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城市地下空间资源综合利用实践——以成都市地质环境图集(2017) 数据集为例

王东辉　倪化勇　李鹏岳　郝明

(中国地质调查局成都地质调查中心，四川 成都 610081)

摘要：在全面收集地质和工程勘察资料基础上，系统梳理了成都市地下空间资源综合利用需要防范关注的 7 类地质问题以及需要统筹保护的 4 类地质资源。根据城市地下空间资源综合利用约束性地质要素（地质问题、地质资源）和地质结构在垂向上的差异，将成都市 0～200 m 地下空间划分为 0～30 m、30～60 m、60～100 m、100～200 m 4 个层位，在此基础上，提出了成都市地下空间分区、分层开发利用建议，编制了《支撑服务成都市地下空间资源综合利用地质环境图集》。图集范围覆盖成都市中心城区、高新西区、高新南区、国际生物城、天府新区成都直管区、天府空港新城、简州新城、淮州新城等重点地区，包括 39 张图件和 1 个地质调查报告。图集为成都市城市地下空间综合利用、城市空间优化拓展、城市功能品质提升以及国土空间开发、空间转型升级和城市集约、绿色、可持续发展提供了地质依据，对于全国其他城市开展同类图集编制具有示范和借鉴意义。

关键词：城市地质；地下空间；地质问题；地质资源；编图；城市地质调查工程；成都市；四川省

数据服务系统网址：http://dcc.cgs.gov.cn

1　引言

党的十八大明确提出要建设新型城镇化国家，随着城市建设明显提速，城市扩张、人口剧增等所带来的系列问题，城市化对资源环境消耗和衍生问题，社会发展不平衡不充分带来的空间分配和利用问题都给城镇化发展带来严峻的挑战（孙利萍等，2018）。科学、有序、高效、协同开发利用地下空间，统筹地上、地表、地下空间资源利用，是应对系列城市问题的重要措施之一（王成善等，2019；李晓昭等，2019；杨文采等，2019；郭朝斌等，2019；Chen ZL et al., 2018; Zacharias J and He J, 2018）。大力推进城

第一作者简介：王东辉，男，1982 年，高级工程师，硕士，从事水工环、城市地质调查相关工作；E-mail：16216813@qq.com。

市地质调查，查明城市地上、地表、地下空间资源环境地质问题，是保障城市高质量发展、安全发展的重要基础性工作（林良俊等，2017；Andersen TR et al., 2017）。

近些年来，以上海、北京、杭州、徐州、丹阳等城市为代表的城市地质调查工作为城市绿色发展、安全发展，国土资源管理和城市规划建设等提供了重要支撑。但是，传统地质成果图件表达方式、表达内容等依然存在专业性强、可读性弱，地质数据丰富、系统性建议不足等问题。探索全新的成果表达形式，编制一套科学的决策用图，是推动城市地质工作系统服务城市行政管理的重要举措。

成都是中国西部地区重要的中心城市，正在实施“东进、南拓、西控、北改、中优”的城市空间发展新战略，构建“双核联动、多中心支撑”网络化功能体系，加快建设全面体现新发展理念的国家中心城市。科学评价城市地下空间资源对优化成都市城市规划布局和国土空间开发、实现空间转型升级和城市集约、绿色，可持续发展具有重要作用。

为了支撑服务成都市城市地下空间资源开发利用总体规划编制和实施，提升成都市城市地下空间资源开发利用地质环境条件和问题认识，中国地质调查局与成都市人民政府联合启动了“成都市城市地质水平和城市地下空间资源地质调查项目”。本图集为项目实施的前期预研究成果，主要目的是系统梳理成都市地下空间资源综合利用资源环境地质条件、需要防范关注的重大地质问题、需要统筹保护的关键地质资源，为深入开展调查评价工作提供指导，为开展成都市城市地下空间总体规划提供地质支撑。图集的编图区范围见图 1。

图集由序图、城市地下空间资源分区分层综合利用地质建议、0 ~ 30 m 地下空间资源综合利用地质建议、30 ~ 60 m 地下空间资源综合利用地质建议、60 ~ 100 m 地下空间

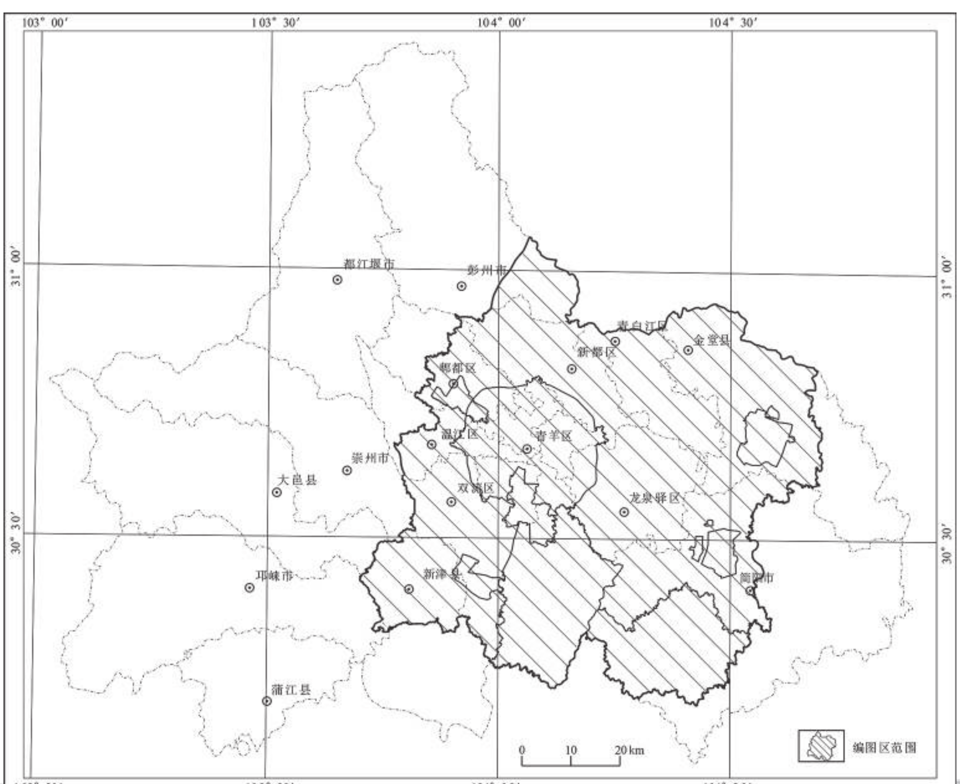

图 1　编图范围示意图

资源综合利用地质建议、100 ~ 200 m 地下空间资源综合利用地质建议、基础地质支撑条件、附件等 8 个部分构成，共计 39 张专业图件和 1 个地质调查报告。图集数据库的元数据简表如表 1 所示。

2 数据采集和处理方法

2.1 数据基础

图集以成都市 2017 年以前已有地质和工程勘察资料为基础，包括区域地质背景类、城市建设规划类、地质勘查类 3 大类约 155 份资料（表 2）。

表 1 数据库 (集) 元数据简表

条目	描述
数据库（集）名称	支撑服务成都市地下空间资源综合利用地质环境图集（2017）数据集
数据库（集）作者	王东辉，中国地质调查局成都地质调查中心 倪化勇，中国地质调查局成都地质调查中心 郭子奇，中国地质调查局成都地质调查中心 王春山，中国地质调查局成都地质调查中心 李鹏岳，中国地质调查局成都地质调查中心 陈绪钰，中国地质调查局成都地质调查中心 唐业旗，中国地质调查局成都地质调查中心 李胜伟，中国地质调查局成都地质调查中心
数据时间范围	2017
地理区域	东经102°54′ ~ 104°53′、北纬30°05′ ~ 31°26′
数据格式	shp、png
数据量	4 GB
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“成渝经济区宜宾-万州沿江发展带1：50 000环境地质调查”（DD20160249）、“成都多要素城市地质调查”（DD20189210）
语种	中文
数据库（集）组成	本图集包含基础地理类、地质剖面类、专题类及地质调查报告附件4大类空间图层: 1. 基础地理类图层：编图区乡镇、成都市机场、成都市县界、高速、国道、省道、四川省地级市、四川省会、四川省市界、四川省县、四川水系、铁路、乡镇。 2. 地质剖面类图层：地铁1号线、地铁2号线、地铁7号线、30 ~ 60 m C-C’剖面图、100 ~ 200 m C-C’剖面图、60 ~ 100 m D-D’剖面图、100 ~ 200 m D-D’剖面图、60 ~ 100 m E-E’剖面图、B-B’剖面综合建议图、C-C’剖面综合建议图。 3. 专题类图层：0 ~ 30 m适宜性、30 ~ 60 m适宜性、30 ~ 60 m相对隔水层分布区、60 ~ 100 m含膏盐泥岩分布区、60 ~ 100 m基岩含水层分布区、60 ~ 100 m适宜性、60 ~ 100 m微咸水分布区、60 ~ 100 m优质水源地分布区、100 ~ 200 m含膏盐泥岩分布区、100 ~ 200 m基岩含水层、100 ~ 200 m适宜性、100 ~ 200 m微咸水分布区、100 ~ 200 m下部含水层、成都市地质灾害、地层、地层产状、地埋管地源热泵潜力评价、地下水水源热泵潜力评价、地貌分区、地下水富水性分区、地震、地震动峰值加速度区划、地质遗迹、第四系厚度等值线、第一隔水层底板埋深等值线、断裂、富水砂砾石分布区、工程地质分区、轨道交通、含膏盐泥岩分布区、环城生态带、活动断裂、夹关组分布区、矿泉水、芒硝厂区、膨胀性黏土分布区、平原区相对隔水层分布区、软土分布区、生态涵养区、瓦斯分布区、微咸水分布区、文物古迹、优质水源地分布区、综合适宜性分区。 4. 附件：支撑服务成都市城市地下空间资源综合利用地质调查报告（2017）

表 2　主要数据基础简表

类	亚类	主要内容	资料来源
区域地质背景类	基础地质类	1∶200 000、1∶250 000区域地质调查成果	朱兵等，2013
	水文地质类	地下水资源评价、水文地质普查及1∶200 000、1∶500 000区域水文地质调查成果	李永健等，2002；黄荣开等，1977；刘云从等，1978；李家康等，1977；徐启彬等，1977
	环境地质类	水工环综合勘查、矿山地质环境调查、地下水污染调查、城市群环境地质调查、地质环境监测、地质灾害调查等成果	汪天寿等，2005；刘俊贤等，1990
	地球化学类	多目标地球化学调查、土地质量地球化学调查等成果	刘应平等，2002
	资源类	地热、浅层地热能、地下水调查评价成果，文物古迹、公园湿地等资料	刘俊贤等，1990；杨明等，2013
城市建设规划类	气象水文类	气候、降水、水文等资料	
	城市社会经济现状	城市规模、人口、社会经济发展等资料	
	城市规划建设现状	城市总体规划、重大工程建设规划、轨道交通规划等资料	
	城市土地利用现状	多期遥感影像图及解译成果、土地三调成果	
	城市地下空间开发利用现状	地铁、地下商场、人防工程、地下管线等资料	
地质勘查类	岩土工程勘察类	桥梁、地铁、房屋等建设工程岩土工程勘查成果，含钻探、基坑及相应的测试成果，约3 000个钻孔。	
	水源地勘查类	水文地质钻探成果、水质分析成果，约160个钻孔	
	油气勘查类	钻探、二维地震成果，4个钻孔	
	物探类	重力、磁法、电法、地震等综合研究成果	

编图用矢量 (栅格) 文件数据库以各种基础地理要素为数据基础，在充分收集最新数据的情况下，经过一致化处理，利用 ArcGIS 软件进行数据入库，完成数据库的制作。

资料主要来自于成都地质调查中心、成都市规划和自然资源局、四川省地质调查院、四川省地质勘查开发局成都水文地质工程地质队、四川省地质勘查开发局成都水文地质工程地质中心、四川省煤田地质工程勘察设计研究院、四川省煤田地质局成都兴蜀勘察基础工程公司、中国地质调查局探矿工艺研究所、成都理工大学、全国地质资料馆、成都市国土资源局、四川省地质资料馆、四川省地质环境监测总站、成都市规划管理局、成都市城建档案馆、成都市防震减灾局、成都轨道交通有限公司、中铁二院工程集团有限责任公司、中国建筑西南勘察设计研究院有限公司。

2.2　数据处理过程

2.2.1　数据准备

将收集到的区域地质背景、城市建设规划、地质勘查类资料进行分类整理，形成平面类、剖面类、点类、插图类资料。其中平面类图件投影系统为高斯-克吕格投影参数，18 度带投影，坐标系统为西安 80。

2.2.2 数据整理过程

（1）将收集到的平面类资料进行数字化整理，并进行一致化处理，统一形成 shp 格式的矢量文件。

①数据格式一致化处理：将不同类型、不同格式的平面类数据统一转换为 ArcGIS 软件的 shp 格式。

②坐标系一致化处理：以多期遥感影像图及解译成果和土地三调成果为基准，将收集到的坐标系不一致各类文件进行坐标系一致化处理，统一投影为西安 80，18 度带，高斯-克吕格投影参数。

③属性一致化处理：将收集资料进行属性分类整理，对属性命名和数据类型重新梳理，形成全区一致、各图件通用的属性格式。

（2）运用 AutoCAD、CorelDRAW 等可生成交换文件格式的软件，对收集到的剖面资料进行拼接、再处理，形成具有属性的点、线、面文件，并转换为 shp 矢量文件。

（3）对区内重要的点状资料进行 EXCEL 整理，数据须包含坐标、点数据说明等内容。

（4）对重要的地质现象、经典的地质剖面等照片类资料，进行数字重绘，形成不低于 300 dpi 的 png 格式文件。

2.2.3 图集编制过程

以“资料开发+钻孔标准化+地质条件分析”为编制基础。在《图集》编制过程中，全面收集分析了编图区域内已有的 155 份地质调查资料，并进行了系统整理与二次开发；选取 6 500 余个勘察钻孔成果进行了标准化，绘制了多条纵横交错的区域性控制剖面，初步建立了编图区 200 m 以浅三维地质格架（Zhou D et al., 2019；何静等，2019），形成了对不同地貌单元之间地质结构横向分区差异性以及同一地貌单元内部地质结构垂向分层差异性的基本认识与编图基础，在横向上划分出平原、台地、低山、丘陵 4 个地貌分区，垂向上将 0 ~ 200 m 地下空间资源划分为 0 ~ 30 m、30 ~ 60 m、60 ~ 100 m、100 ~ 200 m 等 4 个层位（彭建兵等，2019）。

以“约束城市地下空间利用的地质结构、地质问题、地质资源”为表达要素，综合利用地质条件、地质资源和地质问题分析成都市地下空间资源的禀赋条件，系统梳理出成都城市地下空间资源综合利用的约束性要素，并将其分为两类：一是需要防范关注的地质问题（黄强兵等，2019；胡志平等，2019；周圆心等，2019），二是需要统筹保护的资源（王婉丽等，2017）。

以“地下空间开发利用地质适宜性宏观评价”为表达核心，依据成都地下空间开发利用存在的地质问题和资源的分布、约束程度，对成都城市地下空间开发利用适宜性进行了分区分层评价（江思义等，2019；蒋旭等，2018；郝爱兵等，2018；吴炳华等，2017；张晶晶等，2016；张璐等，2014；张平和肖宇，2014；柳昆等，2011）。并在此基础上结合开发利用方式，提出了成都地下空间分区分层综合利用建议。

以“横向分区和垂向分层相结合”为表达方式，充分结合成都市城市规划和地质地貌单元以及水文地质条件、工程地质岩组以及地质问题、资源的空间分布，采用平面图和剖面图相结合的方式，简洁、直观地表达出平面上的 4 个地貌分区以及垂向上 4 个层位在地下空间利用中存在的地质问题、资源、适宜性和开发利用方式（Darroch N et al., 2018；Chen XS, 2018）。

3 数据样本描述

3.1 数据格式

地下空间开发利用地质建议图.mxd，早更新世活动断裂.shp，编图区地形.tif。

3.2 图层内容

图层主要包括遥感影像图、基础地理图、专题图以及剖面类图 4 个部分，各个图层包含其所有的要素图层（表 3）。

表 3 图层内容分类汇总表

分类	要素	要素内容	表达内容
遥感	遥感	遥感影像、地形阴影	植被、生态、建筑、水系等变化情况
地理要素	交通	铁路、高速、省道、国道、	交通线路分布
	行政区划	地级市、县、乡镇、行政区边界、发展布局规划	各行政区界线及发展布局规划
	水系	水系，湖泊	河流、湖泊
专题图	地质资源	文物古迹、矿泉水点、地质遗迹、优质水源、砂砾石厚度等值线，地埋管地源热泵分区、地下水水源热泵潜力评价	各类地质资源空间分布
	地质问题	地下水污染状况、地质灾害、断层、含膏岩泥岩等值线、成都黏土、软土、含瓦斯地层	各类地质问题空间分布
	地质建议	0 ~ 30 m/30 ~ 60 m/60 ~ 100 m/100 ~ 200 m地下空间开发利用地质适宜性	地下空间开发利用地质适宜性
剖面图	构造	断裂构造、褶皱、背斜	构造形态
	地铁	地物、地下工程、监测点，换乘站，地下地铁线路、地铁运用地质建议	地铁空间展布、运营地质建议、监测点分布

3.3 数据属性

ArcGIS 中每个图层都需要有相对应的文件和属性表，文件一般分为点文件、线文件、面文件、栅格文件，属性表分为遥感类属性、地理要素属性、专题图层属性和剖面图属性表（表 4）。

4 数据质量控制和评估

以多期遥感影像图及土地三调成果为图件基础图层，设置基准参考点，对收集到的各类资料进行误差校正，保证图件套合精度，利用 ArcGIS 软件的数据库功能，对整理好的 shp 文件进行一一检验入库，完成数据库的构建。

5 结论

《图集》包括序图、地下空间资源综合利用地质建议、基础地质支撑条件和附件 4 大类内容，利用 ArcGIS 软件编制，包括.shp、.png 两种数据格式共 39 张图片。数据集由基础地理类、地质剖面类、专题类及地质调查报告 4 大类约 66 个空间图层组成。《图集》是全面实施“成都市城市地质和城市地下空间资源地质调查”项目的重要基础，在成都市地下空间开发利用规划编制过程中得到了具体应用。《图集》在编图思路、表达方式等方面进行了探索，对于全国其他城市开展同类图集编制具有示范和借鉴意义。

表 4　各要素主要属性内容

分类	要素	要素内容	要素主要属性内容
遥感	遥感	遥感影像、地形阴影	OID，Value，Count
地理要素	交通	铁路、国道、高速、省道、	Fid，shape*，PYNAME，NAME，MAPID，ID，KIND，SNODE_ID，ENODE_ID，FUNCCLASS，LENGTH，ADMINCODEL，SPEEDCLASS，VEHCL_TYPE，SPDLMTE2S，SPDSECS2e，SPDSRCE2S
	行政区划	地级市、县、乡镇、行政区边界、发展布局规划	Fid，shape*，NAME，PYNAME，MAPID，KIND，ZIPCODE，ADMINCODE，DISPLAY_X，DISPLAY_Y，ADDRESS，FID_县界，AREA，PERMIETER，BOUNT_，BOUNT_ID，GBCODE，ADCODE99，SH2，DI2，X2，CENTRIOD_Y，CENTROID_X，LCFLAG724，Shape_Leng，分区
	水系	水系，湖泊	Fid，shape*，MAPID，ID，长度，CODE，GB，HYDC，TN，NAME，KIND，ADMINCODE，AOICODE，DISPCLASS，XZQMC，KZMJ，JSMJ，ZXMC。
专题图	地质资源	文物古迹、矿泉水点、地质遗迹、优质水源、砂砾石厚度等值线，地埋管地源热泵分区、地下水水源热泵潜力评价	Fid，shape*，年代，地质，名称，类别；出水量，孔深(m)，矿泉水名，埋深，地貌区，适宜性分区，潜力
	地质问题	地下水污染状况、地质灾害、断层、含膏岩泥岩等值线、成都黏土、软土、含瓦斯地层	Fid，shape*，ID，统一编号，样品编号，经度，纬度，位置，类别，综合评价，备注；隐患点类型，规模等级；断层性质，产状倾角，倾向顶板埋深；代号，地质名称，标注
	地质建议	0 ~ 30 m / 30 ~ 60 m / 60 ~ 100 m / 100 ~ 200 m地下空间开发利用地质适宜性	Fid，shape*，适宜性
剖面图	构造	断裂构造、褶皱、背斜	Fid，shape*，ID，花纹，填充图案，要素，注释文字
	地铁	地物、地下工程、监测点，换乘站，地下地铁线路，地铁运营地质建议	Fid，shape*，ID，DXF图元名，DXF图层名，高程，注释文字

致谢：《支撑服务成都市地下空间资源综合利用地质环境图集（2017）》编制过程中，中国地质调查局副局长王昆、总工程师严光生和中国科学院王成善院士等多次听取汇报并提出了中肯的意见，得到了中国地质调查局水环部主任郝爱兵、副主任吴爱民的大力支持，水环部环境处林良俊、胡秋韵对数据的整理和图集的编制进行了具体的指导，在此深表谢意。同时，感谢葛文彬、刘俊贤、成余粮、钱江澎、赵松江、刘民生、刘树根等专家给予的技术指导，感谢具体参编单位、资料提供单位的鼎力相助。感谢审稿专家及编辑部在稿件修改中提出的宝贵意见。

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Practice in Comprehensive Utilization of Urban Underground Space Resources—Taking the Dataset of Geological Environmental Atlas of Chengdu (2017) as a Case Study

WANG Donghui, NI Huayong, LI Pengyue, HAO Ming

(*Chengdu Center*, *China Geological Survey*, *Chengdu* 610081, *China*)

Abstract: In this paper, based on the extensive collection of materials of geological and engineering investigation, seven categories of geological problems to be prevented and noted and four categories of geological resources to be protected in Chengdu were systematically collated for urban underground space utilization. The underground space in Chengdu has a depth of 200 m that is divided into four layers: 0−30 m, 30−60 m, 60−100 m and 100−200 m, which differ in geological elements (in terms of geology and geological resources) constraining urban underground space utilization, as well as geological structure in vertical direction. Afterwards, the recommendation that the urban underground space in Chengdu should be developed and utilized by zones and layers was proposed, and the *Geological Environmental Atlas of Chengdu for Supporting and Serving Comprehensive Utilization of Urban Underground Space Resources* (also referred to as the *Atlas*) was drafted. The *Atlas* contains thirty-nine maps and one geological survey report. It covers key areas of Chengdu, including the Central Urban Area, both the South and West Parks of Chengdu Hi-Tech Industrial Development Zone, Tianfu International Bio-town, Tianfu New Area (under the direct administration of Chengdu Municipality), Tianfu International Airport City, Jianzhou New Town and Huaizhou New Town. The *Atlas* will provide the geological basis for comprehensive utilization of urban underground space, optimization and expansion of urban space, quality improvement of urban functions, the development of land spaces, transformation and upgrade of the space, and intensive, environmentally-friendly and sustainable urban development of Chengdu. Furthermore, it will offer a demonstration and reference for other cities to prepare an atlas of this kind.

About the first author: WANG Donghui, male, born in 1982, senior engineer with master of science, engages in hydrogeology, engineering geology, and environmental geology as well as urban geological survey; E-mail: 16216813@qq.com.

Key words: urban geology; underground space; geological problems; geological resources; mapping; urban geological survey engineering; Chengdu; Sichuan
Data service system URL: http://dcc.cgs.gov.cn

1 Introduction

It was clearly stated in the 18th National Congress of the Communist Party of China that China must develop into a new urbanization country. However, the urbanism faces severe challenges arising from marked acceleration of urban construction, urban expansion and a rapid increase in population, consumption of resources, usage of the environment and issues with spatial distribution and utilization caused by imbalanced and inadequate social development (Sun LP et al., 2018). And an important measure to solve these challenging problems is to develop and utilize underground space in a scientific, organized, efficient and synergetic manner based on the overall planning of the utilization of the above ground, ground and underground spaces (Wang CS et al., 2019; Li XZ et al., 2019; Yang WC et al., 2019; Guo CB et al., 2019; Chen ZL et al., 2018; Zacharias J and He J, 2018). Ascertaining the existing issues of resources, environment and the geology of the above ground, ground and underground spaces by vigorous urban geological surveys, plays a fundamental role in ensuring high-quality and safe urban development (Lin LJ et al., 2017; Andersen TR et al., 2017).

In recent years, the urban geological surveys in the cities represented by Shanghai, Beijing, Hangzhou, Xuzhou, and Danyang have provided important support for the environmentally-friendly and safe urban development, the management of land resources and the planning and construction of cities. However, traditional geological maps are still expressed in a complex and technical language that is difficult to understand. Moreover, these maps tend to contain rich geological data but inadequate systematical recommendations. Therefore, exploring a brand-new method to communicate geological survey results and preparing a set of scientific maps used for decision-making are of great importance for urban geological work to systematically serve urban public administrations.

The transformation of Chengdu, one of China's most important central cities in the west, into a national central city, which comprehensively reflects the new development concept, can be accelerated by implementing a new development strategy of urban space. That is, "to advance in the east, expand in the south, upgrade in the west, improve in the north and optimize in the center" and to construct a functional system network consisting of "two cores operating collaboratively and multiple centers providing support". Scientific assessment of urban underground space resources plays an important role in the optimization of urban planning and layout, the development of land spaces, the transformation and upgrade of spaces and the intensive, environmentally-friendly and sustainable development of Chengdu.

China Geological Survey (CGS) and the People's Government of Chengdu jointly launched a project titled the *Survey of Urban Geology and Urban Underground Space*

Resources of Chengdu. The project aims to support and serve the preparation and implementation of the overall plan for the development and utilization of urban underground space resources in Chengdu and to be more aware of conditions and problems related to its geological environment. The *Atlas* is the pre-research result obtained at the early stage of the project. The purpose of it is to systematically show the environmental geological conditions, the critical geological problems to be prevented and noted, and major geological resources to be protected for the comprehensive utilization of urban space, so as to offer guidance on detailed surveys and to provide geological basis for the overall planning of the urban underground space in Chengdu. The region to be mapped in the *Atlas* is shown in Fig. 1.

The *Atlas* consists of an introductory map, geological recommendations for the comprehensive utilization of urban underground space resources by zones and layers and also for underground space utilization at the depth intervals of 0–30 m, 30–60 m, 60–100 m and 100–200 m, basic geological support conditions and one attachment. There are 39 professional maps and one geological survey report in the *Atlas* in total. The brief metadata table of the dataset of the *Atlas* is shown in Table 1.

2 Methods for Data Acquisition and Processing

2.1 Data Basis

The *Atlas* is based on materials from a geological and engineering investigations of

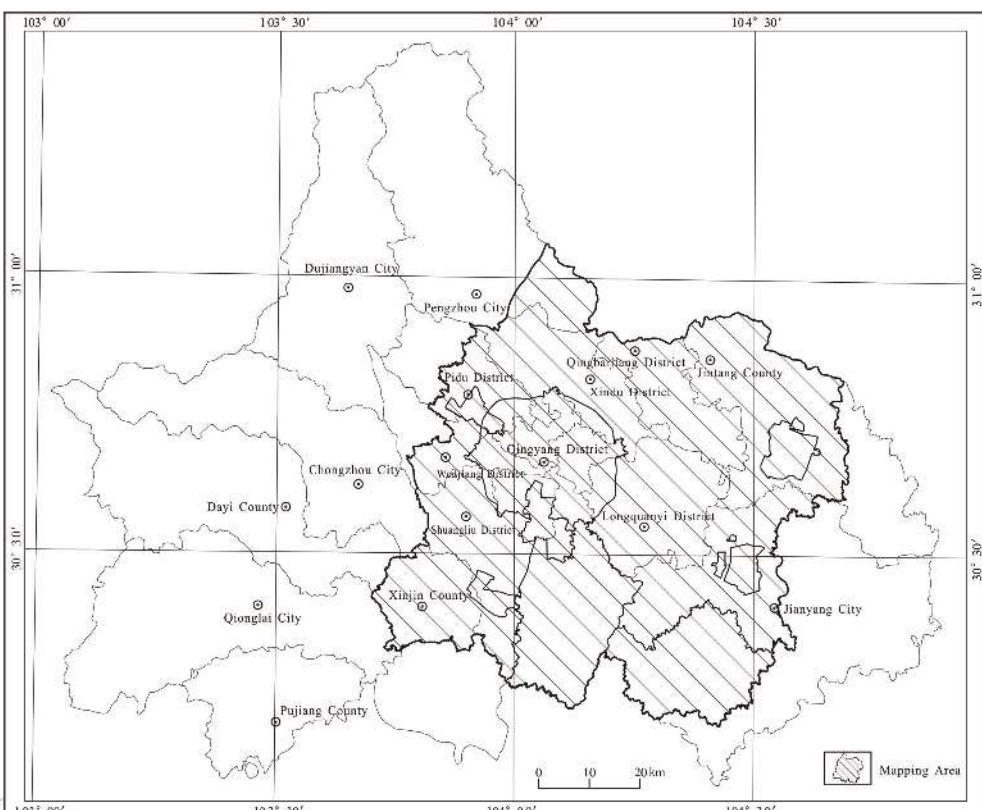

Fig. 1 Diagram of the Region to be Mapped in the *Atlas*

Chengdu that were obtained before 2017, including about 155 pieces of data from three major categories: regional geological background, urban construction planning and geological investigations (Table 2).

The vector (grid) file database for mapping was developed by collecting and uniformizing data, with various basic geographical elements as a basis for the data, and successively inputting it into the database using the software, ArcGIS.

The data mainly came from the Chengdu Center of China Geological Survey, Chengdu Municipal Bureau of Planning and Natural Resources, Sichuan Institute of Geological Survey, Chengdu Team of Hydrogeology and Engineering Geology of Sichuan Bureau of Geology & Mineral Resources, Chengdu Center of Hydrogeology and Engineering Geology of Sichuan Bureau of Geology & Mineral Resources, Sichuan Institute of Coal Field Geological Engineering Exploration and Design, Chengdu Xingshu Reconnaissance Infrastructure Engineering Company of Sichuan Coalfield Geological Bureau, Institute of Exploration Technology of China Geological Survey, Chengdu University of Technology, National Geological Archives of China, Chengdu Land and Resources Bureau, Sichuan Geological Archives, Sichuan Geological Environmental Monitoring Station, Chengdu Planning and Management Administration, Chengdu Urban Construction Archives, Chengdu Bureau for Earthquake Disaster Reduction, Chengdu Rail Transit Group Co., Ltd., No.2 Engineering Group Co., Ltd. of CREC and China Southwest Geotechnical Institute Investigation & Design Co. Ltd.

Table 1 Metadata Table of Database (Dataset)

Items	Description
Database (dataset) name	Dataset of Geological Environmental Atlas of Chengdu (2017) for Supporting and Serving Comprehensive Utilization of Urban Underground Space Resources
Database (dataset) authors	Wang Donghui, Chengdu Center, China Geological Survey Ni Huayong, Chengdu Center, China Geological Survey Guo Ziqi, Chengdu Center, China Geological Survey Wang Chunshan, Chengdu Center, China Geological Survey Li Pengyue, Chengdu Center, China Geological Survey Chen Xuyu, Chengdu Center, China Geological Survey Tang Yeqi, Chengdu Center, China Geological Survey Li Shengwei, Chengdu Center, China Geological Survey
Data acquisition time	2017
Geographic area	E 102°54′–104°53′, N 30°05′–31°26′
Data format	.shp,.png
Data size	4 GB
Data service system URL	http://dcc.cgs.gov.cn
Fund project	China Geological Survey Projects named “1 : 50 000-scale Environmental Geological Survey of Yibin–Wanzhou Development Belt Along the Yangtze River in the Chengdu–Chongqing Economic Zones” (DD20160249) and “Multi-element Urban Geological Survey of Chengdu” (DD20189210)
Language	Chinese

Continued table 1

Items	Description
Database (dataset) composition	The *Atlas* covers map layers of four major categories, i.e., basic geographic layers, geologic profiles, thematic layers and a geological survey report. **1. Basic geographic layers.** This covers the towns, airports, county borders, expressways, national highways and provincial highways of the region to be mapped, and prefecture-level cities, capital, city borders, counties, water systems, railways and towns of Sichuan Province. **2. Geologic profiles.** This covers subways #1, #2 and #7, C-C’ profiles of the underground spaces at the depths of 30−60 m and 100−200 m, D-D’ profiles of the underground spaces at the depths of 60−100 m and 100−200 m, E-E’ profile of the underground spaces at the depth of 60−100 m and comprehensive recommendation maps of B-B’ and C-C’ profiles. **3. Thematic layers.** This covers the suitability of the underground spaces at the depths of 0−30 m, 30−60 m, 60−100 m and 100−200 m, distribution area of the relative aquiclude at the depth of 30−60 m, distribution area of mudstone bearing gypsum salt at the depths of 60−100 m and 100−200 m, bedrock aquifer distribution area at the depths of 60−100 m and 100−200 m, brackish water distribution area at the depths of 60−100 m and 100−200 m, distribution area of high-quality water sources at the depths of 60−100 m, and aquifer distribution area at the depth of 100−200 m, geological disasters, strata, stratum occurrence, assessment of ground-source and groundwater-source heat pump potential, landform-based zones, groundwater-yield-property-based zones, earthquakes, peak ground acceleration zoning, geological relics, quaternary thickness contours, depth contours of the footwall of the first aquiclude, fractures, distribution area of sandy gravel bearing rich water, engineering geology-based zones, rail transit, distribution area of mudstone bearing gypsum salt, ecological belt encircling the city, active fractures, distribution area of Jiaguan Formation, mineral water, sodium sulphate factory area, distribution area of expansive clay, distribution area of relative aquiclude in plains, distribution area of soft soil, ecological conservation area, gas distribution area, distribution area of brackish water, cultural relics, distribution area of high-quality water sources and comprehensive suitability-based zones. **4. Attachment.** one geological survey report supporting and serving comprehensive utilization of urban underground space resources in Chengdu (2017)

2.2 Data Processing

2.2.1 Data Preparation

The data of planes, profiles, points and illustrations were obtained following the classification and collation of the information collected on regional geological background, urban construction planning and geological investigation. The planar maps were prepared with the Gauss-Krüger Projection parameter, 18 degree zone and 1980 Xi’an Coordinate System.

2.2.2 Data Collation

The collected data were processed as follows.

Table 2 Main Basic Data

Category	Sub-category	Main content	References
Regional geological background	Basic geology	1 : 200 000-scale and 1 : 250 000-scale regional geological survey results	Zhu B et al., 2013
	Hydrogeology	groundwater resource assessment, hydrogeological reconnaissance survey and 1 : 200 000-scale and 1 : 500 000-sclale regional hydrogeological survey results	Li YJ et al., 2002, Huang RK et al., 1977; Liu YC et al., 1978; Li JK et al., 1977; Xu QB et al., 1977
	Environmental geology	Results of the comprehensive survey of hydrogeology, engineering geology and environmental geology; as well as the geo-environmental survey of mines, groundwater pollution survey, environmental geological survey of urban agglomerations, geological environmental monitoring, geologic disaster survey, etc.	Wang TS et al., 2005; Liu JX et al., 1990
	Geochemistry	Results of the multi-purpose geochemical survey, geochemical survey of land quality, etc.	Liu YP et al., 2002
	Resources	Results of survey and assessment of geothermal energy, shallow geothermal energy and groundwater; information on cultural relics, parks, wetlands, etc.	Liu JX et al., 1990;Yang M et al., 2013
Urban construction planning	Hydrometeorology	Data on climate, precipitation and hydrology, etc.	
	Urban society and economy	Data on the area, population, social and economic development of the urban area, etc.	
	Urban planning and construction	Data on overall urban planning, construction planning of major projects, rail transit planning, etc.	
	Utilization of urban land	Multi-phase remote sensing images and their interpretation of results and results of the third nationwide land survey	
	Development and utilization of urban underground spaces	Data on subways, underground malls, civil air defense projects, underground pipelines, etc.	
Geological investigation	Geotechnical investigation	Results of geotechnical investigations for the construction of bridges, subways, houses, etc. including the information on drilling of about 3 000 boreholes and foundation pits, including the test results	
	Water source investigation	Results of hydrogeological drilling of about 160 boreholes and analytical results of water quality	
	Oil & gas exploration	Results of drilling of four boreholes and 2D seismic exploration	
	Geophysical prospecting	Comprehensive research results of gravity, magnetic and electrical prospecting and seismic exploration	

(1) Digitalize and uniformize the plan data collected to generate vector files of.shp format in a unified way.

① Uniformize data formats. Convert all plan data of different types and formats into.shp files that can be processed by ArcGIS in a unified way.

② Uniformize coordinate systems. By taking multi-phase remote sensing images and their interpretation of the results, including the results of the third nationwide land survey, as benchmarks and uniformize all the files collected from different coordinate systems into the files of the 1980 Xi' an Coordinate System, with the 18 degree zone and Gauss-Krüger projection parameters selected.

③ Uniformize attributes. Reclassify the data collected by their attributes and recollate the attribute names and data types to form attribute formats that are consistent throughout the region to be mapped and universal in all maps.

(2) Use the software that will generate exchange formats, such as AutoCAD and CorelDRAW, to splice and reprocess the profile data collected, thus generating files of points, lines and planes containing attributes; then convert the files into vector files of.shp format.

(3) Organize the materials of important points into EXCEL files. The coordinates and data description of the points must be contained.

(4) Replot the images regarding significant geological phenomena and classical geological profiles into digital.png files with the resolution of at least 300 dpi.

2.2.3 *Atlas* Preparation

The *Atlas* was prepared based on data development, borehole standardization and analysis of geological conditions. During the preparation of the *Atlas*, 155 existing pieces of geological survey data from 16 categories within the region, which is going to be mapped, were intensively collected and analyzed. Furthermore, the data were systematically organized and developed again. Results of more than 6 500 investigated boreholes were selected to be standardized. Multiple crisscrossed regional control sections were plotted and the 3D geological framework for the underground space at a depth of no greater than 200 m was initially set up (Zhou D et al., 2019; He J et al., 2019). The difference in horizontal zones of geological structure between different topographical units and the difference in vertical layers of geological structure within a single topographical unit were basically understood. This is the basis of map preparation. As a result, the region was divided into four landform-based zones horizontally (i.e., plain, platform, low mount and hill) and into four layers of underground space resources vertically (i.e., 0–30 m, 30–60 m, 60–100 m and 100–200 m) (Peng JB et al., 2019).

The elements to be expressed include geological structure, geological problems and geological resources that constrain the utilization of urban underground spaces. The endowments of underground space resources in Chengdu were comprehensively analyzed by comprehensively using geological conditions, geological resources and geological problems. Consequently, the elements constraining the comprehensive utilization of urban underground space resources in Chengdu were systematically collated. They were divided into two categories, i.e., geological problems to be prevented and noted (Huang QB et al., 2019; Hu ZP et al., 2019; Zhou YX et al., 2019) and resources to be protected as a whole (Wang WL et al., 2017).

The core idea to be expressed is the macro-assessment of the geological suitability for the development and utilization of underground spaces. The suitability was assessed by zones and layers according to the geological problems and resource distribution that affect the development and utilization of the underground spaces as well as their constraint degree (Jiang SY et al., 2019; Jiang X et al., 2018; Hao AB et al., 2018; Wu BH et al., 2017; Zhang JJ et al., 2016; Zhang L et al., 2014; Zhang P et al., 2014; Liu K et al., 2011). Based on this, and in combination with the ways for development and utilization, the recommendations for comprehensive utilization of the underground space resources by zones and layers were proposed.

The *Atlas* was expressed by combining horizontal zones with vertical layers. By taking into full consideration the urban planning, geological and topographical units, hydrogeological conditions, engineering geological rock formations, geological problems and spatial distribution of the resources in Chengdu. Also, by combining planes with profiles; the geological problems, resources, suitability and ways for the development and utilization of the resources were concisely and vividly expressed by four landform-based zones horizontally and four layers vertically (Darroch N et al., 2018; Chen XS, 2018).

3 Description of Data Samples

3.1 Data Formats

The formats of geological recommendation maps for the development and utilization of underground space resources, the maps of Early Pleistocene active faults and topographical maps of the mapping region are.mxd,.shp, and.tif respectively.

3.2 Contents of Map Layers

Map layers mainly consist of four categories (i.e., the remote sensing images, basic geographical layer, thematic layers and profiles), with each map layer containing all element map layers of its category (Table 3).

3.3 Data Attributes

Corresponding files and attribute tables are required for each map layer in ArcGIS. The files generally consist of points, lines, planes and grids; and the attribute tables include four categories, i.e., remote sensing, geographical element, thematic layer and profile (Table 4).

4 Data Quality Control and Assessment

Benchmarks were set by taking multi-phase remote sensing images and results of the third national land survey as basic layers of the maps. The various materials collected were corrected to ensure the overlapping accuracy of the maps. The.shp files collated were all reviewed and

Table 3 Map Layer Contents Summary by Categories

Category	Element	Contents of element	Contents to be expressed
Remote sensing	Remote sensing	Remote sensing images, topographic shadow	Changes in vegetation, ecology, buildings, water systems, etc.
Geographical element	Transportation	Railways, expressways, national and provincial highways	Distribution of transport routes
	Administrative division	Borders and development layout & planning of prefecture-level cities, counties, towns and administrative districts	Borders and development layout & planning of various administrative districts
	Water systems	Water systems and lakes	Rivers, lakes
Thematic layer	Geological resources	Cultural relics, location of mineral water, geological relics, high-quality water sources, sandy-gravel thickness contour, geothermal heat pump-based zones and potential assessment of groundwater-source heat pumps	Spatial distribution of various geological resources
	Geological problems	Groundwater pollution, geological disasters, faults, contour of mudstone bearing gypsum salt, Chengdu clay, soft soil and gas-bearing strata	Spatial distribution of various geological problems
	Geological recommendations	Geological suitability for the development and utilization of underground spaces at the depths of 0−30 m, 30−60 m, 60−100 m and 100−200 m	Geological suitability for the development and utilization of underground spaces
Profile	Structures	Fractures, folds and anticlines	Tectonic patterns
	Subways	Surface features, underground projects, monitoring points, interchange stations, subway routes and geological recommendations for subway construction	Spatial distribution of subways, geological recommendations for subway operation and distribution of monitoring points

then inserted into the database by utilizing the database function of ArcGIS. In this way, the database was developed.

5 Conclusion

The *Atlas* consists of an introductory map, geological recommendations for comprehensive utilization of urban underground space resources, basic geological support conditions and attachments. It was prepared with the software ArcGIS and includes a total of 39 maps in the formats.shp and.png. The database is comprised of about 66 spatial layers of four categories (i.e., basic geographical elements, geological profiles, thematic layers and geological survey report). As an important basis for complete implementation of the project titled *Survey of Urban Geology and Urban Underground Space Resources Geology of Chengdu*, the *Atlas* was specifically applied in the preparation of the plan for the development

Table 4 Contents of Main Attributes of Each Element

Category	Element	Contents of element	Contents of main attributes of the element
Remote sensing	Remote sensing	Remote sensing images, topographic shadow	OID, Value, Count
Geographical element	Transportation	Railways, national and provincial highways, expressways	Fid, shape*, PYNAME, NAME, MAPID, ID, KIND, SNODE_ID, ENODE_ID, FUNCCLASS, LENGTH, ADMINCODEL, SPEEDCLASS, VEHCL_TYPE, SPDLMTE2S, SPDSECS2e, SPDSRCE2S
	Administrative division	Borders and development layout & planning of prefecture-level cities, counties, towns and administrative districts	Fid, shape*, NAME, PYNAME, MAPID, KIND, ZIPCODE, ADMINCODE, DISPLAY_X, DISPLAY_Y, ADDRESS, FID_county border, AREA, PERIMETER, BOUNT_, BOUNT_ID, GBCODE, ADCODE99, SH2, DI2, X2, CENTRIOD_Y, CENTROID_X, LCFLAG724, Shape_Length, zone
	Water systems	Water systems and lakes	Fid, shape*, MAPID, ID, length, CODE, GB, HYDC, TN, NAME, KIND, ADMINCODE, AOICODE, DISPCLASS, XZQMC, KZMJ, JSMJ, ZXMC
Thematic layer	Geological resources	Cultural relics, location of mineral water, geological relics, high-quality water sources, sandy-gravel thickness contour, geothermal heat pump-based zones, potential assessment of groundwater-source heat pumps	Fid, shape*, age, geology, name, category; water yield, borehole depth (m), mineral water name, burial depth, landform-based zone, suitability-based zone, potential
	Geological problems	Groundwater pollution, geological disasters, faults, contour of mudstone bearing gypsum salt, Chengdu clay, soft soil and gas-bearing strata	Fid, shape*, ID, unified No., sample No., longitude, latitude, position, category, integrated assessment, remarks; type of potential risk spots, scale level; fault nature, occurrence strike, burial depth of roof; code, geological name, marking
	Geological recommendations	Geological suitability for the development and utilization of underground spaces at the depth of 0–30 m / 30–60 m/ 60–100 m / 100–200 m	Fid, shape*, suitability
Profile	Structures	Fractures, folds and anticlines	Fid, shape*, ID, ornamental pattern, filling symbol, element, notes
	Subways	Surface features, underground projects, monitoring points, interchange stations, subway routes and geological recommendations for subway construction	Fid, shape*, ID, DXF primitive name, DXF map layer name, elevation, notes

and utilization of urban underground spaces of Chengdu. The mapping thinking and expression ways explored in the *Atlas* will offer a demonstration and reference for other cities across China to prepare an atlas of this kind.

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