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晋冀蒙交界东六马坊幅 1∶50 000 地质图数据库

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摘要: 东六马坊幅 (K50E023002) 位于晋冀蒙交界地区的恒山—桑干高压麻粒岩带内，属华北克拉通典型的早前寒武纪高级变质岩区。东六马坊幅 1∶50 000 地质图数据库按照中国地质调查局新颁布的《区域地质调查技术要求 (1∶50 000)》(DD 2019-01) 和行业其他统一标准及要求，采用现代变质岩区填图技术方法和数字填图采集系统编制完成。该图幅对区内新太古代—新生代地层、岩浆岩、变质作用以及构造等进行了详细的划分厘定：建立了新太古代桑干岩群和古元古代集宁岩群 4 个构造–岩石地层单位以及中元古代—新生代 13 个地层单位；建立了新太古代—古元古代和中元古代—中生代 (变质) 侵入岩演化序列；识别出早前寒武纪 3 期变形构造样式和中—新生代印支期、燕山期和喜马拉雅期断裂构造形迹；识别出 2 类不同原岩性质的高压基性麻粒岩，并对变质作用期次进行了划分。图幅采用特殊线段及花纹表达了古老造山带深部地壳岩石塑性流变特征及构造变形样式，重塑了古元古代造山构造演化过程。该数据库为 MapGIS 格式，数据内容主要由 1∶50 000 地质图库、图饰部分及角图等组成，并包含 9 个锆石 U–Pb 年龄数据，数据量为 53.8 MB。东六马坊幅 1∶50 000 地质图创新了高级变质岩区填图和图面表达方法，为高级变质岩区填图工作提供了参考范例。

关键词: 东六马坊幅；1∶50 000；地质图；数据库；华北克拉通；变质岩区填图；地质调查工程

数据服务系统网址: http://dcc.cgs.gov.cn

1 引言

华北克拉通是全球范围内少数几个保留有≥3.8 Ga 岩石的古老克拉通之一 (Liu DY et al., 1992, 2008; Wan YS et al., 2005, 2012; Wang YF et al., 2015; 张家辉等, 2013, 2018)，记录了太古宙—元古宙完整的地质历史，是研究中国前寒武纪地质演化的天然实验室。

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新太古代末期 (~ 2.5 Ga) 大规模新生的 TTG 岩浆岩的就位 (耿元生等, 2010)，以及相关的构造–变质–岩浆事件是华北克拉通形成过程中最重要的地质事件，标志着华北微陆块的拼合与早期克拉通化过程 (翟明国和卞爱国, 2000; 翟明国, 2011; 王惠初等, 2011; 万渝生等, 2017)，奠定了华北克拉通演化的基础。元古宙时期，华北克拉通经历的地质演化可以分为古元古代裂解–碰撞造山事件和中—新元古代在伸展背景上发育的大规模基性岩墙群侵位、非造山岩浆活动以及裂陷槽的火山–沉积事件等，它们被认为与全球 Columbia 超大陆的汇聚和裂解事件相对应 (翟明国, 2014)，这两期代表不同构造含义的全球性事件是中国划分古元古代和中元古代界限 (~ 1.8 Ga) 的主要依据。

晋冀蒙交界地区是华北克拉通典型的早前寒武纪麻粒岩相高级变质区，大致以大同—兴和一线为界划分为 2 套高级变质岩系，分别为南东部麻粒岩系和北西部孔兹岩系 (图 1b)。孔兹岩系为一套特殊的含石墨、矽线石和石榴子石的麻粒岩相变砂泥质岩和大理岩组合，以集宁丰镇一带出露较好，现称为集宁岩群。麻粒岩系主要分布在大同—天镇—怀安—宣化一带，在早期的地质工作中被笼统地称为桑干片麻岩或桑干杂岩，在 20 世纪 70 年代初开展的 1∶200 000 区域地质调查[1,2] 工作中被当作变质地层处理，划归为桑干群，形成时代为太古宙。20 世纪 80 年代以来，该区逐步建立起以太古宙英云闪长质–奥长花岗质–花岗闪长质片麻岩 (TTG 片麻岩) 或灰色片麻岩杂岩为主体的地质格架，变质表壳岩呈层状包体零星“漂浮”在片麻岩杂岩中 (刘宇光和郭敬辉, 1993)。现今，该区早前寒武纪变质杂岩被统称为怀安杂岩。由于该地区具有变质程度深、构造变形复杂，且普遍受到变质–深熔作用改造等特征，各岩石填图单位间的划分对比研究存在较大困难。同时，研究者对区内广泛出露的具有退变“白眼圈”结构的高压基性麻粒岩的峰期变质时限是 ~ 1.85 Ga (Zhao GC et al., 2005, 2008; Guo JH et al., 2002, 2005)，还是 ~ 1.95 Ga (翟明国, 2009; Zhang HF et al., 2016); ~ 1.85 Ga 麻粒岩相变质事件的构造含义是碰撞造山挤压背景 (Zhao GC et al., 2012)，还是造山后的抬升冷却 (翟明国, 2009; Wei CJ et al., 2014); 孔兹岩带和以怀安杂岩为代表的中部造山带是否为 2 个不同的古元

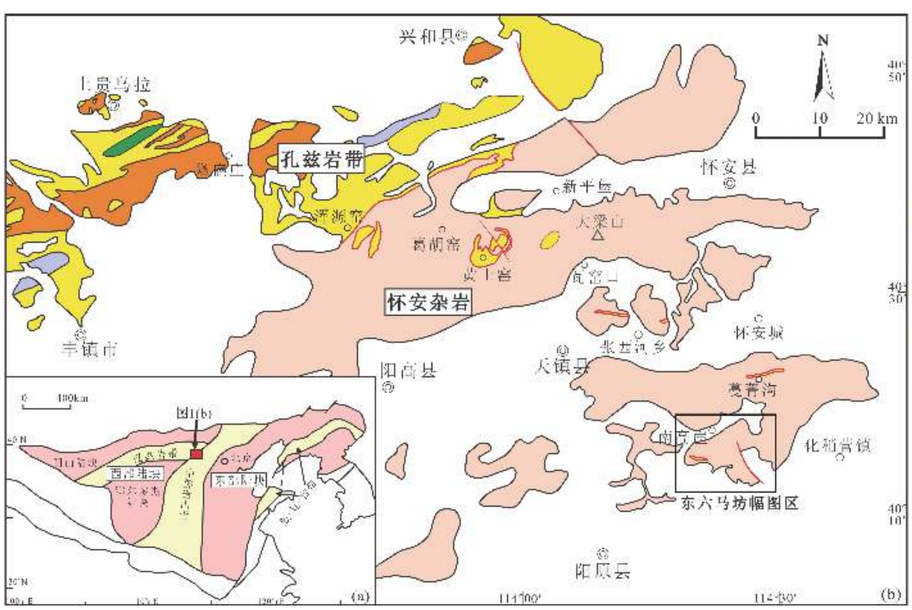

图 1　华北克拉通古元古代构造区划图 (a，据 Zhao GC et al., 2005 修改)
和晋冀蒙交界地区早前寒武纪地质简图 (b)

1—怀安杂岩；2—孔兹岩系；3—斑状花岗岩；4—白岗岩；5—徐武家变质基性岩墙；6—断层或构造接触

古代造山带，且两者间是否存在构造边界 (Zhao GC et al., 2010; Wang LJ et al., 2015; Liao Y and Wei CJ, 2019) 等问题长期存在争议。

最近 20 年来，在晋冀蒙交界地区开展了一系列 1∶250 000[3,4] 和 1∶50 000[5,6] 区域地质调查工作，系统地对区内地质单位进行了划分厘定，为该区地质矿产编图奠定了重要基础。2016—2018 年，中国地质调查局天津地质调查中心组织实施了“燕山—太行成矿带丰宁和天镇地区地质矿产调查”项目，重点对晋冀蒙交界天镇—怀安地区高压基性麻粒岩和内蒙古土贵乌拉地区超高温泥质麻粒岩的成因及其所代表的变质动力学过程开展新一轮区域地质调查及研究，其中包含东六马坊幅 (K50E023002) 地质图数据库 (表 1；张家辉等, 2020)。该图幅位于晋冀蒙交界处的恒山—桑干高压麻粒岩带内，处于 Zhao et al.(2005) 所划的古元古代中部造山带内，并与孔兹岩带相邻 (图 1a)，地质构造意义非常重要，它不仅是国内外研究高压麻粒岩相变质作用的经典地区，更是通过高压麻粒岩的成因和构造背景的研究，揭示深部地壳的物质组成、下地壳结构以及古板块构造作用的关键。东六马坊幅 1∶50 000 地质图 (图 2) 在总结前人研究工作资料基础上，采用现代变质岩区填图技术方法，对区内新太古代至新生代地层、岩浆岩、变质作用以及构造等进行了重新划分厘定，取得了一系列重要进展，为区域地质事件的划分与对比提供新的依据，同时该图幅的图面表达方法为高级变质岩区地质编图提供了参考范例。

表 1　数据库 (集) 元数据简表

条目	描述
数据库(集)名称	晋冀蒙交界东六马坊幅1∶50 000地质图空间数据库
数据库(集)作者	张家辉，中国地质调查局天津地质调查中心 王惠初，中国地质调查局天津地质调查中心 田　辉，中国地质调查局天津地质调查中心 任云伟，中国地质调查局天津地质调查中心 杨济远，河北省区域地质调查院
数据时间范围	2016—2018年
地理区域	经纬度：东经114°15′~114°30′，北纬40°10′~40°20′
数据格式	*.wl, *.wp, *.wt
数据量	53.8 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“燕山—太行成矿带丰宁和天镇地区地质矿产调查”(DD20160042)资助
语种	中文
数据库(集)组成	该数据库(集)主要由1∶50 000地质图库、图饰部分及角图等组成。地质图包括沉积岩、岩浆岩、变质岩、第四系、脉岩、构造、地质界线、产状、样品、照片、同位素年龄、岩性柱、填图单位等。图饰部分包括沉积岩综合柱状图、图切地质剖面图、图例、接图表、责任栏等，角图包括构造–岩石地层单位柱状图、侵入岩演化序列表柱状图、构造纲要图、高压基性麻粒岩及P–T轨迹图、变质相划分图、古元古代构造演化模式图、调查区大地构造位置图、图名、中国地质调查局局徽、比例尺等

2　数据采集和处理过程

2.1　基础数据采集

东六马坊幅 (K50E023002) 地质图数据库以中国人民解放军总参谋部测绘局

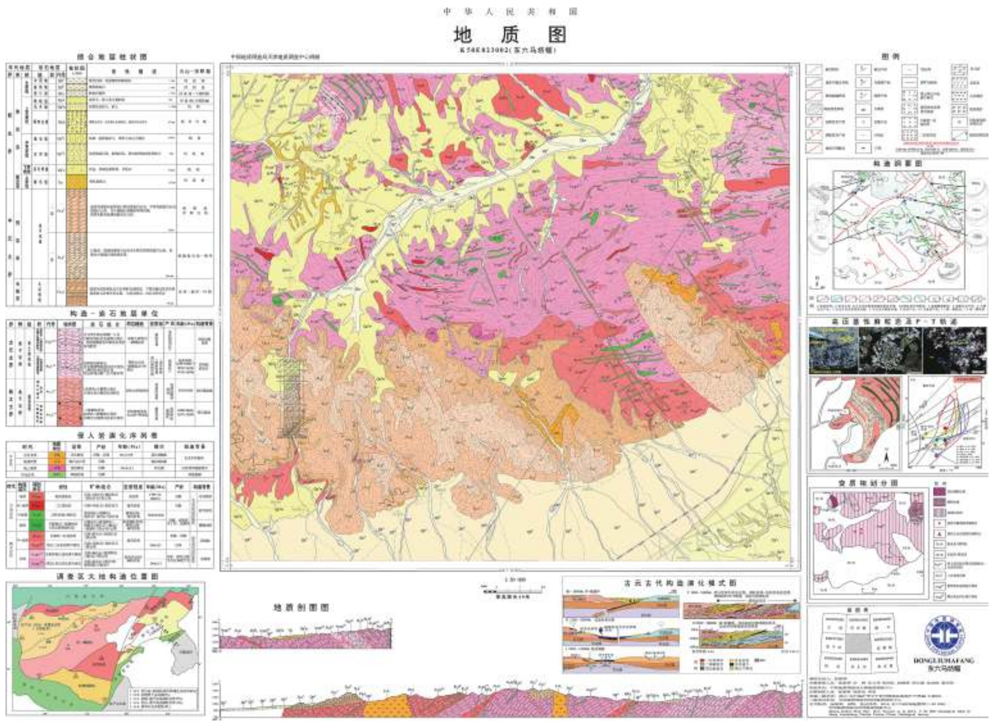

图 2　晋冀蒙交界地区 1：50 000 东六马坊幅地质图示意图

1971 年 1：50 000 地形图为基础，将 1：50 000 地形图经 MapGIS 等计算机软件矢量化处理，形成 1：25 000 地形图，对点 (wt)、线 (wl)、区 (wp) 矢量化数据采用地形数据转换参数（比例尺为 1：25 000，单位为 mm，坐标类型为平面直角坐标系统，投影类型为高斯–克吕格 (横切椭圆等角) 投影，椭球参数为西安 80/1975 年 I.G.U.U 推荐椭球）进行投影转换，形成 1：25 000 图幅的背景图层。本次填图采用 DGSS 数字化填图系统，在加强对测区地层、岩石、构造调查的同时，深入研究了高级变质岩的物质组成、构造变形特征以及变质–深熔作用过程。变质深成岩运用“特征变质矿物+原岩岩性+构造”填图方法，突出原岩岩性的表达，强调构造变形样式及特征变质矿物组成；变质表壳岩运用“特征变质矿物+岩石组合+构造”填图方法，可很好地区分本区内早前寒武纪不同时代、不同成因的变质表壳岩单元。

2.2　数据处理过程

2.2.1　野外地质填图

野外原始资料采集过程中，以东六马坊幅所辖的 1：25 000 图幅地形图为背景图层，通过野外实际地质路线调查，系统采集地质点 (P)、地质路线 (R)、地质界线 (B)、样品、素描、产状、照片等信息，初步建立数字填图系统野外总图库。

地质点 (P)：分为界线点、构造观察点、岩性控制点。野外地质调查中，在掌上机中仔细填写其属性，包括路线号、地质点号、微地貌、点性、露头、风化程度、填图单位、岩石名称、接触关系及岩性描述等。

地质路线 (R)：野外在系统中填写路线号、地质点号、R 编号、填图单位、岩石名称及沿途地质信息等属性。其中，方向 (度)、本站距离、累计距离为系统自动计算并写入。

地质界线 (B)：野外在系统中填写路线号、地质点号、B 编号、R 编号、界线类型、左侧填图单位、右侧填图单位、接触关系及野外现场证据。

野外调查过程中对地质路线沿途所采集的样品、素描、产状、照片等要素的重要属性进行录入。

2.2.2 室内数据整理及建库流程

(1) 首先将掌上机采集的野外数据导入到电脑数字填图系统中，并对野外路线各地质要素进行编辑完善，同时进行数据质量程序检查，对逻辑检查中提示出现的错误进行更改后根据相关规范进行数据整理及修饰。其中:

地质点 (P)：以 GPS 为准，调整地质点与 GPS 点重合。补充完善其地质描述属性及位置说明，批注信息为薄片鉴定名称，在鉴定结果出来后及时填写。

地质路线 (R)：室内整饰过程中尽量以野外实际行进路径勾绘，并对 R 线段进行光滑处理，相邻 R 过程线段用节点平差法在地质点或界线处相连接。R 线段整饰后，须进行 R 过程距离重新计算，“段首”须重新单击写入。

地质界线 (B)：室内整饰过程中根据野外实际界线走向情况，并遵循“V”字形法则勾绘，保留长度 1 ~ 3 cm。补充地质界线产状，对性质不明断层、第四系界线补充界线走向，对于其他断层、整合界线可参考相邻产状对其要素补充完全。根据界线类型属性的不同更改线性参数。

继而完善样品、素描、产状、照片等要素属性内容和描述内容，并对素描图进行整饰。对地质点、样品和产状分别进行静态标注，样品符号按实际样品类别进行子图整饰。岩性代号和填图单位代号标注在点自由图层，使用一个字符串，在自由线图层添加引线。

之后增添野外路线信手剖面图，编写路线小结，开展多级人工质量检查等，完成单条路线数字化工作内容。

(2) 将野外地质路线及实测地质剖面数据投影到 1∶25 000 实际材料图，在 1∶25 000 实际材料图中合理运用“V”字形法则进行地质连图，完成 4 幅 1∶25 000 的实际材料图整饰工作后，将所有 1∶25 000 的实际材料图投影生成 1∶50 000 的编稿原图。

(3) 将 1∶50 000 编稿原图数据合并到空间数据库中，并对图面拓扑一致性、地质要素表达及图面结构等进行检查，使其完全达到地质图整饰及空间数据库要求后，依次录入基本要素类数据、综合要素类数据及对象类数据。

(4) 最后系统全面地检查空间数据库质量，如：无重叠线、重叠坐标、无悬挂线等。通过上述步骤，制作完成 1∶50 000 东六马坊幅完整的地质图 (图 2) 及空间数据库。

2.2.3 图饰部分编制

(1) 柱状图：对图幅内中元古代—新生代沉积地层单元岩性组合、沉积相等进行综合分析，编制沉积岩综合柱状图；对新太古代—古元古代变质地层根据“特征变质矿物+岩石组合+构造”特征，编制出“构造–岩石地层单位柱状图”；对新太古代—古元古代变质深成岩根据“特征变质矿物+原岩岩性+构造”特征，编制“侵入岩演化序列表柱状图”。

(2) 图切剖面：图幅内的构造线主体方向为东西向或北西—南东向。为了有效地反映图幅内总体建造及构造特征，布置了 2 条北东向图切剖面，其中一条贯穿全区，控制了区内新太古代变质深成岩、新太古代—古元古代变质表壳岩、中元古代沉积盖层、中生代侵入岩及新生代松散堆积物；另一条主要控制了新识别出的西赵家窑一带出露的由高压基性麻粒岩和大理岩组成的古元古代黄土窑岩组。

2.2.4 角图编制

(1) 构造纲要图：通过对早前寒武纪变形构造解析，确定了新太古代和古元古代3期变形构造样式。第1期变形 (D1): 形成于新太古代末期 (2.55 ~ 2.5 Ga)，该期构造样式遭受古元古代造山作用的强烈改造，构造样式无法识别，主要以太古宙花岗–绿岩带的构造格局为主。第2期变形 (D2): 发生在古元古代俯冲造山过程的早期，增厚的造山带根部地壳岩石开始发生黏性层状流动变形，造成下部地壳近S或SSE向的层流，发育很好的流面构造 (S2)，仅局部保留在TTG岩石和变质表壳岩构造团块 (变基性岩+BIF组合) 中，该期面理 (S2) 总体产状为175° ~ 190°∠25° ~ 45°，线理 (L2) 产状为150° ~ 160°∠45° ~ 60°。第3期变形 (D3): 形成于古元古代造山晚期，在地壳折返–剥露过程中，差异性隆升，形成区域性广泛存在的面理构造 (S3) 和SW向矿物拉伸线理和A型褶皱，总体面理产状 (S3) 倾向为150° ~ 210°，倾角在不同岩性中变化较大，线理 (L3) 的倾伏向指向SW(210° ~ 250°)，倾伏角15° ~ 50°。同时对中–新生代脆性断裂构造进行了系统总结：印支期 (晚三叠世) 构造线为E–W向，局部保存该期构造形迹；燕山期 (晚侏罗世—早白垩世) 构造线为NE、NEE和NW向，该期表现为太行山隆起；喜马拉雅期 (中新世—上新世) 构造线为以NE向为主，局部为NEE向，兼具右旋剪切作用，形成山西地堑系。综合各类构造要素，编制了本图幅的构造纲要图。

(2) 高压基性麻粒岩及P–T轨迹图：区内高压基性麻粒岩一般呈似斑状变晶结构，变斑晶为石榴子石。石榴子石大小不等，一般为3 ~ 10 mm，最大可达15 ~ 20 mm。镜下观察可见石榴子石变斑晶中含大量包裹体，包裹体有斜长石、角闪石、单斜辉石和石英等，代表早期的矿物组成。此外，围绕石榴子石周边存在“白眼圈”后成合晶或冠状体结构，冠状体一般为浅色，通常的矿物组合为斜方辉石+斜长石后成合晶或斜方辉石+斜长石+单斜辉石冠状体，此外部分石榴子石周边生长斜长石+角闪石后成合晶。基质主要由斜长石和角闪石组成。另外，野外常见全退变高压基性麻粒岩，表现为岩石中可见大量球状浅色矿物集合体，5 ~ 15 mm大小。显微镜下观察表明，球状集合体主要矿物组成为斜长石+单斜辉石+斜方辉石+角闪石，局部可见核部残留小颗粒石榴子石残晶，这种结构表明球状浅色矿物集合体为石榴子石退变质作用形成。根据本次研究，在高压基性麻粒岩中识别出四期变质作用，结合本区及邻区前人研究结果，勾画出近等温降压型 (ITD) 顺时针P–T演化轨迹。

(3) 变质相划分图：区内变质岩变质程度整体较高，经受了高角闪岩相–麻粒岩相变质作用，局部发生高压麻粒岩相变质作用。变质岩主要以区域变质岩为主，并伴随着强烈的深熔作用。此外，区内另一特殊的变质岩类型为含石榴子石“白眼圈”结构的高压基性麻粒岩，它反映了峰期高压麻粒岩相变质作用。根据岩石中的矿物组合确定经历的变质程度，以最高变质级别确定岩石的变质相，编制出变质相划分图。

(4) 古元古代构造演化模式图：对测区内变质相及变质期次、变形构造等进行了重新梳理，结合区域大地构造演化过程，对古元古代裂解、俯冲、碰撞、抬升过程进行了模拟，并对构造演化期次进行了划分，综合编制了古元古代构造演化模式图。

3 数据内容评述

东六马坊幅1∶50 000地质图数据库主要由基本要素类、综合要素类、对象类数据及独立要素类数据组成。

3.1 基本要素类

本图幅含有 7 种基本要素类数据，分别为：地质体面实体、地质界线、产状、样品、照片、同位素年龄及河、湖、海、水岸线。

“地质体面实体”共有 550 个实体，其属性包含以下内容：地质体面实体标识号 (由区内类型、图幅号和数据编号组成)、地质体面实体类型代码 (地质代码)、地质体面实体名称、地质体面实体时代等属性 (表 2)。

表 2 东六马坊幅地质图地质体面实体属性表

序号	数据项名称	标准编码	数据类型	实例
1	地质体面实体标识号	FEATURE_ID	字符串	AK50E023002000003234
2	地质体面实体类型代码(地质代码)	FEATURE_TYPE	字符串	Jx_1g^1
3	地质体面实体名称	GEOBODY_NAME	字符串	蓟县系下统高于庄组一段
4	地质体面实体时代	GEOBODY_ERA	字符串	Jx_1

“地质界线”共有 1 367 个实体，其属性包含以下内容：要素标识号、地质界线 (接触) 代码 (地质代码)、地质界线类型、界线左侧地质代号或上盘、界线右侧地质代号或下盘、界面走向、界线倾向、界线倾角等属性 (表 3)。

表 3 东六马坊幅地质图地质界线属性表

序号	数据项名称	标准编码	数据类型	实例
1	要素标识号	FEATURE_ID	字符串	AK50E023002000005998
2	地质界线(接触)代码(地质代码)	FEATURE_TYPE	字符串	11
3	地质界线类型	BOUNDARY_NAME	字符串	侵入接触
4	界线左侧地质代号或上盘	LEFT_UNIT_CODE	字符串	Pt_1N^2
5	界线右侧地质代号或下盘	RIGHT_UNIT_CODE	字符串	$\beta\mu Pt_2$
6	界面走向/°	STRIKE	整数型	280
7	界面倾向/°	DIP_DIRECTION	整数型	10
8	界线倾角/°	DIP_ANGLE	整数型	36

“产状”共有 214 个实体，其属性包含以下内容：要素标识号、产状类型名称代码、产状类型名称、走向、倾向、倾角等属性 (表 4)。

表 4 东六马坊幅地质图产状属性表

序号	数据项名称	标准编码	数据类型	实例
1	要素标识号	FEATURE_ID	字符串	AK50E023002000001878
2	产状类型名称代码	FEATURE_TYPE	字符串	3
3	产状类型名称	ATTITUDE_NAME	字符串	片麻理产状
4	走向/°	STRIKE	整数型	60
5	倾向/°	DIP_DIRECTION	整数型	330
6	倾角/°	DIP_ANGLE	整数型	45

“样品”共有 56 个实体，其属性包含以下内容：要素标识号、样品编号、样品类型代码、样品类型名称、样品岩石名称等属性 (表 5)。

表 5 东六马坊幅地质图样品属性表

序号	数据项名称	标准编码	数据类型	实例
1	要素标识号	FEATURE_ID	字符串	AK50E023002000000241
2	样品编号	SAMPLE_CODE	字符串	D9001_1
3	样品类型代码	FEATURE_TYPE	字符串	b
4	样品类型名称	SAMPLE_NAME	字符串	b薄片
5	样品岩石名称	ROCK_NAME	字符串	灰黑色中细粒角闪斜长二辉麻粒岩

“照片”共有 822 个实体，其属性包含以下内容：要素标识号、照片编号、照片题目、照片说明等属性 (表 6)。

表 6 东六马坊幅地质图照片属性表

序号	数据项名称	标准编码	数据类型	实例
1	要素标识号	FEATURE_ID	字符串	AK50E023002000003309
2	照片编号	SOURCE_ID	字符串	D7603_2
3	照片题目	SAMPLE_CODE	字符串	白云岩、紫红页岩互层
4	照片说明	PHOTO_TITLE	字符串	大红峪组岩组岩石组合宏观地质特征

“同位素年龄”共有 9 个实体，其属性包含以下内容：要素标识号、样品编号、样品名称、年龄测定方法、测定年龄、被测定出地质体单位及代号、测定分析单位、测定分析日期等属性 (表 7)。

表 7 东六马坊幅地质图同位素年龄属性表

序号	数据项名称	标准编码	数据类型	实例
1	要素标识号	FEATURE_ID	字符串	AK50E023002000000001
2	样品编号	SAMPLE_CODE	字符串	TW8040_1
3	样品名称	SAMPLE_NAME	字符串	灰黑色中细粒二辉磁铁石英岩
4	年龄测定方法	MEASURING_KINDS	字符串	锆石U–Pb
5	测定年龄	AGE	字符串	2 480±24Ma(D)/1847±15Ma(M)
6	被测定出地质体单位及代号	GEOBODY_CODE	字符串	Ar@3y.$ibr
7	测定分析单位	UNIT	字符串	天津地质调查中心同位素实验室
8	测定分析日期	DATE	字符串	20171114

注：@表示下标；$表示上标。

“河、湖、海、水岸线”共有 32 个实体，其属性包含以下内容：要素标识号、图元类型、图元名称等属性 (表 8)。

表 8 东六马坊幅地质图河、湖、海、水岸线属性表

序号	数据项名称	标准编码	数据类型	实例
1	要素标识号	FEATURE_ID	字符串	AK50E023002000000021
2	图元类型	FEATURE_TYPE	字符串	21010
3	图元名称	FEATURE_NAME	字符串	常年河

3.2 综合要素类

本图幅只包含变质相带及标准图框 (内图框)2 种综合要素类数据。

“变质相带”共有 282 个实体，其属性包含以下内容：要素标识号 (由区内类型、图幅号和数据编号组成)、变质相带地质体代码、变质相带类型、变质作用类型、变质程度、变质温压条件、变质相带岩石名称、变质相带岩石颜色、变质相带岩石结构、变质相带岩石构造及变质相带矿物组合及含量等属性 (表 9)。

表 9 东六马坊幅地质图建造–构造图层属性表

序号	数据项名称	标准编码	数据类型	实例
1	要素标识号	Feature_Id	字符串	AK50E023002000002742
2	变质相带地质体代码	Feature_Type	字符串	$Ar_3gn^{\gamma\delta o}$
3	变质相带类型	META_MORPHIC_TYPE	字符串	麻粒岩相
4	变质作用类型	META_TYPE	字符串	区域中高温变质作用
5	变质程度	META_DEGREE	字符串	高级
6	变质温压条件	TP_CONDITION	字符串	中压高温
7	变质相带岩石名称	ROCK_NAME	字符串	(黑云)英云闪长质片麻岩
8	变质相带岩石颜色	COLOR	字符串	灰白色、灰黄色
9	变质相带岩石结构	ROCK_TEXTURE	字符串	鳞片粒状变晶结构
10	变质相带变质构造	ROCK_STRUCTURE	字符串	片麻状或条带状构造
11	变质相带矿物组合及含量	ASSOCIATION	字符串	斜长石60%～65%，条纹长石不足5%，黑云母10%～16%

“标准图框 (内图框)”共有 4 个实体，其属性包含以下内容：图名、图幅代号、比例尺、坐标系统、高程系统、左经度、下纬度、图形单位等属性 (表 10)。

表 10 东六马坊幅地质图标准图框属性表

序号	数据项名称	标准编码	数据类型	实例
1	图名	MAP_NAME	字符串	东六马坊
2	图幅代号	SHEET_CODE	字符串	K50E023002
3	比例尺	SCALE	字符串	50 000
4	坐标系统	COORDINATE_SYSTEM	字符串	国家大地坐标系
5	高程系统	HEIGHT_SYSTEM	字符串	黄海高程系
6	左经度	LEFT_LONGITUDE	字符串	1 141 500
7	下纬度	LOW_LATITUDE	字符串	401 000
8	图形单位	COORDINATES_UNIT	字符串	毫米

3.3 对象类数据

本图幅共包含 49 个对象类数据，分 7 种，分别为：沉积 (火山) 地层单位 (STRATA)、非正式地层单位 (INF_STRATA)、侵入岩岩石年代单位 (INTRU_LITHO_CHRONO)、脉岩 (面)(_DIKE_OBJECT)、断层 (FAULT)、变质岩地 (岩) 层单位 (METAMORPHIC) 及图幅基本信息 (_SHEET_MAPINFO)。

3.4 独立要素类

本图幅独立要素类包括沉积岩综合柱状图、图切地质剖面图、图例、接图表、责任栏等图饰部分及构造–岩石地层单位柱状图、侵入岩演化序列表柱状图、构造纲要图、高压基性麻粒岩及 P–T 轨迹图、变质相划分图、古元古代构造演化模式图、调查区大地

构造位置图、图名、中国地质调查局局徽、比例尺等角图部分。

4 数据质量控制和评估

在东六马坊幅 1∶50 000 地质图数据库建设过程中，严格执行中国地质调查局地质调查技术标准《数字地质图空间数据库》(DD 2006-06)。具体质量监控包括：

(1) 过程监控：每做完一步，建库人员都要进行 100% 自检、项目组进行 100% 互检，主要检查接边属性是否正确，检查拓扑关系是否正确，数据入库后检查按图幅显示是否完整，按图例、图层检查属性及面元颜色、填充图案是否正确等。

(2) 属性数据检查：检查图层命名的标准化程度、图层属性表是否齐全、记录是否完整、属性代码是否准确、属性格式是否正确、数据项内容和图元与属性的对应性等，在建库过程中经过多层次、多环节的质量检查与监督，确保数据库中数据准确无误。

(3) 图面质量检查：对 MapGIS 输出的全要素彩色喷墨地质图内、图外整饰部分的注记、子图等规范性，地质图颜色、压盖关系处理以及角图绘制合理等问题，聘请地质专家进行 3 次以上的图面检查工作。

东六马坊幅 1∶50 000 地质图在中国地质调查局“2018 年度全国区域地质调查优秀图幅展评会”获评为优秀图幅。

5 数据价值

东六马坊幅 1∶50 000 地质图数据库在前人区域地质调查和科研工作基础上，创新运用变质岩区填图技术方法，取得了如下成果：(1) 重新厘定了调查区早前寒武纪变质表壳岩地层单位，确定了新太古代桑干岩群阳高岩组和古元古代集宁岩群黄土窑岩组，并进一步划分了 4 个岩性段 (表 11; 张家辉等, 2019a, 2019b; 田辉等, 2019)；(2) 详细解体了早前寒武纪变质深成岩，划分出新太古代二辉石英闪长质片麻岩、(黑云) 英云闪长质片麻岩、紫苏奥长花岗质片麻岩、二长花岗质片麻岩和片麻状二长花岗岩以及古元古代石榴二长花岗岩、岩墙型高压基性麻粒岩和二辉麻粒岩等填图单位 (表 12)；(3) 建立了测区中元古代沉积地层层序，划分出长城系大红峪组、蓟县系高于庄组 2 个填图单位；(4) 新识别出晚三叠世、晚侏罗世和早白垩世 3 期岩浆事件，建立了中生代岩浆演化序列；(5) 厘定出古元古代基性岩墙型和基性火山岩型 2 类不同原岩性质的高压麻粒岩 (表 13; 张家辉等, 2019c)，为研究古元古代造山带提供了基础资料；(6) 新确定了早前寒武纪、中元古代和中新生代等 3 个构造层，对各构造层的构造变形特征、变形期次进行了详细调查，初步建立了古元古代构造演化格架；(7) 初步建立了高级变质岩区“特征变质矿物+岩石组合 (原岩岩性)+构造”填图方法，并系统总结了变质深成岩和变质表壳岩的研究方法和鉴别标志。

东六马坊幅 1∶50 000 地质图在的图面表达主要特色有：早前寒武纪变质基底突出流变构造样式，并以断流线表达；古元古代变质表壳岩与新太古代变质深成岩间采用构造接触关系，以红线标识；新太古代阳高岩组中的 BIF 夹层，采用橘黄色粗线表示；中元古代稳定沉积盖层区域用白云岩地层花纹表示；地质图两侧添加了构造纲要图、变质相图、特征岩石类型——高压基性麻粒岩的岩相学特征及 P–T 轨迹图，进一步丰富了图面。图幅研究成果可以为科研和地质矿产调查提供有益参考，地质图面表达方式可以为变质岩区填图工作提供范例。

表 11　晋冀蒙交界东六马坊幅区早前寒武纪变质表壳岩构造–地层单元划分

时代	构造岩石地层			代号	岩石组合	原岩性质	分布地区	产状	年龄/Ma	矿产
古元古界	集宁岩群	黄土窑岩组	含石墨–矽线–石榴片麻岩–变粒岩–大理岩岩段	$Pt_1h.^{ggm}$	含石墨矽线石榴钾长/二长片麻岩、含石墨矽线钾长变粒岩和透辉大理岩为主，局部夹石榴子石英岩、钙镁硅酸盐岩以及浅粒岩等	富黏土质长石砂岩建造，夹少量碳酸盐岩和石英砂岩	主要分布于周家山–朱家沟–史家庄一带、席麻沟–莲花石以及冷家沟–东减昌沟等地	带状构造岩片	碎屑锆石：1988 ~ 2300 变质锆石：1827 ~ 1837	石墨矿
			石榴高压麻粒岩–大理岩岩段	$Pt_1h.^{gm}$	高压基性麻粒岩、含石墨透辉/蛇纹石化大理岩、二辉斜长角闪岩等以及黑云矽线石榴二长片麻岩等	基岩火山岩夹碳酸盐岩(洋壳组合)，含少量碎屑岩	主要分布在西赵家窑	构造岩片	结晶年龄：>2026	
新太古界	桑干岩群	阳高岩组	榴云片麻岩岩段	$Ar_3y.^{sg}$	(条带状)石榴黑云斜长片麻岩为主，含石榴斜长变粒岩等	含黏土质杂砂岩建造	全区均有出露，主要分布在黑石山至团山村北一带	长条状、带状或透镜状	碎屑锆石：~2522 变质锆石:~2471 ;1831 ~ 1838	
			二辉麻粒岩–铁英岩岩段	$Ar_3y.^{ibr}$	变基性岩(二辉麻粒岩)为主，夹条带状二辉磁铁石英岩，局部含石榴黑云斜长片麻岩	基性火山岩夹磁铁石英岩，含少量陆源碎屑岩	全区均有出露，分布广，规模小	透镜状，局部呈长条状	结晶年龄：~2489 变质年龄：~1807	阿尔戈马型BIF铁矿

表 12　天镇–怀安地区变质深成岩特征

时代	岩性	代号	构造层次	矿物组合	风化外貌	变质程度	锆石同位素年龄/Ma			产状	岩浆系列	构造背景
							继承年龄	原岩年龄	变质年龄			
古元古代	花岗伟晶岩	$Pt_1\gamma\rho$	浅部	石英+斜长石+微斜长石+条纹长石±黑云母	肉红色	未变质		1809±9、1 797±14		岩脉	高钾钙碱性系列	固结冷却
	二长花岗岩脉	$Pt_1\eta\gamma$	中–浅部	石英+斜长石+条纹长石	肉红色	角闪岩相	2 429～2 497	1844±17、1846±13		岩脉		碰撞抬升
	二辉麻粒岩或二辉斜长麻粒岩	Pt_1N^2	中–深部	紫苏辉石+透辉石+斜长石+角闪石±黑云母	灰黑色	麻粒岩相–角闪岩相		～1918(?)	1820±10、1834±9	岩墙或透镜体状	拉斑玄武岩系列	古元古代造山旋回
	石榴角闪二辉麻粒岩	Pt_1N^1	深部	石榴子石+紫苏辉石+透辉石+斜长石+角闪石+磁铁矿±黑云母±石英	灰黑色	高压麻粒岩相–麻粒岩相–角闪岩相		2 250～2 200(?)	1957±23、1909±12、1836±18	岩墙、岩脉或布丁状、透镜体状	拉斑玄武岩系列	碰撞加厚
	石榴花岗岩	$Pt_1g\eta\gamma$	中–浅部	石英+斜长石+条纹长石+石榴子石±磁铁矿	肉红色	麻粒岩–角闪岩相		2 031±21	1837±12	岩株	A型花岗岩	陆内裂解

续表 12

时代	岩性	代号	构造层次	矿物组合	风化外貌	变质程度	锆石同位素年龄/Ma			产状	岩浆系列	构造背景
							继承年龄	原岩年龄	变质年龄			
新太古代末期	片麻状二长花岗岩	$Ar_3\eta\gamma$	中–浅部	石英+斜长石+条纹长石±黑云母	肉红色	角闪岩相		2 472±10、2 486±21、2 448±9	1885～1833	岩株、岩脉	高钾钙碱性G_2系列	新太古代克拉通化 岩浆弧
	黑云二长花岗质片麻岩	$Ar_3gn^{\beta\eta\gamma}$		石英+斜长石+条纹长石+黑云母	肉红色			2 440±30	变质边较窄	岩体		
	含紫苏奥长花岗质片麻岩	$Ar_3gn^{\nu\gamma o}$		石英+斜长石+紫苏辉石±角闪石+黑云母(暗色矿物≤5%)	灰白色			2 492±18	变质边较窄			
	(黑云)英云闪长质片麻岩	$Ar_3gn^{\gamma\delta o}$	中部	石英+斜长石+黑云母±紫苏辉石±角闪石	灰白色	高角闪岩相–麻粒岩相		2 476±10、2 474±18、2 473±16、2 466±13、2 459±13	变质边较窄	岩体，相互间为渐变过渡，协调的构造接触关系	DTT系列	
	紫苏英云闪长质片麻岩	$Ar_3gn^{\nu\gamma\delta o}$	中–深部	石英+斜长石+紫苏辉石±角闪石+黑云母	灰黑色	麻粒岩相		2 497±25、～2 525	1858±18			
	二辉石英闪长质片麻岩	$Ar_3gn^{\psi\delta o}$		石英+斜长石+紫苏辉石+透辉石±角闪石±黑云母	灰黑色			2 480～2 515	1822±42、1843±28			

表 13　天镇–怀安地区 2 类高压基性麻粒岩特征

时代	类型	岩性	填图单元	变质程度	原岩性质	年龄	产状关系	分布
古元古代	II类	高压基性麻粒岩	$Pt_1h.^{gm}$	HT–HP麻粒岩相(峰期)、麻粒岩相–角闪岩相(退变)	基性火山岩	原岩年龄：2.15～2.2Ga(?) 变质年龄：1.82～1.83Ga	与大理岩和变质泥–砂质碎屑岩伴生	在西赵家窑村一带出露
	I类		Pt_1N^1		基性岩脉/墙、基性透镜体	原岩年龄：～2.2Ga(?) 变质年龄：～1957; 1850～1867Ma	呈透镜状或似脉状产出于变质深成岩体之中	全区均有出露，分布广，规模小

6 结论

(1) 晋冀蒙交界东六马坊幅 (K50E023002)1∶50 000 地质图是按照中国地质调查局新颁布的区域地质调查技术要求及规范，采用现代变质岩区填图理念和图面表达方法编制形成的优秀图幅之一，为高级变质岩区填图工作提供了参考范例。

(2) 按照数字填图工作流程，系统编制了东六马坊幅 (K50E023002)1∶50 000 地质图数据库，具有查询检索、分层提取、拼接裁剪、缩放及工程输出等处理功能，可作为编制各种不同比例尺地质图和专题图件的基础信息库。

(3) 该图幅对区内新太古代—新生代地层、岩浆岩、变质作用以及构造等进行了详细的划分厘定：建立了新太古代桑干岩群和古元古代集宁岩群 4 个构造–岩石地层单位以及中元古代—新生代 13 个地层单位；建立了新太古代—古元古代和中元古代—中生代 (变质) 侵入岩演化序列；识别出早前寒武纪 3 期变形构造样式和中—新生代印支期、燕山期和喜马拉雅期断裂构造形迹；识别出 2 类不同原岩性质的高压基性麻粒岩，并对变质作用期次进行了划分。研究成果可为地质找矿及科学研究提供基础地质资料。

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注释：

❶ 山西省区域地质测量大队. 1969. 1∶200 000 大同幅地质图说明书 (内部资料)
❷ 河北省区域地质测量大队. 1970. 1∶200 000 天镇幅地质图说明书 (内部资料)
❸ 河北省区域地质矿产调查研究所. 2008. 1∶250 000 张家口市幅区域地质调查报告 (内部资料)
❹ 山西省地质调查院. 2014. 1∶250 000 大同市幅区域地质调查报告 (内部资料)
❺ 山西省地质矿产局区调队. 1996. 1∶50 000 阳高测区区域地质调查报告 (内部资料)
❻ 山西省地质调查院. 2014. 1∶50 000 天镇测区地质报告 (内部资料)

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1∶50 000 Geological Map Database of the Dongliumafang Map-sheet at the Junction of Shanxi, Hebei and Inner Mongolia

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Abstract: The Dongliumafang Map-sheet (K50E023002) is located in the Hengshan-Sanggan high-pressure granulite belt at the junction of Shanxi, Hebei and Inner Mongolia. The 1∶50 000 Geological Map Spatial Database of Dongliumafang Map-sheet was compiled in accordance with the Technical Requirement for Regional Geological Survey (1∶50 000) (DD 2019−01) newly issued by China Geological Survey and other relevant uniform standards and requirements, by using modern mapping technology for metamorphic rock area and digital mapping acquisition system. The map-sheet gave a detailed definition of the strata, magmatic rocks, metamorphism and tectonic structure in the Neoarchean-Cenozoic era in the area: four tectonic-lithostratigraphic units of the Neoarchean Sanggan Group and the Paleoproterozoic Jining Group, and 13 Mesoproterozoic-Cenozoic stratigraphic units have been established; the evolutionary series of Neoarchean-Paleoproterozoic and Mesoproterozoic-Mesozoic (metamorphic) intrusive rocks have been established; the structural deformation style of three periods of Early Precambrian, and the fracture structure in the Mesozoic-Cenozoic Indosinian, Yanshanian and Himalayan periods have been identified; two types of high-pressure basic granulites with different protolith properties have been identified, with metamorphic periods divided. The map-sheet uses special line segments and patterns to express the plastic rheological characteristics and structural deformation style of deep crustal rocks in the ancient

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orogenic belt, and has reconstructed the evolution process of Paleoproterozoic orogenic tectonics. The database adopts a MapGIS format and comprises 1：50 000 geological map library, map appearance and corner maps, and contains nine data pieces of zircon U-Pb age, with a data volume of 53.8 MB. The 1：50 000 Geological Map of Dongliumafang Map-sheet has innovated the mapping techniques for high-grade metamorphic areas as well as map expression methods, setting an example for mapping work on high-grade metamorphic rock areas.

Key words: Dongliumafang Map-sheet; 1：50 000; geological map; database; north China Craton; mapping of metamorphic rock area; geological survey engineering

Data service system URL: http://dcc.cgs.gov.cn

1 Introduction

As one of the few ancient cratons in the world with rocks ≥ 3.8 Ga (Liu DY et al., 1992, 2008; Wan YS et al., 2005, 2012; Wang YF et al., 2015; Zhang JH et al., 2013, 2018), the North China Craton records the complete geological history of the Archean—Proterozoic era, and represents a natural laboratory for studying Precambrian geological evolution in China. During formation of the North China Craton, emplacement of large-scale newly produced TTG magmatic rocks in the late Neoarchean (~ 2.5 Ga) (Geng YS et al., 2010), and associated tectonic-metamorphic-magmatic events are the most important geological events, marking the amalgamation of the North China micro-continental blocks and the early cratonization process (Zhai MG et al., 2000; Zhai MG, 2011; Wang HC et al., 2011; Wan YS et al., 2017), laying the foundation for the evolution of the North China Craton. During the Proterozoic, the geological evolution of the North China Craton can be divided into the Paleoproterozoic breakup-collision orogenic event, Mesoproterozoic-Neoproterozoic large-scale mafic dike group emplacement and non-orogenic magmatism developed against an extensional background, and the volcanic-sedimentary event of the rift trough. They are considered to correspond to the convergence and breakup events of the Columbia supercontinent (Zhai MG, 2014). These two global events representing different tectonic meanings are the main basis for China to divide the Paleoproterozoic and Mesoproterozoic boundaries (~ 1.8 Ga).

The junction area between Shanxi, Hebei and Inner Mongolia represents a typical granulite facies high-grade metamorphic area of the Early Precambrian in the North China Craton. It can be divided into two sets of high-grade metamorphic rock series along the Datong-Xinghe line, i.e., the granulite series in the southeast and the khondalite series in the northwest (Fig. 1b). The khondalite series is a set of special combination of graphite-sillimanite-garnet bearing metamorphic argillaceous rock of granulite facies and marble, which are better exposed in the Jining-Fengzhen area, now referred to as the Jining rock group. The granulite series is mostly distributed in the Datong-Tianzhen-Huai'an-Xuanhua area and was as a whole referred to as the Sanggan gneiss or Sanggan complex in early geological work. It was regarded as metamorphic strata in the 1：200 000 regional geological survey[❶❷] carried out in the early 1970s, and classified as part of the Sanggan Group formed in the Archean. Since the

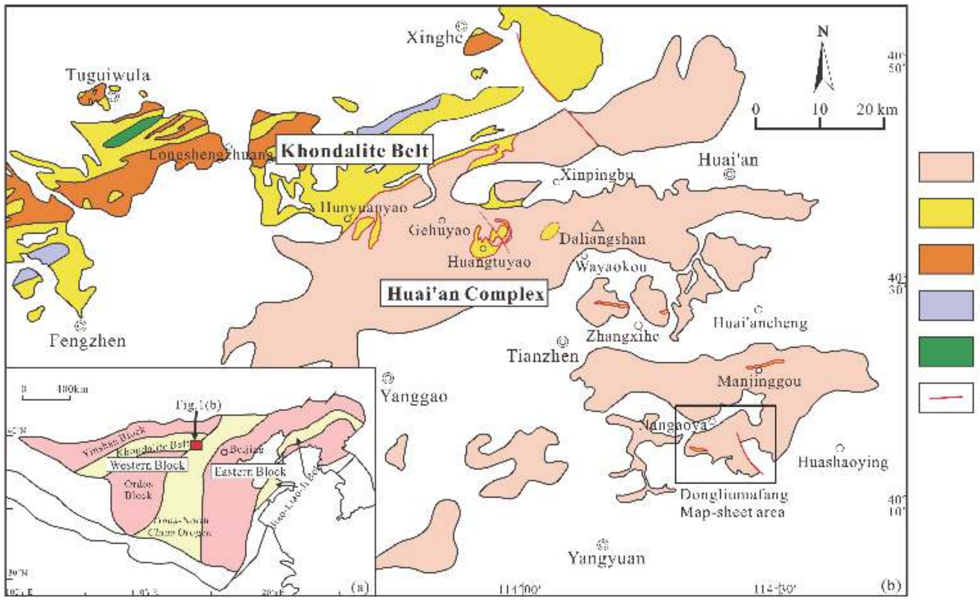

Fig. 1 Paleoproterozoic tectonic zoning map of North China Craton (a, modified from Zhao GC et al., 2005) and early Precambrian geological diagram of the junction area between Shanxi, Hebei and Inner Mongolia (b)

1—Huai'an complex; 2—Khondalite series; 3—Porphyritic granite; 4—Alaskite; 5—Xuwujia metamorphic mafic dike; 6—Fault or tectonic contact

1980s, the geological framework of Archean tonalitic-trondjemitic-granodioritic gneiss (TTG gneiss) or grey gneiss complex has been gradually established in this area. The geological framework is mainly composed of an Archean tonalitic-trondjemitic-granodioritic gneiss complex, with scattered supracrustal rocks "floating" in gneiss complexes as layered xenoliths (Liu YG and Guo JH, 1993). Today, the early Precambrian metamorphic complexes in this area are collectively referred to as Huai'an complexes. Due to the deep metamorphism and complicated structural deformation in this area, and the fact that it is generally characterized by metamorphism-anatomy, it is difficult to divide and compare the mapping units of various rocks. At the same time, there has long been debate over the following issues: 1) whether the time limit of peak metamorphism of high-pressure basic granulite with retrogressive "white eye rim" structure widely exposed in the area is ~1.85 Ga (Zhao GC et al., 2005, 2008; Guo JH et al., 2002, 2005), or ~1.95 Ga (Zhai MG, 2009; Zhang HF et al., 2016); 2) whether the tectonic origin of the ~1.85 Ga granulite facies metamorphism event is collision orogeny compression background (Zhao GC et al., 2012) or post-orogenic uplift and cooling (Zhai MG, 2009; Wei CJ et al., 2014); 3) whether the khondalite belt and the central orogenic belt represented by the Huai'an complex are two different Paleoproterozoic orogenic belts, and whether there is a tectonic boundary between them (Zhao GC et al., 2010; Wang LJ et al., 2015; Liao Y and Wei CJ, 2019).

In the last 20 years, a series of 1∶250 000[3,4] and 1∶50 000[5,6] regional geological surveys have been carried out in the junction areas of Shanxi, Hebei and Inner Mongolia, systematically dividing and defining geological units and laying an important foundation for geological and mineral mapping in this area. From 2016 to 2018, the Tianjin Center of the

China Geological Survey organized and implemented the "Geological and Mineral Survey in Fengning and Tianzhen Areas of Yanshan-Taihang Metallogenic Belt" project in an attempt to investigate the genesis and metamorphic dynamics of high-pressure basic granulites in the Tianzhen-Huai'an area at the junction of Shanxi, Hebei and Inner Mongolia and ultra-high temperature argillaceous granulites in the Tuguiwula area of Inner Mongolia. It contains the geological map database (Table 1; Zhang JH et al., 2020) of Dongliumafang Map-sheet (K50E023002), which is located in the Hengshan-Sanggan high-pressure granulite belt at the junction of Shanxi, Hebei and Inner Mongolia, within the Paleoproterozoic orogenic belt defined by Zhao et al. (2005), and adjacent to the khondalite belt (Fig. 1a). With great geological tectonic significance, it has been a classic area for studying high-pressure granulite facies metamorphism at home and abroad, and in particular, a key to understanding the material composition of the deep crust, the structure of the lower crust and the tectonics of the paleo-plate through studying the genesis and tectonic setting of the high-pressure granulite. Building on previous research, the 1∶50 000 Geological Map of Dongliumafang Map-sheet (Fig. 2) uses modern mapping techniques for the metamorphic rock area, and redivides and

Table 1 Metadata Table of Database (Dataset)

Items	Description
Database (dataset) name	1∶50 000 Geological Map Database of the Dongliumafang Map-sheet at the Junction of Shanxi, Hebei and Inner Mongolia
Database (dataset) authors	Zhang Jiahui, Tianjin Center, China Geological Survey Wang Huichu, Tianjin Center, China Geological Survey Tian Hui, Tianjin Center, China Geological Survey Ren Yunwei, Tianjin Center, China Geological Survey Yang Jiyuan, Hebei Institute of Regional Geological Survey
Data acquisition time	2016—2018
Geographic area	114°15′—114°30′ E, 40°10′—40°20′ N
Data format	*.wl, *.wp, *.wt*
Data size	53.8 MB
Data service system URL	http://dcc.cgs.gov.cn
Fund project	China Geological Survey Project "Geological and Mineral Survey in Fengning and Tianzhen Areas of Yanshan-Taihang Metallogenic Belt" (DD20160042)
Language	Chinese
Database (dataset) composition	The database (dataset) is composed of 1∶50 000 geological map library, map appearance and corner maps. The geological maps include sedimentary rock, magmatic rock, metamorphic rock, Quaternary System, dike, tectonics, geological boundary, attitude, sample, photograph, isotopic age, lithologic column, and mapping unit. Map appearance includes the columnar section of sedimentary rock, cutting profile, legend, index map and duty table. Corner maps include columnar section of structural-lithostratigraphic unit, columnar section of intrusive rock evolution sequence table, structural outline map, high-pressure basic granulite and P–T path map, metamorphic facies division map, Paleoproterozoic tectonic evolution model map, geotectonic location map of the survey area, map name, emblem of the China Geological Survey, and scale

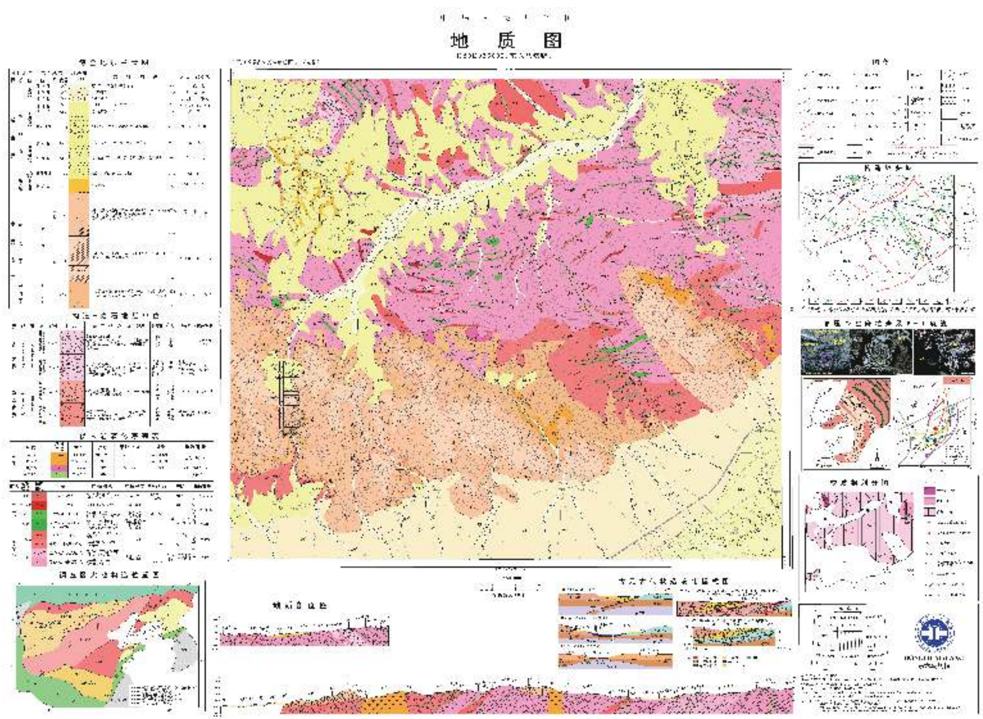

Fig. 2 Schematic diagram of 1：50 000 geological map spatial database of Dongliumafang map-sheet at the junction of Shanxi, Hebei and Inner Mongolia

redefines the Neoarchean-Cenozoic strata, magmatic rocks, metamorphism and structures in the area, achieving a series of important progress. It provides a new basis for the division and correlation of regional geological events, while at the same time offers an example for the geological mapping of high-grade metamorphic rock areas with its new map expression methods.

2 Data Acquisition and Processing Process

2.1 Basic Data Acquisition

The Geological Map Database of Dongliumafang Map-sheet (K50E023002) is based on the 1：50 000 topographic map (1971) of the Bureau of Surveying and Mapping of the People's Liberation Army General Staff Department. The 1：50 000 topographic map was vectorized by computer software such as MapGIS, forming a 1：25 000 topographic map. For the vectorized data of point (wt), line (wl), area (wp), the topographic data conversion parameters (scale: 1：25 000, unit: mm, coordinates type: rectangular coordinate system, projection type: Gauss-Kruger projection, ellipsoid parameter: Xi'an 80/1975 I.G.U.U) were used for projection conversion, forming a background layer of the 1：25 000 map-sheet. The present project adopted the DGSS digital mapping system for mapping. While strengthening the investigation of strata, rocks and structures in the survey area, we studied in detail the material composition and structural deformation characteristics of high-grade metamorphic rocks and the process of metamorphism-anatexis. For metamorphic plutonic rocks, the mapping method of "characteristic metamorphic minerals+protolith lithology+structure" was used to highlight the expression of protolith lithology and emphasize the structural deformation style and characteristic metamorphic mineral composition. For metamorphic supracrustal rocks, the mapping method of “diagnostic metamorphic mineral+rock association+structure” was used to effectively distinguish early Precambrian metamorphic supracrustal rock units of different eras and genesis types.

2.2 Data Processing

2.2.1 Field Geological Mapping

In the process of field original data acquisition, the 1 ∶ 25 000 topographic map under the jurisdiction of the Dongliumafang Map-sheet was taken as the background layer. Through field actual geological route investigation, information such as geological point (P), geological route (R), geological boundary line (B), sample, sketch, attitude, and photography were systematically collected, and the master field library of the digital mapping system was initially established.

Geological point (P): divided into boundary point, structural observation point and lithology control point. In the field geological survey, its attributes were carefully filled in the mobile digital system, including route number, geological point number, micro-geomorphology, outcrop weathering degree, mapping unit, rock name, contact relation and lithology description.

Geological route (R): attributes such as route number, geological point number, R code, mapping unit, rock name and geological information along the way were filled in the system in the field. Among them, azimuth, distance of the station, and accumulated distance were automatically calculated and filled in by the system.

Geological boundary (B): route number, geological point number, B code, R code, boundary type, left mapping unit, right mapping unit, contact relation and field evidence were filled in the system in the field.

During field investigation, important attributes of sample, sketch, attitude, photograph and other features collected along the geological route were imported.

2.2.2 Indoor Data Sorting and Database Construction Process

(1) Firstly, the field data collected by the mobile digital system was imported into the computer-based digital mapping system, and various geological features of the field route were edited and refined. At the same time, the data quality was checked by programming. After correcting the errors prompted in the logic check, data was sorted and modified according to relevant specifications:

Geological point (P): geological point was adjusted to overlap with GPS point. Its geological attributes and location description were added and refined. This includes the name of slice identification, which would be filled in after the identification results become available.

Geological route (R): laboratory-based route mapping was conducted to reflect the actual field route as accurately as possible. The R-line segment was smoothed, and adjacent R-line segments were connected at geological points or boundaries through adjustment by method of junction point. The R-line segment distance must be recalculated after finishing, and the "segment head" must be clicked to fill in.

Geological boundary line (B): a length of 1–3 cm was reserved according to the actual strike of the boundary and the V-like rule, and the attitude of the geological boundary was added. The strike of the geological boundary for faults of an unknown nature and the Quaternary boundary was added. The features of other faults and integrated boundaries could be supplemented by referring to adjacent attitude. The linear parameters were changed according to the different types of boundary.

Description of sample, sketch, attitude, and photography was then completed and refined, and the sketch map was finished. Geological point, sample, and attitude were marked separately. The sample symbols were finished according to the actual sample category. The lithologic code and mapping unit code were marked on the point free layer, and a string was used to add leads to the free line layer.

The free hand cutting profile was then added, the route summary was compiled, and multi-level manual quality inspection was carried out to complete the digitalization of a single route.(2) The data of field geological route and measured geological profile were projected to the 1∶25 000 actual material maps for mapping by correctly adopting the V-like rule. After finishing four 1∶25 000 actual material maps, all 1∶25 000 actual material maps were projected to generate the 1∶50 000 original map.

(3) The 1∶50 000 original map data were integrated into the spatial database, and the topological consistency of the map, the expression of geological features and the map structure were checked to ensure that they fully meet the requirements of geological map finishing and spatial database. Then the data of the basic feature class, complex feature class and object class were imported in order.

(4) Lastly, the quality of the spatial database was systematically and comprehensively checked to ensure, for example, that there were no overlapping lines, no overlapping coordinates, and no lines with untouched endpoints. By following the above steps, a complete 1∶50 000 geological map (Fig. 2) and spatial database of Dongliumafang Map-sheet were compiled.

2.2.3 Map Appearance Compilation

(1) Columnar section: the lithologic combination and sedimentary facies of Mesoproterozoic-Cenozoic sedimentary stratigraphic units in the map were comprehensively analysed to compile a columnar section of sedimentary rocks; a "structural-lithostratigraphic unit columnar section" was compiled according to the characteristics of "diagnostic metamorphic mineral+rock association+structure" for Neoarchean-Paleoproterozoic metamorphic strata; the "columnar section of intrusive rock evolution sequence table" was compiled for Neoarchean-Paleoproterozoic metamorphic plutons according to the characteristics of "diagnostic metamorphic mineral+protolith lithology+structure".

(2) Cutting profile: the main direction of the structural line in the map is E–W or NW–SE. In order to effectively reflect the overall formation and structural characteristics in the map-sheet, two NE-trending cutting profiles were arranged, one of which runs through the whole

region and controls the Neoarchean metamorphic plutons, Neoarchean-Paleoproterozoic metamorphic supracrustal rocks, Mesoproterozoic sedimentary cap rocks, Mesozoic intrusive rocks and Cenozoic loose deposits in the area; the other mainly controls the newly recognized Paleoproterozoic Huangtuyao Formation composed of high-pressure basic granulite and marble exposed in the Xizhaojiayao area.

2.2.4 Corner Map Compilation

(1) Structural outline: based on the analysis of Early Precambrian deformation structure, three periods of structural deformation style in the Neoarchean and Paleoproterozoic have been determined. The first period of deformation (D1): formed at the end of the Neoarchean (2.55–2.5 Ga). The tectonic style in this period was greatly altered by Paleoproterozoic orogeny. Its structural style cannot be identified, but is dominated by the tectonic pattern of the Archean granite-greenstone belt. The second period of deformation (D2): occurred in the early stage of Paleoproterozoic subduction orogeny. The crustal rocks at the root of the thickened orogenic belt began to undergo viscous layered flow deformation, resulting in near S- or SSE-trending laminar flow in the lower crust, with well-developed flow surface structure (S2), and were only partially preserved in TTG rocks and metamorphic supracrustal rock tectonic agglomerates (metamorphic basic rocks+BIF assemblage). The attitude of foliation (S2) in this period is 175°–190°∠25°–45°; the attitude of lineation (L2) is 150°–160°∠45°–60°. The third period of deformation (D3): formed in the late stage of Paleoproterozoic orogeny. During the exhumation process, differential uplift resulted in wide-ranging foliation structures (S3), SW-trending mineral stretching lineation and A-type folds in the region. The general foliation attitude (S3) dip is 150°–210°, and the dip angle varies greatly in different lithologies. The dip direction of lineation (L3) points SW (210°–250°) and the dip angle is 15°–50°. At the same time, the brittle Mesozoic-Cenozoic fault structures were systematically summarized: the Indosinian (Late Triassic) structural line is EW-trending, and the structural features of this period are partially preserved; the Yanshanian (Late Jurassic-Early Cretaceous) tectonic line is NE, NEE and NW, which is characterized by Taihangshan uplift. The Himalayan (Miocene—Pliocene) tectonic line is mainly NE-trending and partially NEE-trending, with dextral shearing, forming Shanxi Graben system. The structural outline of this map-sheet was compiled by comprehensively considering different tectonic features.

(2) High-pressure basic granulite and P-T path diagram: the high-pressure basic granulites in the area generally show porphyry-like crystalline structure, with the porphyroblast being garnet. The garnet varies in size, generally 3–10 mm, and may reach up to 15–20 mm. Microscopic observation shows that the garnet porphyroblast contains a large number of inclusions. These inclusions include plagioclase, hornblende, clinopyroxene and quartz, representing early mineral composition. In addition, around the garnet are “white eye rim” symplectite or coronal structure. The coronal body is generally light in color. The common mineral association is orthopyroxene+plagioclase symplectite or orthopyroxene+plagioclase+clinopyroxene coronal body. In addition, plagioclase and hornblende symplectite are grown around some garnet. The matrix is mainly composed of plagioclase and hornblende. In

addition, fully retrogressive high-pressure basic granulites are common in the field, as manifested in a large number of spherical light-colored mineral aggregates that can be seen in the rocks, with a size of 5–15 mm. Microscopic observation shows that the main mineral composition of spherical aggregates is plagioclase+clinopyroxene+orthopyroxene+hornblende, with residual small-particle garnet crystals in the core in certain parts, which indicates that the spherical light-colored mineral aggregates were formed by garnet retrogressive metamorphism. According to this study, four periods of metamorphism were identified in the high-pressure basic granulites. Considering previous research results in this area and its neighboring areas, a clockwise P-T path dominated by near-isothermal decompression characteristics (ITD) was outlined.

(3) Metamorphic facies division map: characterized by a high metamorphic degree overall, the metamorphic rocks in the area are subject to high amphibolite facies-granulite facies metamorphism, with the occurrence of high-pressure granulite facies metamorphism in certain parts. The metamorphic rocks are mainly of a regional nature with strong anatexis. In addition, another special metamorphic rock type in the area is the garnet-bearing high-pressure basic granulite with a “white eye rim” structure, which reflects high-pressure granulite facies metamorphism at its peak. To compile the metamorphic facies division map, the metamorphic degree experienced was determined according to the mineral association in the rock, and the metamorphic facies of the rock was determined according to the highest metamorphic grade.

(4) Paleoproterozoic tectonic evolution model map: the metamorphic facies and metamorphic stages and deformation structures in the survey area were re-sorted, and the Paleoproterozoic breakup, subduction, collision and uplift processes were simulated while considering the regional tectonic evolution process. The tectonic evolution periods were divided, and the Paleoproterozoic tectonic evolution model map was comprehensively compiled.

3 Data Content Review

The 1∶50 000 Geological Map Database of Dongliumafang Map-sheet is mainly composed of basic feature class, complex class, object class and independent feature data.

3.1 Basic Feature Class

This map contains seven kinds of basic feature data, namely geological polygon, geological boundary line, attitude, sample, photograph, isotopic age, and river-lake-sea-water coastline.

There are 550 entities in “geological polygon”, and their attributes include the following contents: geological polygon identification number (composed of type, map-sheet number and data code in the area); geological polygon feature type (geological code); geological polygon name; geological polygon era; and other attributes (Table 2).

“Geological boundary line” has a total of 1367 entities, and its attributes include the following contents: feature identification number; geological boundary line (contact) code (geological code); boundary name; code of geobody on the left side of the boundary or

Table 2 Attribute table of geological polygon in the geological map of Dongliumafang map-sheet

Serial number	Data item	Standard code	Data type	Examples
1	Geological polygon identification number	FEATURE_ID	String	AK50E023002000003234
2	Geological polygon feature type (geological code)	FEATURE_TYPE	String	Jx_1g^1
3	Geobody polygon name	GEOBODY_NAME	String	1^{st} Member of Gaoyuzhuang Formation of Lower Jixian System
4	Geobody polygon era	GEOBODY_ERA	String	Jx_1

hangingwall; code of geobody on the right side of the boundary or hangingwall; strike; dip direction; and dip angle (Table 3).

"Attitude" has 214 entities, and its attributes include the following: feature identification number; attitude type code; attitude name; strike; dip direction; and dip angle (Table 4).

"Sample" contains 56 entities, and its attributes include the following: feature identification number; sample code; sample type code; sample name; and rock name (Table 5).

"Photograph" has 822 entities, and its attributes include the following: feature identification number; photograph code; photograph title; and photograph note (Table 6).

"Isotopic age" has a total of nine entities, and its attributes include the following: feature identification number; sample code; sample name; age measuring method; age; unit and code

Table 3 Attribute table of geological boundary in the geological map of Dongliumafang map-sheet

Serial Number	Data item	Standard code	Data type	Examples
1	Feature identification number	FEATURE_ID	String	AK50E023002000005998
2	Geological boundary line (contact) code (geological code)	FEATURE_TYPE	String	11
3	Boundary name	BOUNDARY_NAME	String	Intrusive contact
4	Code of geobody on the left side of the boundary or hangingwall	LEFT_UNIT_CODE	String	Pt_1N^2
5	Code of geobody on the right side of the boundary or hangingwall	RIGHT_UNIT_CODE	String	$\beta\mu Pt_2$
6	Strike/°	STRIKE	Integer	280
7	Dip direction/°	DIP_DIRECTION	Integer	10
8	Dip angle/°	DIP_ANGLE	Integer	36

Table 4 Attribute table of attitude in the geological map of Dongliumafang map-sheet

Serial number	Data item	Standard code	Data type	Examples
1	Feature identification number	FEATURE_ID	String	AK50E023002000001878
2	Attitude type code	FEATURE_TYPE	String	3
3	Attitude type name	ATTITUDE_NAME	String	Gneissic foliation
4	Strike/°	STRIKE	Integer	60
5	Dip direction/°	DIP_DIRECTION	Integer	330
6	Dip angle/°	DIP_ANGLE	Integer	45

Table 5 Attribute table of sample in the geological map of Dongliumafang map-sheet

Serial number	Data item	Standard code	Data type	Examples
1	Feature identification number	FEATURE_ID	String	AK50E023002000000241
2	Sample code	SAMPLE_CODE	String	D9001_1
3	Sample type code	FEATURE_TYPE	String	b
4	Sample name	SAMPLE_NAME	String	b Section
5	Rock name	ROCK_NAME	String	Grey-black medium-fine-grained hornblende-plagioclase-pyroxene granulite

Table 6 Attribute table of photograph in the geological map of Dongliumafang map-sheet

Serial number	Data item	Standard code	Data type	Examples
1	Feature identification number	FEATURE_ID	String	AK50E023002000003309
2	Photograph code	SOURCE_ID	String	D7603_2
3	Photograph title	SAMPLE_CODE	String	Interbedded dolomite and purplish red shale
4	Photograph note	PHOTO_TITLE	String	Macrogeological characteristics of rock association of Dahongyu Formation

of measured geobody; measuring and analysing unit; and measuring and analysing date (Table 7).

There are 32 entities in the "river-lake-sea-water coastline", with the following attributes: feature identification number; feature type; and feature name (Table 8).

Table 7 Attribute table of isotopic age in the geological map of Dongliumafang map-sheet

Serial number	Data item	Standard code	Data type	Examples
1	Feature identification number	FEATURE_ID	String	AK50E0230020 0000 0001
2	Sample code	SAMPLE_CODE	String	TW8040_1
3	Sample name	SAMPLE_NAME	String	Grey-white medium-fine-grained pyroxene–magnetite quartzite
4	Age measuring method	MEASURING_KINDS	String	Zircon U–Pb
5	Age	AGE	String	2 480±24 Ma(D)/1847±15 Ma(M)
6	Unit and code of measured geobody	GEOBODY_CODE	String	Ar@3y.$ibr
7	Measuring and analysing unit	UNIT	String	Isotope Laboratory of Tianjin Center, China Geological Survey
8	Measuring and analysing date	FEATURE_ID	String	November 14, 2017

Note: @ indicates subscript; $ denotes superscript.

3.2 Complex Feature Class

This map only contains two kinds of complex feature data: metamorphic facies belt and standard frame (internal map frame).

The "metamorphic facies belt" consists of 282 entities, with the following attributes: feature identification number (composed of type, map number and data number in the area); geobody code in metamorphic facies zone; metamorphic facies zone type; metamorphic type; metamorphic degree; metamorphic temperature-pressure conditions; rock name of metamorphic facies zone; rock color of metamorphic facies zone; rock texture of metamorphic facies zone; rock structure of metamorphic facies zone; and mineral association and content of metamorphic facies zone (Table 9).

"Standard frame (internal map frame)" has four entities, with the following attributes: map name; sheet code; scale; coordinate system: height system; left longitude; lower latitude;

Table 8 Attribute table of river-lake-sea-water coastline in the geological map of Dongliumafang map-sheet

Serial Number	Data item	Standard code	Data type	Examples
1	Feature identification number	FEATURE_ID	String	AK50E023002000000021
2	Feature type	FEATURE_TYPE	String	21 010
3	Feature name	FEATURE_NAME	String	Perennial river

Table 9 Attribute table of formation-structure layer in the geological map of Dongliumafang map-sheet

Serial Number	Data item	Standard code	Data type	Examples
1	Feature identification number	Feature_Id	String	AK50E023002000002742
2	Geobody code in metamorphic facies zone	Feature_Type	String	$Ar_3gn^{\gamma\delta o}$
3	Metamorphic facies zone type	META_MORPHIC_TYPE	String	Granulite facies
4	Metamorphic type	META_TYPE	String	Regional medium-high temperature metamorphism
5	Metamorphic degree	META_DEGREE	String	High-grade
6	Metamorphic temperature-pressure conditions	TP_CONDITION	String	Medium pressure and high temperature
7	Rock name of metamorphic facies zone	ROCK_NAME		(Biotite) tonalitic gneiss
8	Rock color of metamorphic facies zone	COLOR		Grey-white, grey-yellow
9	Rock texture of metamorphic facies zone	ROCK_TEXTURE		Lepido-granoblastic texture
10	Rock structure of metamorphic facies zone	ROCK_STRUCTURE	String	Gneissic or banded structure
11	Mineral association and content of metamorphic facies zone	ASSOCIATION		60%–65% plagioclase, less than 5% perthite and 10%–16% biotite

and coordinates unit (Table 10).

3.3 Object Class Data

This map-sheet contains 49 object class data, which are divided into 7 types, namely: sedimentary (volcanic) stratigraphic unit (STRATA); informal stratigraphic unit (INF_STRATA); intrusive rock lithochronological unit (INTRU_LITHO_CHRONO); dike (area) (_DIKE_OBJECT); fault (FAULT); metamorphic rock stratigraphic (formation) unit (METAMORPHIC); and basic information of map-sheet (_SHEET_MAPINFO).

3.4 Independent Feature Class

The independent feature class in this map-sheet includes sedimentary rock columnar section, cutting profile, legend, index map, duty table, and columnar section of structural-lithostratigraphic unit, columnar section of intrusive rock evolution sequence table, structural outline map, high-pressure basic granulite and P–T path map, metamorphic facies division map, Paleoproterozoic tectonic evolution model map, geotectonic location map of the survey area, map name, emblem of the China Geological Survey, and scale.

4 Data Quality Control and Evaluation

During the construction of the 1 ∶ 50 000 Geological Map Database of Dongliumafang Map-sheet, the technical standard for geological survey "Digital Geological Map Spatial Database" (DD 2006-06) issued by the China Geological Survey was strictly implemented. Specific quality monitoring measures include:

(1) Process monitoring: after each step was completed, the database developers would carry out 100% self-examination and the project team shall carry out 100% mutual inspection, mainly checking the correctness of the edge connection attribute and the topological relationship, the completeness of map-sheet presentation after being input into the database, as well as the correctness of attribute, surface element color, and filling pattern according to legend and map layer.

(2) Attribute data check: checking the standardization degree of layer naming, the completeness of the layer attribute table, the completeness of records, the accuracy of attribute

Table 10 Attribute table of standard map frame in the geological map of Dongliumafang map-sheet

Serial Number	Data item	Standard code	Data type	Examples
1	Map name	MAP_NAME	String	Dongliumafang
2	Sheet code	SHEET_CODE	String	K50E023002
3	Scale	SCALE	String	50 000
4	Coordinate system	COORDINATE_SYSTEM	String	China Geodetic Coordinate System
5	Height system	HEIGHT_SYSTEM	String	Yellow Sea Height System
6	Left longitude	LEFT_LONGITUDE	String	1 141 500
7	Lower latitude	LOW_LATITUDE	String	401 000
8	Coordinates unit	COORDINATES_UNIT	String	mm

code, the correctness of attribute format, the data item content, and the correlation between graphic elements and attributes. During the construction of the database, multi-level and multi-stage quality inspection and supervision were carried out to ensure data accuracy.

(3) Map surface quality inspection: geological experts were engaged to conduct over three examinations of the notes of the internal and external finishing parts of the full-feature color inkjet geological map output by MapGIS, the standardization of sub-maps, the color of the geological map, overlapping relation, and the drawing of corner maps, etc.

The 1∶50 000 Geological Map of Dongliumafang Map-sheet was rated as an excellent map in the "2018 National Exhibition and Evaluation Conference on Excellent Maps of Regional Geological Survey" of the China Geological Survey.

5 Data Value

The 1∶50 000 Geological Map Database of Dongliumafang Map-sheet is based on previous regional geological surveys and research work, and adopts innovative mapping techniques for metamorphic rock areas, achieving the following results: (1) the early Precambrian metamorphic supracrustal rock stratigraphic units in the investigation area have been re-determined; the Yanggao Formation of the Neoarchean Sanggan Rock Group and the Huangtuyao Formation of the Paleoproterozoic Jining Rock Group have been identified, and four lithologic segments have been further divided (Table 11; Zhang JH et al., 2019a, 2019b; Tian H et al., 2019). (2) the early Precambrian metamorphic plutons have been classified into various mapping units, i.e., Neoarchean two-pyroxene quartz dioritic gneiss, (biotite) tonalite dioritic gneiss, charnokite trondjemitic gneiss, monzonitic gneiss and gneissic monzonitic granite, and Paleoproterozoic garnet monzonitic granite, dike-type high-pressure basic granulite and two-pyroxene granulite (Table 12). (3) the Mesoproterozoic sedimentary stratigraphic sequence in the survey area has been established, with two mapping units identified, namely the Dahongyu Formation of the Changcheng System and the Gaoyuzhuang Formation of the Jixian System. (4) three magmatic events of the Late Triassic, Late Jurassic and Early Cretaceous were newly recognized and a Mesozoic magmatic evolution sequence was established. (5) two types of high-pressure granulites with different protolith properties have been determined, namely, Paleoproterozoic mafic dike-type granulite and basic volcanic-rock-type granulite (Table 13; Zhang JH et al., 2019c), providing basic data for the study of Paleoproterozoic orogenic belts. (6) three tectonic layers of the early Precambrian, Mesoproterozoic and Mesozoic-Cenozoic have been newly determined, the characteristics and periods of the tectonic deformation of each tectonic layer have been investigated in detail, and the tectonic evolution framework of the Paleoproterozoic has been preliminarily established. (7) The mapping unit approach characterized by “diagnostic metamorphic mineral+rock association (protolith lithology)+structure” in high-grade metamorphic rock areas has been preliminarily established, and the research methods and identification marks of metamorphic plutonic rocks and metamorphic supracrustal rocks have been systematically reviewed.

The main features of the 1∶50 000 Geological Map Database of Dongliumafang Map-

Table 11 Tectonic-stratigraphic unit division of early Precambrian metamorphic supracrustal rocks in the Dongliumafang map-sheet area at the junction of Shanxi, Hebei and Inner Mongolia

Era	Tectonic lithostratigraphy			Code name	Rock association	Original rock property	Distribution area	Attitude	Age/Ma	Minerals
Paleoproterozoic	Jining Group	Huangtuyao Formation	Graphite-sillimanite-bearing garnet-biotite gneiss-leptynite-marble member	$Pt_1h.^{ggm}$	Dominated by graphite-sillimanite-garnet-bearing K-feldspar/monzonitic gneiss, graphite-sillimanite-bearing K-feldspar leptynite and diopside marble, with partially distributed garnet quartzite, calcium magnesium silicate rock and leucoleptite.	Clay-rich feldspathic sandstone formation with a small amount of carbonate rock and quartz sandstone	Mainly distributed in the Zhoujiashan-Zhujiagou-Shijiazhuang area, Ximagou-Lianhuashi and Lengjiagou-Dongjianchanggou	Banded tectonic sheet	Detrital zircon: 1988–2300; Metamorphic zircon: 1827–1837	Graphite ore
			Garnet high-pressure granulite-marble member	$Pt_1h.^{gm}$	High-pressure basic granulite, graphite-bearing diopside/serpentined marble, two-pyroxene amphibolite, biotite sillimanite garnet monzonite gneiss	Bedrock volcanic rock mixed with carbonate rock (oceanic crust combination), containing small amounts of clastic rock	Mainly distributed in Xizhaojiayao	Tectonic slice	Crystallization age:>2 026	

Continued table 11

Era	Tectonic lithostratigraphy			Code name	Rock association	Original rock property	Distribution area	Attitude	Age/Ma	Minerals
Neoarchean	Sanggan Group	Yanggao Formation	Garnet-biotite gneiss member	$Ar_3y.^{sg}$	Mainly (banded) garnet biotite plagioclase gneiss, and garnet-bearing plagioclase granulite	Clay-bearing sandstone formation	With outcrops across the whole region, mainly distributed from Heishishan to the north of Tuanshan village	Striped, banded or lenticular	Detrital zircon:–2522; Metamorphic zircon:–2471;1831–1838	
			Two-pyroxene granulite-itabirite member	$Ar_3y.^{ibr}$	Dominated by meta-basic rocks (two-pyroxene granulite), intercalated with banded two-pyroxene magnet quartzite and partially containing garnet biotite plagioclase gneiss	The basic volcanic rocks are mixed with magnet quartzite and contain a small amount of terrigenous clastic rocks	With small-scale outcrops widely distributed across the whole region	Lenticular, partially striped	Crystallization age: ~2489; Metamorphic age:~1807	Algoma-type banded iron formation (BIF)

Table 12　Characteristics of metamorphic plutonic rocks in Tianzhen-Huai'an area

Era	Lithology	Code name	Structural hierarchy	Mineral association	Weathered appearance	Degree of metamorphism	Zircon Isotopic Age/Ma			Attitude	Magmatic series	Tectonic setting	
							Inherited Age	Protolith age	Metamorphic age				
Paleoproterozoic	Granite pegmatite	$Pt_1\gamma\rho$	Shallow part	Quartz + plagioclase + microcline + perthite + biotite	Meat red	Not metamorphised		1809±9, 1797±14		Dike	High-K calc-alkaline series	Paleoproterozoic orogenic cycle	Consolidation and cooling
	Adamellite dike	$Pt_1\eta\gamma$	Middle-Shallow	Quartz + plagioclase + perthite	Meat red	Amphibolite facies	2429–2497	1844±17, 1846±13		Dike			Collision and uplift
	Two-pyroxene granulite or two-pyroxene plagioclase granulite	Pt_1N^2	Middle-Deep	Hypersthene + diopside + plagioclase + hornblende + biotite	Grey-black	Granulite facies-amphibolite facies		~1918(?)	1820±10, 1834±9	Dike or lenticular	Tholeiite series		
	Garnet hornblende two-pyroxene granulite	Pt_1N^1	Deep	Garnet + hypersthene + diopside + plagioclase + hornblende + magnetite±biotite±quartz	Grey-black	High pressure granulite facies-granulite facies-amphibolite facies		2250–2200 (?)	1957±23, 1909±12, 1836±18	Dike or pudding-like, lenticular	Tholeiite series		Collision and thickening
	Garnet granite	$Pt_1g\eta\gamma$	Middle-Shallow	Quartz + plagioclase + microcline + perthite± magnetite	Meat red	Granulite-amphibolite facies		2031±21	1837±12	Stock	A type granite		Intracontinental cleavage

Continued table 12

Era	Lithology	Code name	Structural hierarchy	Mineral association	Weathered appearance	Degree of metamorphism	Zircon Isotopic Age/Ma			Attitude	Magmatic series	Tectonic setting
							Inherited Age	Protolith age	Metamorphic age			
Late stage of Neoarchean	Gneissic adamellite	$Ar_3\eta\gamma$	Middle-Shallow	Quartz + plagioclase + striped feldspar + biotite	Meat red	Amphibolite facies		2472±10, 2486±21, 2448±9	1885–1833	Stock, dike	High-K calc-alkaline G2 series	Neoarchean cratonization Magmatic arc
	Biotite monzonitic granitic gneiss	$Ar_3gn_{\beta\eta\gamma}$		Quartz + plagioclase + perthite + biotite	Meat red			2440±30	Narrow metamorphic edge	Rock mass		
	Charnokite-bearing trondjemitic gneiss	$Ar_3gn_{\nu\gamma o}$	Central	Quartz + plagioclase + hypersthene±hornblende + biotite (dark mineral ≤ 5%)	Grey-white	High amphibolite facies-granulite facies		2492±18	Narrow metamorphic edge	Gradual transition exists between rock masses, featuring smooth tectonic contact relation	DTT Series	
	Tonalite dioritic gneiss	$Ar_3gn_{\gamma\delta o}$	Middle-Deep	Quartz + plagioclase + biotite±hypersthene± hornblende	Grey-white	Granulite facies		2476±10, 2474±18, 2473±16, 2466±13, 2459±13	Narrow metamorphic edge			
	Charnokite tonalite dioritic gneiss	$Ar_3gn_{\nu\gamma\delta o}$		Quartz + plagioclase + hypersthene±hornblende±biotite	Grey-black			2497±25,–2525	1858±18			
	Two-pyroxene quartz diorite gneiss	$Ar_3gn_{\psi\delta o}$		Quartz + plagioclase + hypersthene + diopside±hornblende±biotite	Grey-black			2480–2515	1822±42,1843±28			

Table 13 Characteristics of two types of high-pressure basic granulites in Tianzhen-Huai'an area

Era	Type	Lithology	Mapping Unit	Metamorphic degree	Protolith property	Age	Attitude relationship	Distribution
Paleoproterozoic	Type II	high-pressure basic granulite	$Pt_1h.^{gm}$	HT-HP granulite facies (peak period), granulite facies-amphibolite facies (retrogressive)	Basic volcanic rock	Protolith age: 2.15–2.2 Ga (?);Metamorphic age: 1.82–1.83 Ga	Associated with marble and metamorphic argillaceous-sandy clastic rocks	Exposed in the area of Xizhaojiayao village
	Type I		Pt_1N^1		Mafic dike, basic lens	~2.2Ga(?)Metamorphic age: ~1957 Ma; 1850–1867 Ma	Exists in metamorphic plutonic rock bodies in lenticular or vein-like form	With small-scale outcrops widely distributed across the whole region

sheet are as follows: the early Precambrian metamorphic basement features rheological structural style and is represented by dashed flow line; for the Paleoproterozoic metamorphic supracrustal rocks and Neoarchean metamorphic plutonic rocks, structural contact relation is adopted, marked by red lines; the BIF interlayer in the Neoarchean Yanggao Formation is represented by orange thick lines; the stable sedimentary cover area in the Mesoproterozoic is represented by dolomite stratigraphic patterns; on both sides of the geological map, structural outline, metamorphic facies map and petrographic characteristics of high-pressure basic granulite (diagnostic rock type) as well as P-T path map are added, further enriching map contents. The research result of the map-sheet can provide useful references for scientific research and geological and mineral survey, while the adopted expression methods may serve as an example for mapping in metamorphic rock areas.

6 Conclusion

(1) The 1∶50 000 Geological Map of Dongliumafang Map-sheet (K50E023002) at the Junction of Shanxi, Hebei and Inner Mongolia is one of the excellent maps compiled according to the technical requirements and specifications for regional geological survey newly issued by the China Geological Survey. It adopts modern mapping concepts and mapping expression methods for metamorphic rock areas, providing an example for mapping of high-grade metamorphic rock areas.

(2) In accordance with the work flow of digital mapping, the 1∶50 000 Geological Map Database of Dongliumafang Map-sheet (K50E023002) was systematically compiled, which possesses the processing functions of query, retrieval, hierarchical extraction, splicing and clipping, scaling and engineering output, and can be used as a basic database for compiling geological maps and thematic maps of various scales.

(3) The map offers a detailed division and definition of the Neoarchean-Cenozoic strata, magmatic rocks, metamorphism and structures in the area: it has established four structural-lithostratigraphic units of the Neoarchean Sanggan Group and the Paleoproterozoic Jining Group, and 13 stratigraphic units of the Mesoproterozoic-Cenozoic era; it has established the evolution sequence of Neoarchean-Paleoproterozoic and Mesoproterozoic-Mesozoic (metamorphic) intrusive rocks; and identified three periods of early Precambrian structural deformation style and the fracture structure of the Mesozoic-Cenozoic Indosinian, Yanshanian and Himalayan periods. Moreover, it has identified two types of high-pressure basic granulites with different protolith properties and metamorphic periods. The research results can provide basic geological data for geological prospecting and scientific research.

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Notes:

❶ Regional Geological Survey Brigade of Shanxi Province. 1969. 1：200 000 Datong Geological Map Manual (Internal Data).

❷ Regional Geological Survey Brigade of Hebei Province. 1970. 1：200 000 Tianzhen Map-sheet Geological Map Manual (Internal Data).

❸ Regional Survey Institute of Hebei Institute of Geological Survey. 2008. 1：250 000 Zhangjiakou City Map-sheet Regional Geological Survey Report (Internal Data).

❹ Shanxi Institute of Geological Survey. 2014. 1：250 000 Datong City Map-sheet Regional Geological Survey Report (Internal Data).

❺ Regional Survey Team of Shanxi Provincial Geological and Mineral Prospecting Bureau. 1996. Report on Regional Geological Survey of 1：50 000 Yanggao Survey Area (Internal Data).

❻ Shanxi Institute of Geological Survey. 2014. 1：50 000 Tianzhen Survey Area Geological Report (Internal Data).

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