0.87	8.69	4.82	0.56	1.82	25	13.85	0.37	0.68	0.63
Cr/10^{-6}	44.93	77.36	1.72	39.00	33.05	0.85	2.70	110	69.72	0.41	0.64	0.56
Cu/10^{-6}	21.19	99.28	4.69	14.12	10.94	0.78	13.62	63	24.7	0.34	0.86	0.57
Hg/10^{-9}	50.15	292.89	5.84	15.02	5.70	0.38	171.57	80	26.75	0.63	1.87	0.56
Mn/10^{-6}	650.15	593.90	0.91	544.01	318.87	0.59	2.23	1300	695.6	0.50	0.93	0.78
Mo/10^{-6}	2.98	2.84	0.95	2.59	2.04	0.79	1.60	1.3	0.62	2.29	4.81	4.18
Ni/10^{-6}	21.95	70.15	3.20	17.37	13.34	0.77	6.65	89	30.25	0.25	0.73	0.57
Pb/10^{-6}	174.3	5451.5	31.3	14.90	8.18	0.55	7794.18	12	21.81	14.52	7.99	0.68
Sb/10^{-6}	1.88	5.83	3.10	1.02	0.35	0.34	30.70	0.6	0.82	3.13	2.29	1.24
Sn/10^{-6}	2.44	2.62	1.08	2.28	1.13	0.50	2.48	1.7	3.01	1.44	0.81	0.76
W/10^{-6}	4.70	114.08	24.3	0.87	0.52	0.60	1185.2	1.1	1.84	4.27	2.55	0.47
Zn/10^{-6}	132.0	1423.1	10.8	41.37	31.54	0.76	143.99	94	73.89	1.40	1.79	0.56

Notes: *X*, *S, and C*v are the means, standard deviation, and coefficient of variation of an element before the removal of outliers. *X*o, *S*o and *C*vo are the means, standard deviation and coefficient of variation of an element after the removal of outliers. *D* is the superposition strength coefficient and $D = (X \cdot S)/(Xo \cdot So)$. The crust abundance is from Li T (1976), *C* is Clarke of concentration, and $C = X$/crust abundance. The means in Longnan area are from Li TG and Jin ZP (2009). *K*k (concentration coefficient of an element) = the mean content of the element in the study area/the mean of the element in Longnan area; *K*k is the concentration coefficient before the removal of outliers, and *K*k0 is the concentration coefficient after the removal of outliers.

survey area include Pb, W, Au, Cd, Hg, Zn, and Bi, the D values of which are 7 794.18, 1 185.2, 1 057.4, 555.14, 171.57, 143.99, and 141.74, respectively. Therefore, elements with most metallogenic potential in the study area include Pb, W, Au, Cd, Hg, Zn, and Bi.

(2) Partition of elements

Elements whose content has a high standard deviation and a high coefficient of variation (Cv) include Pb, Ba, Zn, Au, and Hg, indicating their unevenly varying content. These elements are unevenly distributed throughout the study area and are prone to get enriched to form deposits in local favorable sections.

As shown in Table 3, the elements varying highly in content (Cv ≥ 2) during this tectonic-geochemical survey include Pb, W, Cd, Bi, Ba, Zn, Au, Ag, Hg, Cu, and Ni, indicating that they are extremely unevenly distributed in strata and are very likely to form deposits; those varying less highly in content (Cv = 1–2) include Cr, As, B, and Sn, indicating that they are unevenly distributed in strata and are likely to form deposits. It is obvious that the more unevenly the elements' content is distributed, the more possibly the elements are enriched to form deposits locally. Otherwise, the more evenly the elements' content is distributed, the more significantly they are controlled by diagenesis and the less possible they are enriched to form deposits.

In summary, elements such as Pb, Zn, Au, W, and Bi vary highly in content and discreteness, experienced intensive epigenetic superposition, and thus are likely to form deposits. This is generally consistent with the known mineral distribution in the area.

(3) Analysis of metallogenic elements

The concentration coefficient (Kk) of an element in an area reflects the enrichment degree of the element's content across the area. The higher the Kk, the higher the element's content and the more favourable for the element's enrichment and mineralization. The Cv of an element reflects the relative variation of the element's content across the area. The higher the Cv, the more obvious the variation of the element's content, the more prone for the element to be enriched locally to form mineral deposits.

For the ease of comparison, the parameter "geochemical metallogenic favorability degree of an element" (also referred to as the metallogenic favorability degree) was used to represent the metallogenic probability of an element. The metallogenic favorability degree (Z) of an element is directly proportional to the concentration coefficient and the coefficient of variation of the element, and the formula is as follows.

$Z = K\text{k} \times C\text{v}$

The metallogenic favorability degrees of the 19 elements in the study area were calculated using this formula and are orderly arranged as shown in Table 4. The Pb element shows the maximum value of metallogenic favorability degree, while the Co element shows the minimum. It can be seen that favorable metallogenic elements in the study area include Pb, Zn (Cd), Au, Ag, and W.

(4) Features of element associations

R-type factor analysis was conducted on the analytical values of the 19 elements in the

Table 4 Metallogenic favorability degree (*Z*) of elements in the survey area

Element	Pb	Au	Cd	W	Ag	Zn	Bi	Hg	Ba	Sb
Z	249.93	88.83	64.79	61.89	22.01	19.3	14.73	10.92	10.16	7.1
Element	Mo	Cu	Ni	As	Cr	B	Sn	Mn	Co	–
Z	4.57	4.03	2.34	1.57	1.1	0.93	0.87	0.85	0.59	–

tectonic-geochemical survey. The orthogonally rotated factor loading matrix was adopted to identify element associations since it can reflect more rational and interpretable element associations than initial factor loading matrix. As a result, six factors were determined.

Factor F1: composed of the elements Ba, Pb, Hg, Zn, and Cd. It is related with exhalative sedimentary lead–zinc deposits, indicating mineralization of Pb and Zn is closely related to Ba, Hg, and Cd.

Factor F2: composed of the elements As, Sb, Ag, and Au. It is related to the hydrothermal activities after a magmatic period, indicating the mineralization of Au is closely related to As, Sb, and Ag.

Factor F3: composed of the elements Co, Cr, and Ni. It is related to the high-temperature hydrothermal activities, with anomalies generally being caused by magmatic activities.

Factor F4: Ag; Factor F5: B; Factor F6: Cd.

The factor analysis indicated the presence of the superposition of multiple metallogenic stages in the area, while the factors F4, F5, and F6 are mainly composed of a single factor. Therefore, it can be finally determined that the first three factors represent three types of element associations in the area.

3.2 Geochemical Characteristics of Elements

Statistics were made for the characteristic values of parameters of the elements in the study area and its geological subareas, aiming to reflect the distribution characteristics of elements and the geochemical processes related to geological metallogenesis in different geological units (Table 5).

As observed from Table 5, there are only a small number (N=6) of samples taken from the geological unit Yanjiahe granodiorite porphyry ($\gamma\delta\mu$T), not statistically significant. The geochemical characteristics of the remaining 11 geological units are as follows:

(1) Upper Silurian Wujiashan Formation (S_3w): rich in Au (K=10.44), Cr, and Ni; the elements varying greatly in content include Au (Cv=5.07), Cr, and Ni; the elements with strong epigenetic superposition include Au (D=965.18) and Ni. These indicate that Au is prone to get enriched to form deposits in this stratum.

(2) Upper Silurian Haijiushan Formation (S_3h): rich in Ag, Cd, Cu, and W; the elements varying greatly in content include W, Cu, Ni, Cr, Cd, As, Mn, and Zn; the elements with strong epigenetic superposition only include W. These indicate that W is prone to get enriched to form deposits in this stratum.

(3) Lower Silurian Anjiacha Formation (D_1a): rich in Au (K=24.14), Cd, Zn (K=8.65), Hg, W, Ag, Pb (K=3.44), Ba, Bi, and Sb; the elements varying greatly in content include W,

Table 5 Parameter values of the elements in various geological units

Geological unit	Parameter	Au	Ag	Sn	Mo	B	Cd	W	Bi	Ba	Co	Cr	Cu	Mn	Ni	Pb	Zn	As	Sb	Hg
K_1js	*N*	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63
	X	8.28	0.11	2.01	3.75	44.70	0.21	3.82	0.22	249.60	9.57	43.35	17.90	723.60	19.58	18.24	49.71	12.46	1.30	42.48
	M	2.70	0.10	1.70	3.50	43.00	0.21	1.29	0.21	233.00	9.90	42.50	16.10	729.00	18.80	16.30	49.20	11.40	1.20	31.00
	S	16.38	0.07	2.19	1.95	45.36	0.09	16.72	0.08	181.45	3.25	21.49	9.71	279.32	10.48	8.19	27.68	7.08	0.39	37.23
	*C*v	1.98	0.65	1.09	0.52	1.02	0.44	4.38	0.36	0.73	0.34	0.50	0.54	0.39	0.54	0.45	0.56	0.57	0.30	0.88
	X_{max}	88.80	0.52	18.20	8.97	344.00	0.44	133.50	0.51	1 233.00	16.70	86.40	41.40	1 499.00	41.90	48.90	141.20	32.40	2.39	202.00
	X_{min}	1.00	0.03	0.40	0.58	3.00	0.03	0.21	0.10	22.00	3.50	5.60	2.60	160.00	3.20	4.50	5.80	0.40	0.64	10.00
	*X*o	2.44	0.11	1.75	3.75	39.87	0.21	1.24	0.22	233.74	9.57	43.35	17.90	723.60	19.58	17.75	48.24	12.46	1.30	35.27
	*S*o	1.03	0.05	0.70	1.95	24.47	0.09	0.70	0.07	131.74	3.25	21.49	9.71	279.32	10.48	7.25	25.29	7.08	0.39	23.99
	*C*vo	0.42	0.50	0.40	0.52	0.61	0.44	0.56	0.33	0.56	0.34	0.50	0.54	0.39	0.54	0.41	0.52	0.57	0.30	0.68
	K	4.40	1.30	0.88	1.45	1.58	1.66	4.40	1.14	1.08	1.10	1.11	1.27	1.33	1.13	1.22	1.20	2.07	1.27	2.83
	D	54.01	1.46	3.58	1.00	2.08	1.00	73.37	1.15	1.47	1.00	1.00	1.00	1.00	1.00	1.16	1.13	1.00	1.00	1.87
T*l*	*N*	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93
	X	3.58	0.09	1.81	2.47	42.22	0.58	1.01	0.22	240.33	10.12	39.79	13.17	657.59	17.62	29.57	145.49	11.23	1.35	136.94
	M	2.30	0.06	1.70	1.98	38.00	0.17	0.89	0.20	192.00	10.40	36.50	12.20	597.00	17.70	18.20	48.30	7.60	1.05	69.00
	S	4.53	0.14	0.95	1.80	30.00	3.73	0.54	0.09	248.81	3.63	25.48	7.31	325.51	7.42	66.43	927.08	13.82	0.78	511.65
	Cv	1.27	1.51	0.52	0.73	0.71	6.48	0.54	0.39	1.04	0.36	0.64	0.56	0.50	0.42	2.25	6.37	1.23	0.58	3.74
	X_{max}	29.20	1.32	5.00	9.96	185.00	36.10	3.67	0.66	2 196.00	21.60	203.50	42.00	1 812.00	40.40	571.70	8 986.40	113.00	4.58	4 950.00
	X_{min}	1.00	0.03	0.40	0.25	3.00	0.03	0.09	0.12	35.00	2.80	4.40	2.80	69.00	3.20	5.60	7.30	1.60	0.50	9.00
	*X*o	2.42	0.07	1.78	2.38	39.75	0.17	0.94	0.21	196.91	9.99	38.01	12.08	595.29	17.37	18.16	47.86	8.09	1.23	66.55
	*S*o	1.17	0.03	0.89	1.63	24.76	0.06	0.35	0.05	93.23	3.44	18.94	5.15	225.15	7.06	5.46	21.15	4.06	0.52	39.56
	*C*vo	0.49	0.44	0.50	0.69	0.62	0.38	0.37	0.24	0.47	0.34	0.50	0.43	0.38	0.41	0.30	0.44	0.50	0.43	0.59
	K	1.91	1.06	0.80	0.95	1.49	4.46	1.16	1.13	1.04	1.16	1.02	0.93	1.21	1.01	1.98	3.52	1.86	1.32	9.12
	D	5.72	6.13	1.08	1.14	1.29	206.16	1.68	1.89	3.26	1.07	1.41	1.55	1.6	1.07	19.81	133.27	4.72	1.64	26.61

Continued table 5

Geological unit	Parameter	Au	Ag	Sn	Mo	B	Cd	W	Bi	Ba	Co	Cr	Cu	Mn	Ni	Pb	Zn	As	Sb	Hg
D_3sl	N	882	882	882	882	882	882	882	882	882	882	882	882	882	882	882	882	882	882	882
	X	11.78	0.22	2.35	2.96	34.68	0.20	3.93	0.50	420.59	9.55	41.37	21.58	720.24	19.11	90.49	66.69	10.32	1.85	37.64
	M	1.80	0.07	2.10	2.34	15.00	0.11	0.67	0.18	107.50	7.60	26.65	10.40	579.50	12.40	13.90	26.30	5.15	0.96	14.00
	S	93.95	1.54	1.51	2.61	53.69	1.08	83.90	7.64	5981.00	7.21	36.53	113.44	566.56	16.46	1666.00	398.20	17.02	6.28	207.35
	Cv	7.98	6.93	0.64	0.88	1.55	5.32	21.35	15.38	14.22	0.76	0.88	5.26	0.79	0.86	18.42	5.97	1.65	3.40	5.51
	X_{max}	1912.00	40.16	26.20	16.01	795.00	29.08	2492.03	226.92	177712.00	118.40	213.10	3208.40	5383.00	187.20	49088.60	10055.60	160.70	132.60	4185.00
	X_{min}	0.20	0.03	0.40	0.25	3.00	0.03	0.05	0.09	8.00	2.00	0.20	1.90	20.00	2.30	2.60	2.70	0.30	0.38	6.00
	Xo	1.68	0.07	2.28	2.54	29.09	0.12	0.83	0.20	201.37	9.00	40.88	14.56	612.37	18.60	13.94	39.62	5.44	1.02	13.77
	So	0.88	0.04	1.17	1.86	30.98	0.06	0.52	0.08	202.76	4.93	35.57	11.62	349.07	14.90	7.56	33.72	4.01	0.33	4.45
	Cvo	0.53	0.58	0.51	0.73	1.07	0.51	0.63	0.40	1.01	0.55	0.87	0.80	0.57	0.80	0.54	0.85	0.74	0.33	0.32
	K	6.27	2.52	1.03	1.14	1.23	1.58	4.53	2.52	1.82	1.10	1.06	1.53	1.32	1.10	6.07	1.61	1.71	1.81	2.51
	D	751.78	109.93	1.33	1.64	2.07	30.15	771.15	237.19	61.62	1.55	1.04	14.47	1.91	1.13	1430.00	19.88	8.05	34.00	127.33
$D_{2-3}hl$	N	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155	155
	X	6.05	0.18	3.02	2.08	21.56	0.23	0.82	0.18	178.63	6.84	25.57	17.37	558.73	13.09	64.82	97.65	10.86	1.68	59.42
	M	1.40	0.10	2.30	1.07	4.00	0.10	0.53	0.14	66.00	5.30	10.90	5.40	453.00	7.90	14.30	21.10	5.60	1.11	17.00
	S	24.90	0.51	7.91	2.42	31.20	0.99	1.04	0.13	387.71	4.80	30.51	73.90	496.62	13.49	314.91	557.92	15.67	2.20	226.89
	Cv	4.12	2.80	2.62	1.16	1.45	4.24	1.27	0.70	2.17	0.70	1.19	4.26	0.89	1.03	4.86	5.71	1.44	1.31	3.82
	X_{max}	271.50	6.02	99.40	11.49	134.00	12.10	9.04	1.11	4374.00	27.70	117.80	917.30	3567.00	66.30	2956.70	6586.00	104.80	20.09	2400.00
	X_{min}	0.10	0.03	0.40	0.25	3.00	0.04	0.12	0.10	16.00	2.00	4.60	2.40	47.00	1.90	3.90	4.50	0.50	0.52	8.00
	Xo	1.55	0.10	2.30	1.79	3.52	0.11	0.60	0.16	138.01	6.51	11.49	8.33	446.32	7.98	13.23	32.74	5.95	1.17	18.28
	So	1.00	0.06	1.06	1.92	0.66	0.05	0.34	0.05	162.29	4.19	8.98	7.22	276.22	5.11	4.63	29.46	4.83	0.48	8.58
	Cvo	0.64	0.53	0.46	1.08	0.19	0.49	0.56	0.31	1.18	0.64	0.78	0.87	0.62	0.64	0.35	0.90	0.81	0.41	0.47
	K	3.22	2.07	1.33	0.80	0.76	1.81	0.95	0.93	0.77	0.79	0.66	1.23	1.03	0.75	4.35	2.36	1.80	1.65	3.96
	D	97.97	16.23	9.76	1.47	290.16	39.89	4.19	2.89	3.09	1.20	7.57	21.35	2.25	4.33	333.12	56.50	5.93	6.60	85.90

Continued table 5

Geological unit	Parameter	Au	Ag	Sn	Mo	B	Cd	W	Bi	Ba	Co	Cr	Cu	Mn	Ni	Pb	Zn	As	Sb	Hg
D_2h	*N*	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735
	X	11.99	0.25	2.37	2.86	35.92	0.44	1.69	0.35	428.09	9.52	44.25	25.27	727.51	20.36	467.34	170.45	14.58	2.17	52.99
	M	2.10	0.07	2.20	2.17	21.00	0.13	0.85	0.20	183.00	8.20	31.20	14.00	584.00	15.60	13.90	40.00	8.30	1.10	15.00
	S	89.55	2.14	1.36	2.51	37.10	3.92	15.21	2.42	4468.00	5.38	36.32	123.39	603.93	15.60	10168.00	1900.00	18.99	6.92	350.68
	Cv	7.47	8.42	0.57	0.88	1.03	8.84	9.03	6.90	10.44	0.57	0.82	4.88	0.83	0.77	21.76	11.14	1.30	3.19	6.62
	X_{max}	2018.60	53.30	13.80	18.07	305.00	85.60	412.48	65.37	121192.00	45.40	230.20	3111.50	6039.00	113.00	272844.00	43935.10	150.50	96.88	6604.00
	X_{min}	0.10	0.03	0.40	0.25	3.00	0.01	0.09	0.10	17.00	1.60	2.70	1.00	25.00	2.30	2.30	4.20	0.60	0.53	6.00
	Xo	2.19	0.08	2.29	2.59	33.82	0.13	0.99	0.22	245.99	9.35	43.83	16.68	603.39	19.90	15.24	46.83	9.04	1.12	15.75
	So	1.25	0.05	1.13	1.99	32.67	0.06	0.58	0.08	210.00	5.00	35.43	11.93	337.35	14.74	8.67	33.74	6.67	0.38	6.44
	Cvo	0.57	0.58	0.50	0.77	0.97	0.47	0.59	0.38	0.85	0.54	0.81	0.72	0.56	0.74	0.57	0.72	0.74	0.34	0.41
	K	6.38	2.89	1.04	1.10	1.27	3.44	1.94	1.78	1.85	1.09	1.13	1.79	1.34	1.17	31.36	4.12	2.42	2.13	3.53
	D	391.25	134.75	1.24	1.39	1.21	226.80	44.51	47.39	37.03	1.09	1.04	15.68	2.16	1.08	35995.00	204.89	4.59	35.00	183.11
D_1a	*N*	318	318	318	318	318	318	318	318	318	318	318	318	318	318	318	318	318	318	318
	X	45.39	0.34	2.38	2.71	24.98	2.25	4.00	0.51	726.21	8.41	32.51	15.24	498.65	18.28	51.29	357.96	12.00	2.35	88.17
	M	1.90	0.12	2.20	1.45	8.00	0.12	0.70	0.18	105.00	6.50	16.75	8.35	373.50	10.40	14.20	28.00	3.85	0.88	17.00
	S	339.29	1.74	1.28	3.77	39.90	22.55	46.97	3.92	7434.00	12.37	69.23	22.75	564.57	56.53	264.03	2755.00	24.60	6.87	450.24
	Cv	7.48	5.11	0.54	1.39	1.60	10.00	11.75	7.75	10.24	1.47	2.13	1.49	1.13	3.09	5.15	7.70	2.05	2.92	5.11
	X_{max}	5288.00	26.23	9.90	41.06	363.00	377.89	827.80	69.65	131771.00	203.70	1078.80	254.20	7281.00	932.50	3413.80	41654.10	156.60	67.67	6019.00
	X_{min}	0.10	0.03	0.40	0.25	3.00	0.01	0.16	0.10	9.00	1.70	2.30	2.40	21.00	2.30	3.00	5.00	0.10	0.44	6.00
	Xo	1.72	0.12	2.32	1.80	14.78	0.13	0.75	0.17	138.41	7.27	25.54	11.44	415.77	13.20	14.03	32.74	3.85	0.89	16.04
	So	0.93	0.06	1.13	1.73	17.16	0.07	0.42	0.06	136.14	4.33	24.23	9.37	275.08	10.04	6.80	24.14	2.74	0.27	5.74
	Cvo	0.54	0.52	0.49	0.96	1.16	0.53	0.55	0.32	0.98	0.60	0.95	0.82	0.66	0.76	0.48	0.74	0.71	0.30	0.36
	K	24.14	3.86	1.05	1.04	0.88	17.47	4.61	2.57	3.14	0.97	0.83	1.08	0.92	1.05	3.44	8.65	1.99	2.31	5.87
	D	9652.00	85.64	1.17	3.27	3.93	5974.00	604.90	207.16	286.53	3.31	3.64	3.24	2.46	7.80	141.97	1248.00	27.95	68.00	431.24

Continued table 5

Geological unit	Parameter	Au	Ag	Sn	Mo	B	Cd	W	Bi	Ba	Co	Cr	Cu	Mn	Ni	Pb	Zn	As	Sb	Hg
S_3h	*N*	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106
	X	2.97	0.18	2.61	2.87	36.47	0.33	2.44	0.22	284.59	8.72	47.9	33.42	531.86	33.19	12.37	45.81	5.78	1.62	27.76
	M	1.7	0.14	2.55	1.84	6	0.12	0.62	0.16	95.5	4.85	16.45	6.25	315.5	9.9	11.25	14.1	2.35	0.88	17
	S	3.94	0.17	1.37	3.77	71.69	0.8	15.41	0.21	342.17	14.12	140.82	149.38	1193.14	121.64	7.52	94.92	13.85	3.22	41.9
	Cv	1.33	0.95	0.52	1.31	1.97	2.46	6.33	0.94	1.2	1.62	2.94	4.47	2.24	3.67	0.61	2.07	2.4	1.99	1.51
	X_{max}	31.7	1.275	7.3	20.83	364	5.872	159.15	1.54	1354	110.1	1362.2	1504.8	12024	1120.7	50.4	794.1	125.1	24.84	398
	X_{min}	0.3	0.031	0.4	0.25	3	0.021	0.16	0.09	4	1.6	4.6	2	23	2.4	4.1	5.4	0.1	0.45	9
	Xo	2.12	0.14	2.53	2.13	7.23	0.14	0.72	0.15	274.41	5.55	25.02	9.72	383.28	11.08	11.23	28.93	2.78	0.89	18.32
	So	1.58	0.08	1.23	2.03	6.22	0.09	0.48	0.03	327.27	3.54	24.88	10.36	323.09	8.47	4.53	26.86	2.38	0.24	7.8
	Cvo	0.74	0.57	0.49	0.95	0.86	0.62	0.67	0.19	1.19	0.64	0.99	1.07	0.84	0.77	0.4	0.93	0.86	0.27	0.43
	K	1.58	2.01	1.15	1.11	1.29	2.52	2.81	1.11	1.23	1	1.23	2.37	0.98	1.91	0.83	1.11	0.96	1.59	1.85
	D	3.5	2.59	1.15	2.5	58.16	20.99	107.81	9.78	1.08	6.27	10.84	49.57	5.12	43.05	1.83	5.6	12.11	25	8.13
S_3w	*N*	129	129	129	129	129	129	129	129	129	129	129	129	129	129	129	129	129	129	129
	X	19.63	0.10	1.96	4.23	39.57	0.20	0.84	0.25	461.66	9.51	78.61	17.75	434.62	55.41	9.25	34.95	4.09	0.88	16.81
	M	2.10	0.06	1.90	3.57	31.00	0.16	0.64	0.18	377.00	7.40	41.70	10.00	369.00	16.00	7.10	28.70	1.80	0.73	12.00
	S	99.47	0.08	1.21	2.89	48.60	0.15	0.67	0.39	509.25	12.75	237.48	22.27	289.46	272.01	6.13	26.32	5.98	0.38	16.59
	Cv	5.07	0.86	0.62	0.68	1.23	0.73	0.79	1.55	1.10	1.34	3.02	1.25	0.67	4.91	0.66	0.75	1.46	0.43	0.99
	X_{max}	879.70	0.53	10.50	14.50	393.00	0.93	5.72	4.32	4723.00	114.60	2129.60	148.60	2319.00	2603.10	38.20	168.30	44.10	3.52	156.00
	X_{min}	0.50	0.03	0.40	0.28	3.00	0.02	0.24	0.10	19.00	2.20	2.30	2.70	23.00	2.70	1.90	4.40	0.20	0.53	9.00
	Xo	2.04	0.08	1.83	4.15	29.99	0.17	0.70	0.17	400.50	7.38	43.66	11.16	384.83	15.58	8.43	30.83	2.06	0.83	12.33
	So	0.99	0.05	0.82	2.76	21.34	0.09	0.31	0.05	293.90	2.48	23.06	7.73	177.34	7.50	4.51	15.98	1.46	0.24	2.72
	Cvo	0.49	0.62	0.45	0.66	0.71	0.53	0.44	0.29	0.73	0.34	0.53	0.69	0.46	0.48	0.54	0.52	0.71	0.29	0.22
	K	10.44	1.10	0.86	1.63	1.40	1.54	0.97	1.26	1.99	1.09	2.02	1.26	0.80	3.19	0.62	0.84	0.68	0.87	1.12
	D	965.18	1.99	1.58	1.07	3.00	1.89	2.60	11.08	2.00	6.63	18.55	4.58	1.84	128.99	1.49	1.87	8.14	1.73	8.33

Continued table 5

Geological unit	Parameter	Au	Ag	Sn	Mo	B	Cd	W	Bi	Ba	Co	Cr	Cu	Mn	Ni	Pb	Zn	As	Sb	Hg
$\eta\gamma$T	N	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
	X	2.49	0.09	3.52	5.56	17.22	0.23	194.31	0.67	508.52	5.36	19.36	10.76	333.22	7.87	26.84	68.77	3.97	0.78	21.04
	M	1.20	0.08	3.20	4.49	9.00	0.17	0.89	0.22	457.00	4.80	14.20	6.70	319.00	5.20	27.50	46.30	3.60	0.72	17.00
	S	2.35	0.06	1.61	4.53	18.43	0.25	1004.00	1.92	324.71	3.01	17.63	8.43	112.32	7.20	11.73	126.93	3.10	0.19	17.06
	Cv	0.95	0.60	0.46	0.81	1.07	1.10	5.17	2.85	0.64	0.56	0.91	0.78	0.34	0.92	0.44	1.85	0.78	0.25	0.81
	X_{-max}	9.30	0.33	7.40	18.34	81.00	1.45	5222.00	10.18	1103.00	14.80	86.30	28.90	641.00	35.00	45.70	699.00	14.10	1.37	98.00
	X_{min}	0.80	0.04	1.50	0.56	3.00	0.10	0.40	0.14	93.00	2.00	5.40	3.50	193.00	2.70	4.10	7.90	0.30	0.54	10.00
	Xo	2.49	0.09	3.52	5.56	11.42	0.17	0.94	0.23	508.52	4.67	15.22	10.76	333.22	5.70	26.84	44.53	3.58	0.75	17.12
	So	2.35	0.03	1.61	4.53	6.87	0.05	0.51	0.07	324.71	1.75	8.72	8.43	112.32	2.65	11.73	16.05	2.40	0.15	5.84
	Cvo	0.95	0.38	0.46	0.81	0.60	0.29	0.54	0.32	0.64	0.38	0.57	0.78	0.34	0.47	0.44	0.36	0.67	0.20	0.34
	K	1.32	1.07	1.55	2.15	0.61	1.79	223.86	3.42	2.20	0.62	0.50	0.76	0.61	0.45	1.80	1.66	0.66	0.76	1.40
	D	1.00	1.97	1.00	1.00	4.05	6.65	405610.00	75.70	1.00	1.97	2.57	1.00	1.00	3.75	1.00	12.22	1.44	1.29	3.59
$\eta o\delta$T	N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
	X	7.72	0.16	4.03	3.88	57.92	0.15	2.39	0.67	689.48	10.82	78.08	16.48	487.08	24.59	26.51	55.11	10.39	2.21	15.87
	M	1.80	0.10	2.70	3.28	25.50	0.12	1.12	0.21	722.50	10.15	58.50	10.60	438.50	16.95	25.95	54.90	4.85	0.80	11.00
	S	33.22	0.28	6.09	2.39	128.29	0.10	4.53	3.37	310.85	5.60	54.89	17.14	444.35	18.96	10.88	34.24	14.90	5.49	20.31
	Cv	4.30	1.76	1.51	0.62	2.22	0.69	1.90	5.01	0.45	0.52	0.70	1.04	0.91	0.77	0.41	0.62	1.43	2.48	1.28
	X_{max}	312.80	2.53	44.10	11.63	1035.00	0.66	34.49	31.99	1839.00	35.40	267.60	132.40	3431.00	80.10	56.60	312.50	80.40	43.42	182.00
	X_{min}	0.40	0.03	0.50	0.26	3.00	0.05	0.29	0.12	18.00	2.20	4.70	3.00	106.00	3.50	4.70	7.20	0.10	0.51	9.00
	Xo	2.13	0.10	2.88	3.48	24.69	0.12	1.17	0.21	676.56	10.55	75.95	13.05	424.02	24.59	26.51	52.22	5.65	0.80	10.65
	So	1.45	0.04	1.12	1.80	15.76	0.04	0.65	0.06	287.30	4.98	51.33	7.77	142.64	18.96	10.88	20.61	3.80	0.20	1.21
	Cvo	0.68	0.42	0.39	0.52	0.64	0.36	0.55	0.29	0.43	0.47	0.68	0.60	0.34	0.77	0.41	0.40	0.67	0.25	0.11
	K	4.11	1.81	1.77	1.50	2.05	1.16	2.75	3.41	2.98	1.25	2.00	1.17	0.90	1.42	1.78	1.33	1.72	2.17	1.06
	D	83.14	10.97	7.60	1.48	19.10	2.84	14.35	179.47	1.10	1.15	1.10	2.79	3.58	1.00	1.00	1.75	7.21	75.80	24.96

Continued table 5

Geological unit	Parameter	Au	Ag	Sn	Mo	B	Cd	W	Bi	Ba	Co	Cr	Cu	Mn	Ni	Pb	Zn	As	Sb	Hg
$\gamma\delta\mu$T	N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	X	2.33	0.42	2.30	1.95	9.33	0.14	17.24	2.49	575.17	5.45	17.67	6.32	332.83	6.83	33.72	34.72	6.20	0.92	13.83
	M	2.30	0.12	2.40	2.39	9.50	0.15	2.22	0.27	588.00	4.60	15.75	6.10	271.50	5.00	26.30	40.90	6.10	0.93	14.00
	S	1.50	0.76	0.58	1.27	3.78	0.03	37.43	5.45	274.68	2.38	11.19	2.33	143.44	5.25	22.71	15.35	3.63	0.23	1.60
	Cv	0.64	1.80	0.25	0.65	0.41	0.21	2.17	2.19	0.48	0.44	0.63	0.37	0.43	0.77	0.67	0.44	0.59	0.25	0.12
	X_{max}	4.70	1.98	2.90	3.56	14.00	0.18	93.63	13.60	911.00	10.10	35.50	10.20	556.00	17.40	78.10	47.60	10.50	1.19	16.00
	X_{min}	0.50	0.06	1.60	0.37	3.00	0.10	1.14	0.13	106.00	3.70	4.80	4.00	210.00	3.70	19.00	12.20	1.80	0.67	12.00
	Xo	2.33	0.42	2.30	1.95	9.33	0.14	17.24	2.49	575.17	5.45	17.67	6.32	332.83	6.83	33.72	34.72	6.20	0.92	13.83
	So	1.50	0.76	0.58	1.27	3.78	0.03	37.43	5.45	274.68	2.38	11.19	2.33	143.44	5.25	22.71	15.35	3.63	0.23	1.60
	Cvo	0.64	1.80	0.25	0.65	0.41	0.21	2.17	2.19	0.48	0.44	0.63	0.37	0.43	0.77	0.67	0.44	0.59	0.25	0.12
	K	1.24	4.81	1.01	0.75	0.33	1.11	19.86	12.61	2.48	0.63	0.45	0.45	0.61	0.39	2.26	0.84	1.03	0.90	0.92
	D	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
$\varphi\delta$T	N	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37
	X	6.26	0.12	2.67	3.59	39.32	0.14	1.18	0.23	685.78	18.68	163.18	22.36	753.57	62.28	23.08	68.96	4.92	0.76	11.97
	M	1.60	0.11	2.20	2.75	16.00	0.13	0.87	0.20	707.00	16.90	112.40	21.10	605.00	41.60	19.90	70.80	3.20	0.70	11.00
	S	18.49	0.05	1.35	3.24	109.58	0.05	0.91	0.11	269.70	11.51	198.52	11.21	699.14	76.16	10.29	29.75	5.95	0.20	2.71
	Cv	2.95	0.43	0.51	0.90	2.79	0.35	0.77	0.48	0.39	0.62	1.22	0.50	0.93	1.22	0.45	0.43	1.21	0.27	0.23
	X_{max}	108.70	0.24	7.50	18.61	680.00	0.29	5.46	0.65	1 311.00	59.90	1 107.00	47.20	4 371.00	427.60	53.70	128.10	32.40	1.38	20.00
	X_{min}	0.70	0.04	1.00	0.45	3.00	0.06	0.34	0.12	49.00	4.10	5.00	2.80	107.00	3.60	9.50	9.10	1.00	0.47	9.00
	Xo	1.63	0.12	2.53	3.17	19.51	0.14	1.06	0.21	685.78	16.64	125.44	22.36	570.67	44.31	23.08	68.96	3.67	0.74	11.97
	So	0.77	0.05	1.09	2.04	12.51	0.05	0.55	0.07	269.70	7.67	99.37	11.21	210.14	32.06	10.29	29.75	2.45	0.18	2.71
	Cvo	0.47	0.43	0.43	0.65	0.64	0.35	0.52	0.33	0.39	0.46	0.79	0.50	0.37	0.72	0.45	0.43	0.67	0.24	0.23
	K	3.33	1.32	1.17	1.38	1.39	1.12	1.35	1.15	2.96	2.15	4.18	1.58	1.39	3.59	1.55	1.67	0.82	0.74	0.80
	D	92.56	1.00	1.31	1.79	17.66	1.00	1.83	1.76	1.00	1.68	2.60	1.00	4.39	3.34	1.00	1.00	3.25	1.18	1.00

Notes: The dimension is 10^{-9} for Au and Hg, and 10^{-6} for other elements. N: Number of samples; X, S, *and* Cv are the arithmetic means, standard deviation, and coefficient of variation of an element before the removal of outliers; Xo, So and Cvo are the arithmetic mean, standard deviation, and coefficient of variation of an element after the removal of outliers; M: median; K: Concentration coefficient, K=X/the mean content of an element in the study area (see Table 3 for details); D: The superposition strength coefficient, D=(X·S)/(Xo·So).

Ba, Cd, Bi, Zn (*C*v=7.70), Au (*C*v=7.48), Pb (*C*v=5.15), Ag, Hg, Ni, Sb, Cr, and As; elements with strong epigenetic superposition include Au (*D*=9 652.00), Cd, Zn (*D*=1 248.00), W, Hg, Ba, Bi, and Pb (*D*=1 419.70). These indicate that Au, Pb, and Zn are prone to get enriched to form deposits in this stratum.

(4) Middle Devonian Huangjiagou Formation (D_2h): rich in Pb (*K*=31.36), Au (*K*=6.38), Zn (*K*=4.12), Hg, Cd, Ag, As, and Sb; the elements varying greatly in content include Pb (*C*v=21.76), Zn (*C*v=11.14), Ba, W, Cd, Ag, Au (*C*v=7.47), Bi, Hg, Cu, and Sb; the elements with strong epigenetic superposition include Pb (*D*=35 995.00), Au (*D*=391.25), Cd, Zn (*D*=204.89), Hg, and Ag. These indicate that Au, Pb, and Zn are prone to get enriched to form deposits in this stratum.

(5) Middle-Upper Devonian Honglingshan Formation ($D_{2-3}hl$): rich in Pb, Hg, Au, Zn and Ag; the elements varying greatly in content include Zn, Pb, Cu, Cd, Au, Hg, Ag, Sn, and Ba; the elements with strong epigenetic superposition include Pb and B. These indicate that Pb, Au, and Ag are prone to get enriched to form deposits in this stratum.

(6) Upper Devonian Shuanglanggou Formation (D_3sl): rich in Au, Pb, W, Bi, Ag, and Hg; the elements varying greatly in content include W, Pb, Bi, Ba, Au, Ag, Zn, Hg, Cd, Cu, and Sb; the elements with strong epigenetic superposition include Pb, W, Au, Bi, Hg, and Ag. These indicate that the elements such as Pb, W, and Au are prone to get enriched to form deposits in this stratum.

(7) Triassic Longwuhe Formation (T*l*): rich in Hg, Cd, and Zn; the elements varying greatly in content include Cd, Zn, Hg, and Pb; the elements with strong epigenetic superposition include Cd and Zn. These indicate that elements such as Zn and Cd are prone to get enriched to form deposits in this stratum.

(8) Lower Cretaceous Jishan Formation (K_1js): rich in As, Au, Hg, and W; the elements with strong differentiation only include W. These indicate that the elements such as W are prone to get enriched to form deposits in this stratum.

(9) Changba biotite monzonitic granite ($\eta\gamma$T): rich in W, Bi, Ba, and Mo; the elements varying greatly in content include W and Bi; the elements with strong epigenetic superposition only include W. These indicate that the elements such as W are prone to get enriched to form deposits in the pluton.

(10) Huangzhuguan quartz monzonitic granite ($\eta o\delta$T): rich in Au, Ba, Bi, W, Sb and B; the elements varying greatly in content include Bi, Au, Sb, and B; the elements with strong epigenetic superposition include Bi and Au. These indicate that the elements such as Bi, Au, and Sb are prone to get enriched to form deposits in this pluton. Main metallogenic elements in the pluton include the elements with high, middle, and low metallogenic temperatures, indicating that all elements are enriched to a different extent, especially Au, Sb, and Bi. It can be inferred that metallogenesis may have occurred in various magmatic intrusion periods. Therefore, the prospecting of Au, Sb, and Bi minerals should be mainly conducted near the internal and external contact zones of the pluton.

(11) Waquanshan fine-grained pyroxene diorite ($\varphi\delta$T): rich in Cr, Ni, Au, Ba, and Co; the

elements varying greatly in content include Au and B. These indicate that the elements such as Au are prone to get enriched to form deposits in this pluton.

4 Quality Control and Assessment of Data

4.1 Quality of Primary Data

The 19 elements were tested and analyzed by the experimental and testing center of The First Geological Mineral Exploration Institute of Gansu Provincial Geology and Mineral Bureau. The analytical methods primarily included ICP–MS and secondarily included AFS and ES. For each element, the analytical method employed and its detection limit, the detection limit as required in the *Specification*, and reported rate are shown in Table 6.

During the sample analysis in this study, all elements were monitored using the national primary reference materials of China, which were added for 68 sample-times. A total of 1 224 items were tested and all of them were approved to be qualified, and thus the qualified rate was up to 100%. The RE values of the gold reference materials used were $-35.24\% \leqslant RE \leqslant 52.27\%$, meeting the requirements in the *Specification*.

Internal inspection and quality control of samples: 5% of total samples were randomly taken for repetitive cryptoanalysis. The deviation of basic analytical values relative to repetitive cryptoanalytical values was calculated. A total of 82 repetitive encrypted samples were added for internal inspection of 1 476 items. The qualified rate of these items was > 95%.

Table 6 Detection limits of analytical methods and reported rates of the elements

Element	Analytical method	Actual detection limit/10^{-6}	Required detection limit/10^{-6}	Rated rate/%
As	AFS	0.2	1.0	99.57
Sb	AFS	0.05	0.2	100
Hg	CVAFS	0.000 3	0.000 5	100
Au	ICP–MS	0.000 1	0.000 3	99.94
W	ICP–MS	0.2	0.5	99.39
Bi	ICP–MS	0.05	0.1	100
Cd	ICP–MS	0.05	0.1	96.59
Cu	XRF	0.9	1.5	100
Pb	XRF	2.0	5.0	99.94
Zn	XRF	1.0	15	100
Ba	XRF	18	50	98.72
Co	XRF	0.8	1.0	100
Cr	XRF	2.5	15	99.82
Mn	XRF	10	30	100
Ni	XRF	1.0	3.0	100
Ag	ES	0.02	0.03	100
Sn	ES	0.6	1	95.01
Mo	ES	0.2	0.5	100
B	ES	1	5	100

After the initial inspection, 3%–5% of anomalous samples were taken and delivered to the lab for analysis in an encrypted form. Their relative deviation was calculated, and the qualified rate of these items was > 95%.

To ensure the analytical quality, 100 samples were treated as a lot, into which encrypted national reference materials were added and analyzed together with samples. $\triangle LgC$ *and* $\triangle\lambda$ were calculated to assess the analytical derivation among various lots and the accuracy and precision of a lot. Meanwhile, daily quality monitoring figures were plotted, aiming to control the analytical quality.

Taken together, the above-mentioned data analysis ensured the authenticity and credibility of the analytical results provided by the experimental and testing center of The First Geological Mineral Exploration Institute of Gansu Provincial Geology and Mineral Bureau. Meanwhile, the analytical quality fully satisfied the requirements in the *Specification of Geochemical Reconnaissance Survey* (1：50 000) (DZ/T0011- 2015).

4.2 Quality of Dataset Building

The Dataset is a part of the *Prospecting Predict*ion *Result Database of Changba Ore Concentration Area, Gansu Province*. It was built based on geochemical survey data models using the software GeoMapBM V2.5 which was initiated by the Technical Guidance Center for Mineral Resources of Ministry of Natural Resources and developed by the Institute of Mathematical Geosciences and Remote Sensing Geology, China University of Geosciences (Wuhan) in 2018. Its attributes were completed in accordance with the *Rules on Structures and Completion of Basic Data Tables for Prospecting Prediction Data Models of Mineral Concentrated Areas*[1]. Therefore, it enjoys integrated data, consistent logics, accurate spacious positioning, correct attribute data, and complete mapping instructions and metadata files. The *Prospecting Predict*ion *Result Database of Changba Ore Concentration Area, Gansu Province* was reviewed by the experts from the Development and Research Center of China Geological Survey. As a result, it scored 90 points overall and its data quality was rated excellent. Related data have been gathered submitted.

5 Delineation and Characteristics of Anomalies

5.1 Delineation of Geochemical Anomalies

Five types of geochemical composite anomalies were determined in the study area according to the characteristics of element associations, namely Cu-Pb-Zn-Ag-Cd composite anomalies, Au-As-Sb-Hg composite anomalies, Ba-Mn-B composite anomalies, W-Sn-Bi-Mo composite anomalies, and Co-Cr-Ni composite anomalies.

The anomalies of the 19 elements were screened according to their associations, area, strength and geological environmental factors, and the ones that overlapped and were obvious related to each other in terms of geological environment, genesis, and space were delineated as final anomalies. Meanwhile, the anomalies with poor associations and poor metallogenic geological conditions were empirically rejected. For some single-element anomalies that were widely distributed, they were artificially divided at the locations where they were weakly connected by comprehensively taking into account the geological conditions and the boundaries of element associations. In this way, integrated anomalies were determined.

A total of 24 integrated anomalies were delineated across the study area (Fig. 1).

5.2 General Characteristics of the Anomalies

The spacious distribution of the element anomalies in the study area is closely related to the regional tectonic lines overall, and is roughly in line with the plutons locally.

(1) Changba−Huangzhuguan−Shaijingxiang area in the north of the Wujiashan anticline: the elements Ag, Au, B, Bi, Cd, Cu, Mn, Mo, Pb, and Zn spread over this area. They are distributed in NW−SE trending and largely in the shape of a long band, consistent with the regional structural line, possibly reflecting a set of element associations related to exhalative sedimentary plumbum-zinc deposits.

(2) Guandian−Anjiacha area in the axial part of the Wujiashan anticline: the elements Ag, Au, B, Ba, Cd, Cu, Mo, and Zn spread over in this area. They are distributed in NWW trending and largely in the shape of a long band, basically in line with the regional structural line, possibly reflecting a set of element associations related to postmagmatic hydrothermal gold deposits.

(3) Bijiashan−Qingyangxia area in the south of the Wujiashan anticline: the elements Ag, As, Au, B, Cd, Cu, Hg, Mn, Pb, Sb, and Zn spread over this area. They are distributed in EW trending and largely in the shape of a long belt, largely in line with the regional structural line, possibly reflecting a set of element associations related to exhalative sedimentary lead–zinc deposits and postmagmatic hydrothermal gold deposits.

(4) Outer contact zone of Huangzhuguan pluton: the elements As, Au, B, Ba, Bi, Co, Cr, Cu, Mo, Ni, Pb, Sn, W, and Z spread over this area. They reflect a set of element associations related to high-, medium- and low-temperature hydrothermal solution. They are distributed surrounding the Huangzhuguan pluton in the shape of an arc.

(5) Outer contact zone of Caoguan pluton: the elements Ag, As, Au, B, Ba, Bi, Co, Cr, Cu, Mo, Ni, Pb, Sb, Sn, W, and Z spread over this area. They reflect a set of element associations related to high-, medium- and low-temperature hydrothermal solution. They are generally distributed along the contact zone of the pluton in the shape of an arc.

6 Conclusions

In this study, a 1 ∶ 50 000 tectonic-geochemical survey was carried out in the Shilipu and Huangzhuguan Map-sheets, Gansu Province, obtaining firsthand geochemical survey data. Based on this, a 1 ∶ 50 000 geochemical dataset of the two map-sheets was built. It will maximally satisfy the demand of researchers for tectonic-geochemical survey data of the two map-sheets and makes information resource sharing available. During the building of the dataset, 344 single-element geochemical anomalies and 24 integrated anomalies were newly discovered, including 14 class-A and 9 class-B integrated anomalies. Furthermore, one Au and two Pb-Zn prospecting target areas were delineated by taking into account the information on geology, minerals, geophysics, geochemistry and remote sensing. This has further expanded the prospecting potential of Au, Pb and Zn in the study area and provided resource information for mining companies in the study area and its surrounding areas.

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Notes:

❶ Zuo Qunchao, Pang Zhenshan, Xue Jianling, Wang Xinqing, et al. 2018. Rules on Structures and Completion of Basic Data Tables for Prospecting Prediction Data Models of Mineral Concentrated Areas[R]. Mineral Exploration Technical Guidance Center of Ministry of Natural Resources, 1–610.

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