doi: 10.12029/gc2020Z120

论文引用格式：张天福, 张云, 程先钰, 孙立新, 程银行, 周小希, 王少轶, 马海林, 鲁超. 2020. 鄂尔多斯盆地北部东胜地区侏罗系—白垩系钻孔数据库与三维地质模型 [J].中国地质，47(S1):220−230.

数据集引用格式：张天福; 张云; 孙立新; 马海林; 程银行. 鄂尔多斯盆地北部东胜地区侏罗系—白垩系钻孔数据(V1).中国地质调查局天津地质调查中心; 内蒙古自治区地质调查院 [创建机构], 2015. 全国地质资料馆 [传播机构], 2020-06-30.10.35080/data.H.2020.P20; http://dcc.cgs.gov.cn/cn//geologicalData/details/doi/10.35080/data.H.2020.P20.

收稿日期：2020-04-07
改回日期：2020-05-31

基金项目：国家重点研发计划课题（编号：2018YFC0604203；2018YFC0604206）、中国地质调查局项目（编号：DD20190813）、国际地球科学计划 ICGP675(砂岩型铀矿表生流体成矿作用) 和国家 973 项目（编号：2015CB4530006）联合资助。

鄂尔多斯盆地北部东胜地区侏罗系—白垩系钻孔数据库与三维地质模型

张天福[1,2]　张云[1,2]　程先钰[1,2]　孙立新[1,2]　程银行[1,2]
周小希[1,2]　王少轶[1,2]　马海林[3]　鲁超[4]

(1. 中国地质调查局天津地质调查中心，天津 300170；2. 中国地质调查局天津地质调查中心非化石能源矿产实验室，天津 300170；3. 内蒙古自治区地质调查院，内蒙古 呼和浩特 010000；4. 核工业二〇八大队，内蒙古 包头 014000)

摘要：随着砂岩型铀矿找矿工作的进一步开展，其对以往钻孔资料集成应用的需求尤为迫切。在煤田钻孔资料“二次开发利用”和“煤铀兼探”新方法、新思路的指导下，通过采集东胜地区钻孔资料属性数据，按照统一的标准和要求，将煤田、铀矿等类型的重要钻孔资料，通过整理、扫描、数据类型转换、录入和集成，建成了东胜地区侏罗系—白垩系综合钻孔数据库，实现了对多源钻孔数据的统一管理。该数据库共包含 3 个 Access 数据库和相应的成果图件。每个 Access 数据库均包含钻孔基本信息表、综合柱状分层表、岩性描述分层表、地层名称及代号表、地层颜色表、测井曲线数据表、测井曲线配置表和钻孔弯曲度测量数据表等 8 张数据表，分别详细记录了地质编录岩性信息、地层分层信息、岩石颜色信息、测井曲线信息、水文分层信息、钻孔样品采样信息、弯曲度测量信息等。通过应用实践，该钻孔数据库成果可实现连井剖面、含煤含铀目的层的顶底板标高、地层等厚图、砂体等厚图及含砂率图等重要基础地质图件的快速生成，从而提高数据的使用效率并为铀矿勘查及研究工作提供重要数据基础。

关键词：钻孔数据集；三维地质模型；砂岩型铀矿；铀矿勘查工程；东胜地区；鄂尔多斯盆地

数据服务系统网址：http://dcc.cgs.gov.cn

1　引言

鄂尔多斯盆地东北部东胜地区煤田、油田地质工作始于 20 世纪 50—60 年代，涵盖石油、地质矿产、煤炭等方面。鄂尔多斯盆地的铀矿地质工作始于 20 世纪 50 年代，直

第一作者简介：张天福，男，1985 年生，助理研究员，现主要从事地质矿产调查与研究工作；E-mail：tianfuzhang85@163.com。

到 21 世纪初期铀矿找矿成果才取得突破性进展，先后发现了大营、纳岭沟、皂火壕等几处大型–超大型砂岩型铀矿床。2010 年以来，中国地质调查局天津地质调查中心组织开展了“我国主要盆地煤铀等多矿种地质调查”计划“鄂尔多斯盆地中西部铀矿选区项目”和“北方砂岩型铀矿调查工程”等工作，以打破常规的跨越式勘查理念，在北方盆地取得一系列重要找矿突破，初步提交 14 个新发现铀矿产地 (金若时和谭志安，2013；苗培森等，2017；金若时等 2017；陈路路等，2018；汤超等，2018；魏佳林等，2018；冯晓曦等 2019；Jin RS et al.，2019，2020)。以可地浸砂岩型铀矿成矿理论为指导，以成矿地质背景和成矿地质条件为基础，创新性的提出煤田、油田钻孔资料“二次开发、快速找铀”的新思路 (金若时和谭志安，2013；苗培森等，2017；金若时等 2017；张天福等，2016，2018，2019)。

随着砂岩型铀矿找矿工作的进一步深入，其对钻孔地质资料集成应用的需求日益迫切 (张云等，2016；周小希等，2016，2019；吕志成等，2018；张天福等，2016，2018，2019)。相对于传统的二维地质数据表示方法，三维模型更能够准确地表达各种地质现象，而钻孔数据是获取三维地质信息的最直观和精确的手段。鄂尔多斯盆地北缘东胜地区已积累有海量的煤–油–铀钻孔、测井资料，为本区钻孔数据库建设和三维地质建模提供了可靠的资料支撑 (焦养泉等，2006，2018；鲁超等，2018)。尤其是纳岭沟和大营 2 个大型铀矿床的新发现，使得该地区勘查井网密度高，钻孔资料丰富，已具备开展钻孔数据库建库和井下三维地质建模的基本条件 (张天福等，2016，2019)。为此，2015—2018 年，中国地质调查局天津地质调查中心组织的“北方砂岩型铀矿调查工程”在鄂尔多斯盆地东北部东胜地区部署了铀矿钻孔数据库建设和基于钻孔数据的三维地质建模试点工作 (俞礽安等，2020；张天福等，2020a)。该工作以东胜地区以往煤田、铀矿钻孔地质资料为数据资源，首次大规模全面采集了钻孔资料属性数据，按照统一的标准和要求，将煤田、铀矿等类型的重要钻孔资料，通过整理、扫描、数据类型转换、录入和集成，建成钻孔数据库。此次钻孔数据库建设，可为铀矿调查工程和砂岩型铀成矿研究提供数据基础和信息技术支撑，对钻孔地质资料的二次开发极具后续利用意义。数据库 (张天福, 2020b) 基本信息如表 1 所示。

鄂尔多斯盆地东北部的东胜区岩浆活动不发育，出露地层以中、新生界为主 (图 1a；Liu CY et al.，2008，2009；焦养泉等，2012，2015)。其中，三叠系、侏罗系多分布于盆地周缘，露头主要见于鄂尔多斯盆地东北缘东胜、准格尔一带 (Li ST et al.，1995；Jiao YQ et al.，2005，2016)，白垩系多分布在盆地中部 (图 1b)。中–下侏罗统延安组 ($J_{1\text{-}2}y$) 及中侏罗统直罗组 (J_2z) 是本次研究的主要目的层，其地层序列相对完整 (图 1c)。

2 数据采集和处理方法

2.1 数据采集

钻孔属性信息是数据库重要数据，由于所采集钻孔资料来源不一、时间跨度较长，数据标准不统一，属性结构存在差异。既有近年来实施的验证钻孔，还有纸质载体的前人钻孔，这种回朔性钻孔数据库建库需要将大量早期纸质钻孔资料进行数字化后才能完成入库。因此，建库过程涉及大量的数字化扫描和智能数字化工作，尤其是测井曲线的数字化，不能依靠人为识别进行高精度采集，需要机器自动跟踪识别。

在分析不同类型钻孔柱状图数据特点基础上，针对回朔性钻孔数据库建库，以钻孔

表 1　数据库 (集) 元数据简表

条目	描述
数据库(集)名称	鄂尔多斯盆地北部东胜地区侏罗系—白垩系钻孔数据库
数据库(集)作者	张天福，中国地质调查局天津地质调查中心 张　云，中国地质调查局天津地质调查中心 孙立新，中国地质调查局天津地质调查中心 马海林，内蒙古自治区地质调查院 程银行，中国地质调查局天津地质调查中心
数据时间范围	2015—2017年
地理区域	内蒙古鄂尔多斯市东胜地区
数据格式	数据库格式为.xls和.mdb; 图集格式为.bwi和.jpg
数据量	2.99 GB
数据服务系统网址	http://dcc.cgs.gov.cn
基金项目	中国地质调查局项目(编号DD20190813)、国家重点研发计划课题(编号：2018YFC0604200)、国家重点基础研究发展计划(973计划2015CB453000)、国际地球科学计划(IGCP675)项目资助
语种	中文
数据库(集)组成	本数据库包含3个Access数据库，每个数据库均包含钻孔基本信息表、综合柱状图分层表、岩性描述分层表、地层名称及代号表、地层颜色表、测井曲线数据表、测井曲线配置表和钻孔弯曲度测量数据表等8张数据表，分别详细记录了地质编录岩性信息、地层分层信息、岩石颜色信息、测井曲线信息、水文分层信息、钻孔样品采样信息、弯曲度测量信息等。成果图件主要包括地层厚度等值线图、砂体厚度等值线图、顶底板埋深等值线图、含砂率等值线图等

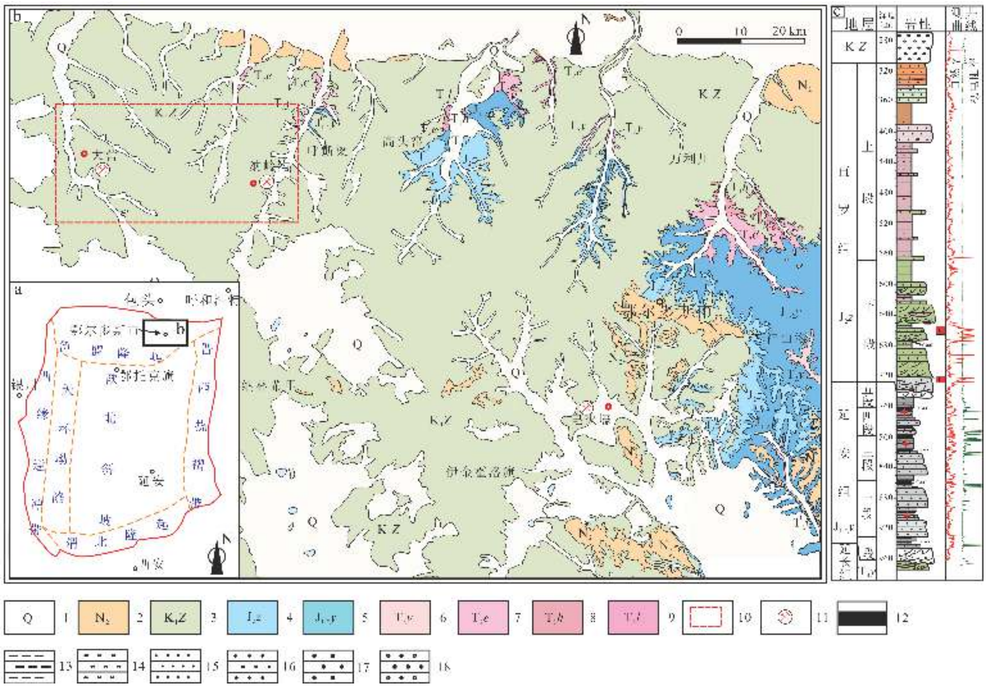

图 1　鄂尔多斯盆地东北缘构造位置图 (a，据杨俊杰和裴锡古，1996 修改)、地质简图 (b) 及钻孔柱状图 (c)

1—第四系；2—新近系上新统；3—下白垩统志丹群；4—中侏罗统直罗组；5—中–下侏罗统延安组；6—上三叠统延长组；7—中三叠统二马营组；8—下三叠统和尚沟组；9—下三叠统刘家沟组；10—研究区；11—砂岩铀矿床；12—煤层；13—泥岩；14—粉砂岩；15—细砂岩；16—中砂岩；17—粗砂岩；18—砾岩

综合柱状图成果图件为建库主要对象。参考钻探相关规范标准，并经过大量钻孔数据分析对比，确定本次建库的观测和解释实体数据。观测实体数据包括：地质编录岩性信息、地层分层信息、岩石颜色信息、测井曲线信息、水文分层信息、钻孔样品采样信息、弯曲度测量信息、岩心物探编录 (γ、$\gamma+\beta$) 信息、岩 (矿) 心照片信息、其他属性信息 (包括重要蚀变、层理等)；解释实体数据包括：测井解释岩性信息、测井解释结果信息、基本化学分析结果信息。确定数据库实体及实体之间的关系后，在逻辑结构设计阶段完成关系模式转换，将观测及解释实体关系全部合并到对端的实体中 (周小希等，2016)，经过数据模型优化后，煤孔资料建库采集最终设计数据表 8 张 (图 2)，砂岩型铀矿钻孔回朔性采集设计数据表最多为 18 张 (图 3)。钻孔属性信息表主要属性字段及逻辑结构见图 3。本文数据采集采用钻孔数据库数据采集和测井曲线数字化软件采集相结合，实现最终的数据库数据采集工作。天津地质调查中心开发实现了基于 C/S 架构的钻孔数据库采集系统，该系统提供了便捷、友好的数据录入、编辑、定制格式批量导入、输出、数据查询和 MapGIS 格式图件转换等功能，使用户能够方便、快捷地将数据导入到数据库中 (周小希等，2016)。

本次钻孔数据库所包含的 195 口钻孔资料来自《内蒙古自治区东胜煤田纳林希里煤炭普查报告》，钻探实施单位为内蒙古煤炭建设工程 (集团) 总公司，由于原始钻孔资料信息有限，本次所采集内容主要包含项目基础信息、钻孔基本信息、岩性信息、地层信息、测井曲线数据信息及钻孔属性信息等 8 张信息表 (图 2)，其余信息表内容为空。

2.2　数据入库

钻孔数据采集过程中，每个钻孔会形成对应的一个完整的 Excel 数据文件，每个 Excel 钻孔数据文件中最多包含 18 张数据表，本次采集 8 张 (图 3)。Access 数据库为传统关系型数据库，属于轻量级文件级数据库，使用方便且适合作为分布式建设数据库。基于以上考虑，本次采用 Access 数据库将 Excel 钻孔数据文件汇总后统一入库。在上述

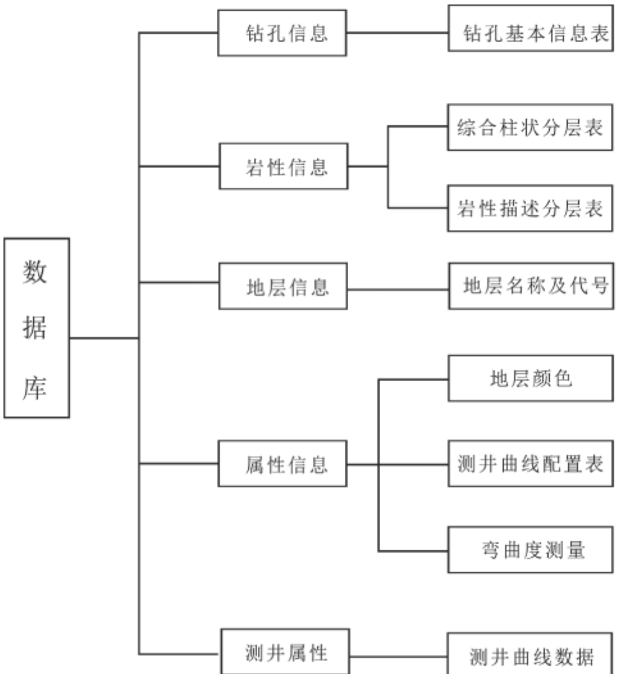

图 2　数据库采集内容

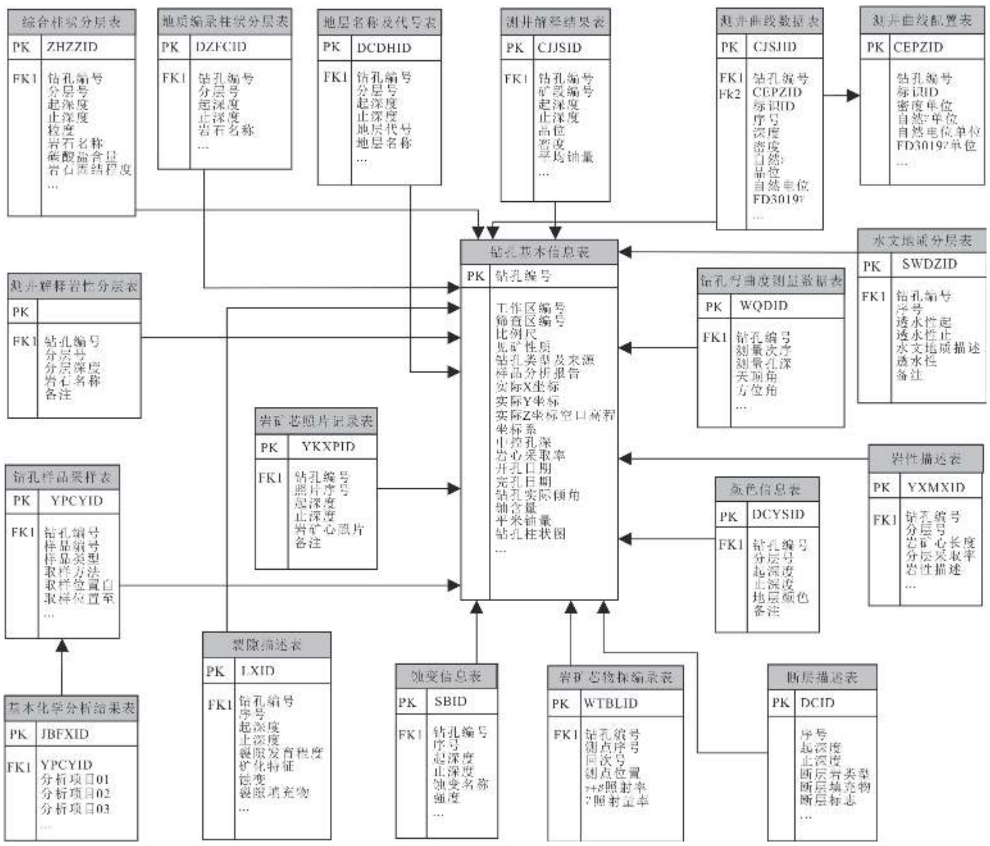

图 3　钻孔属性数据表逻辑结构图 (据周小希等，2016 修改)

工作的基础上，已完成大营—纳岭沟地区 195 口钻孔数据库建库工作，形成对应的 195 个 Excel 钻孔数据文件，汇总统一入库后形成 3 个 Access 数据库。所建立的钻孔数据库已成功应用于砂岩型铀矿成矿研究和三维地质建模工作等。

2.3　数据样本描述

鄂尔多斯盆地东胜地区煤田钻孔数据库为 Excel 表格型和 Access 型数据，包括 195 个 Excel 数据文件和 3 个 Access 数据库文件，Excel 数据文件均按照“工作区编号 (121201150137012)+钻孔号”命名。其中，每个 Excel 数据文件 (图 2) 涵盖 8 张关于本钻孔属性的信息表，如钻孔基本信息、地质编录岩性信息、地层分层信息、岩石颜色信息、测井曲线信息等，每张表在 Access 数据库中均具有唯一的由首字母组成的简写字母代号，如“钻孔基本信息表”简写为“TABLE_ZKJC”、“岩性描述分层表”简写为“TABLE_YXMSFC”。含煤、含铀岩系成果图件格式为*.bwi 格式，主要包括井位、等值线、人文地理要素 3 个图层，井位图层主要内容为参与成图的钻孔井位信息和相关属性信息，等值线图层为根据提取到的钻孔相关属性绘制的平面等值图，人文地理要素为乡镇、县级居民地等地理要素在地表的点位及名称，不同图层可单独或合并显示。三维地质结构模型导出为 Eclipse 模型数据 (*.txt) 格式，本模型可以直观地展示各地层的地貌形态，沉积厚度分布和沉积中心和古隆起剥蚀区 (图 4)。

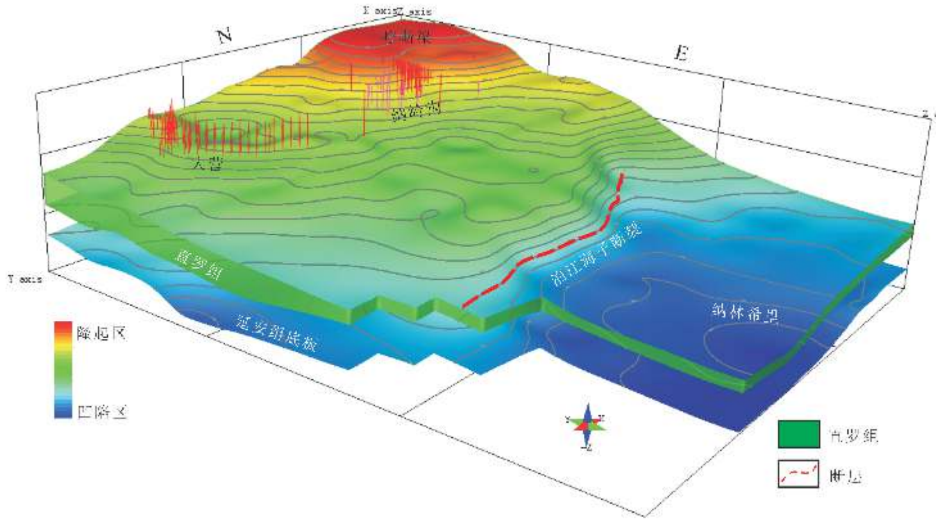

图 4　鄂尔多斯盆地东北部呼斯梁—大营—纳林希里地区中侏罗统直罗组地层及古地貌三维空间展布形态

3　数据库应用

3.1　二维平面图绘制

利用钻孔数据库，基于国产软件 Gxplorer 研究平台的平面图数据管理和成图模块，可快速生成区域井位分布图、地层厚度等值线图 (图 5)、顶底板构造图及储层物性 (岩性、孔隙度、渗透率、饱和度等) 图等。通过不同的网格化算法和变差模型，可以支持图层间的叠加和对比。

3.2　剖面绘制

基于钻孔数据库可快速生成任一方向的连井对比剖面图、砂体对比剖面、栅状连井剖面图 (图 6)，从而为地层及储层的对比分析工作提供便利。

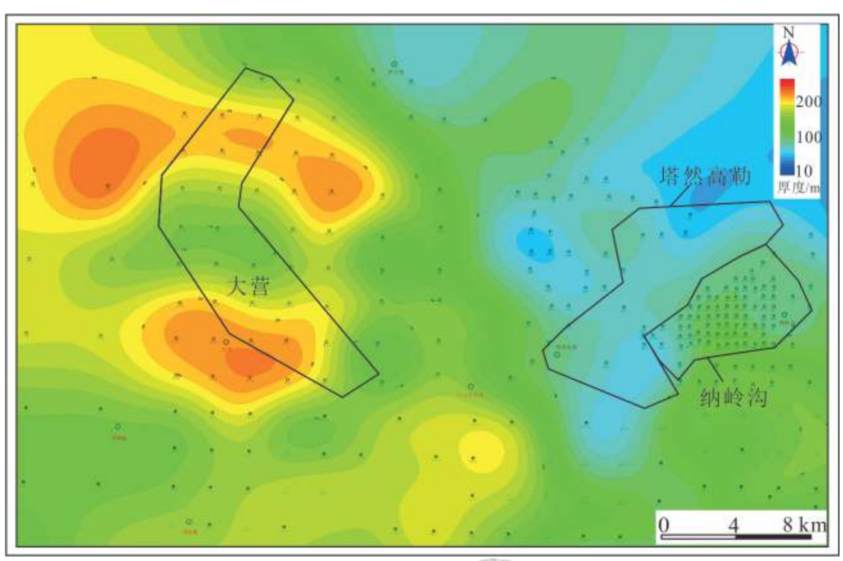

图 5　大营—纳岭沟地区中侏罗统直罗组上段地层厚度等值线图

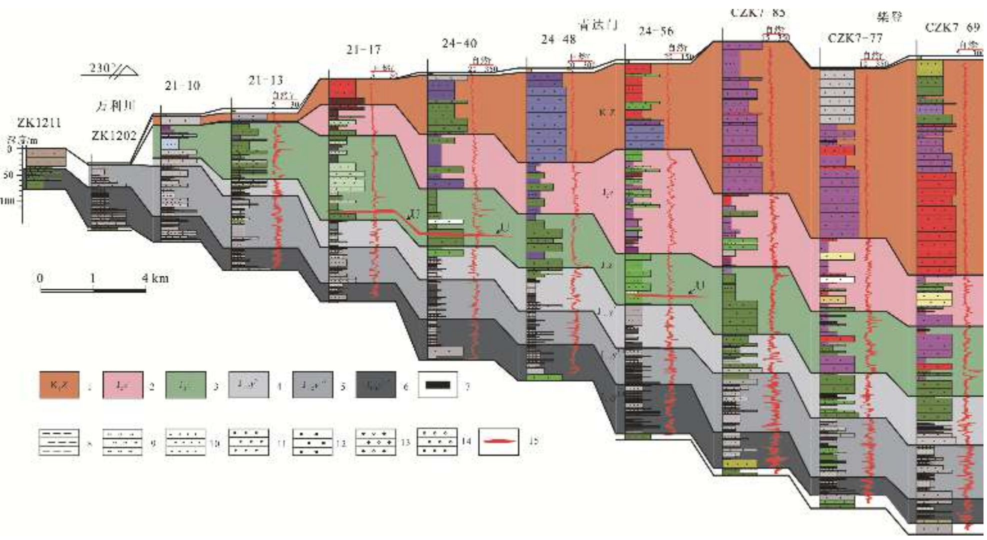

图 6　鄂尔多斯盆地东北缘万利川—柴登地区侏罗系—下白垩统地层对比剖面

1—下白垩统志丹群；2—中侏罗统直罗组上段；3—中侏罗统直罗组下段；4—中–下侏罗统延安组 5 段；5—中—下侏罗统延安组 3–4 段；6—中—下侏罗统延安组 1–2 段；7—煤层；8—泥岩；9—粉砂岩；10—细砂岩；11—中砂岩；12—粗砂岩；13—含砾粗砂岩；14—砾岩；15—铀矿层.

注：地层柱状图中岩性花纹颜色代表岩心颜色

3.3　三维建模

鄂尔多斯盆地东胜地区构造作用整体较弱，断裂构造不发育，地层产状缓倾，因此本次三维地质建模可采用软件 Gxplorer 三维自动建模模块，利用钻孔数据库精细构建不同尺度、不同类型的三维地质模型，进而揭示不同成矿地质要素与铀矿化在三维空间的配置关系。

在小比例尺度上，实现区域地质体结构及恢复后古地貌的三维可视化 (图 4)。在大比例尺度上，结合时间维度上的系列编图和空间维度上不同尺度的切面，并将目标层顶底板构造、区域连井剖面及钻孔砂体数据、测井曲线数据及二维地震数据作为建模地质属性约束条件，精细刻画了铀储层和铀矿化体三维模型。在用户选择需要分析的岩性数据后，系统根据不同区域、不同角度自动对剖面数据进行分组，并利用三维可视化技术组合每个组的剖面图，得到岩性三维地质离散模型 (图 7) 和不同方向的纵切剖面 (图 8)，用于分析岩性粒度离散关系。利用诸如此类图集，用户能够在三维空间多角度的直观分析该地区的岩性分布，这为鄂尔多斯东北部东胜地区砂岩型铀矿成矿规律研究及勘查工作部署提供可靠的模型支撑。

4　数据质量控制

4.1　钻孔数据质量控制

钻孔数据采集坚持按照《北方重要盆地砂岩型铀矿钻孔数据库建库技术要求 (试行)》的统一标准，保证数据的真实性、准确性、逻辑一致性、规范性和完整性，对必要的修改变动之处项目组已充分论证，并有相应的记录和合理性说明。从项目到单位层面逐级做好数据质量控制工作和数据库的审核验收工作，自检率达到 100%，互检率达到 100%，项目检查率达到 60%，上级抽查为 15%。在检查中发现的问题，及时找出原因，并认真整改，做到上报数据库错误率低于 0.3%，并针对数据库检查保留相应的检

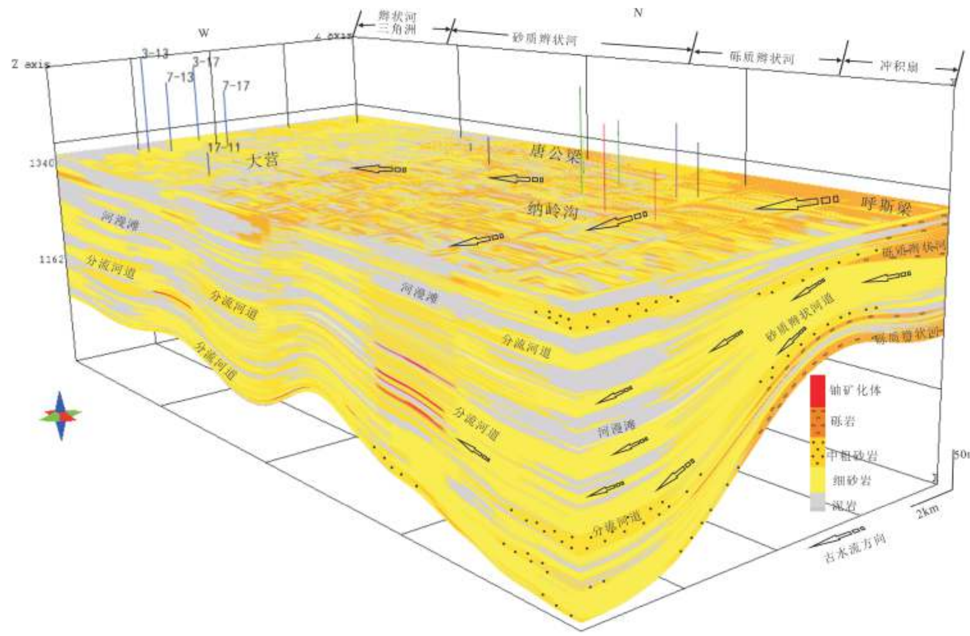

图 7　大营—纳岭沟矿区中侏罗统直罗组下段岩性粒度三维属性模型与铀矿化关系

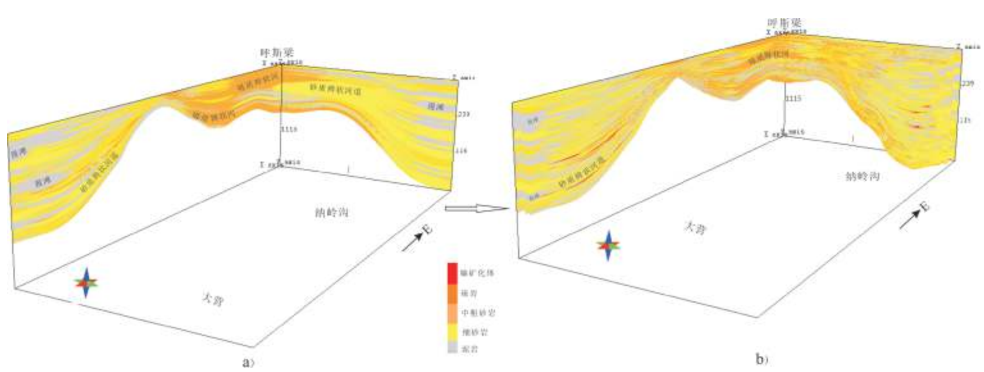

图 8　大营—纳岭沟地区骨架砂体、沉积体系三维空间配置与铀矿化体关系

注：大营—纳岭沟地区存在区域性沉积相变，由呼斯梁向西、向南，沉积体系由砾质辫状河向砂质辫状河再向辫状河三角洲沉积有序转变；其中，大营铀矿化 (红色) 主要发育于辫状河道砂体向辫状河三角洲岩性转换界面处

查记录和修改说明。综上，在数据采集入库和数据处理阶段都进行了严格的质量控制，确保了数据质量。

4.2　成果图集及三维地质模型质量评估

成果图件和三维地质模型构建所采用的钻孔数据全部来源于本次建库钻孔，数据质量可靠。数据库涉及面积约 420 km^2，参与建模钻孔 195 口，整体上钻孔分布较均匀，钻孔网度多为 2 km×2 km。通过编制大量地层连井对比剖面、骨架砂体对比剖面和栅状图并结合测井曲线、地震剖面，检验地层界线划分的合理性与否。若出现不合理之处，通过论证修改更新至钻孔数据库，更新后的钻孔数据库会自动修正成果图件，保证综合图件编制的准确性。二维尺度的地层连井剖面和砂体连井剖面亦可作为三维模型构建的约束条件，并参与建模过程。2018 年 12 月中旬，中国地质调查局天津地质调查中心组织专家对东胜地区数据库建库和三维地质建模工作进行了评审，通过了野外验收。

5 数据价值

本次所建立的东胜地区钻孔数据库，实现了对该地区钻孔资料的统一管理，提高了钻孔地质资料集成应用的工作效率。基于该钻孔数据库和三维建模软件 Gxplorer，进一步实现了钻孔数据自动化成图，使得大量钻孔属性信息更加快速直观的显现出来，并能快速三维可视化表达和实现多条件快速查询功能，这为铀矿勘查、成果集成提供了数据基础和信息技术支撑，也为其他地区钻孔数据库建设和三维建模工作提供很好的借鉴。本次所建立的 Access 型钻孔数据库为传统关系型数据库，属于轻量级文件级数据库，使用方便且兼容性较好，可供其他三维建模软件直接使用。

6 数据使用建议

本数据库格式为.mdb；图集格式为.bwi 和对应的.jpg 格式，本次成果图件的编制和三维地质建模使用的软件平台为西安石文软件公司开发的 Gxplorer 三维建模平台，该平台上井数据处理、解释与成果分析模块名为 Ezwell。

Ezwell 的对象式操作风格使单井解释及图面编辑直观、灵活、高效，可生成形式多样、内容丰富、美观的单井成果图，各种操作简单快捷，容易掌握，如增加图道、编辑图道、编辑曲线、设置充填方式及显示等。可将当前风格保存为模板，增加到模板库，供其他井使用；可根据需求，随时改变模板形成新的图形格式；绘图模板技术可快速生成多种成果图。此外，Ezwell 模块还具有较强的数据预处理功能，包括曲线编辑、曲线校深、曲线拼接、曲线滤波、斜井校直、数据预览、数据计算、数据分析统计、岩心归位等，可生成二维或三维交会图。Ezwell 提供了丰富的图形保存格式，各种成果图如地层综合柱状图、典型曲线图、岩心综合图、综合解释图、交会图等均可保存为矢量图 (EMF、CGM、DXF、PDF 等) 和位图 (BMP、JPEG、JPG、GIF、TIF、TIFF 等) 格式。

7 结论

(1) 鄂尔多斯盆地北部东胜地区侏罗系—白垩系钻孔数据库与三维地质模型以鄂尔多斯盆地北部东胜地区以往煤田、铀矿钻孔地质资料为数据资源，首次大规模全面采集了钻孔资料属性数据，按照统一的标准和要求，将煤田、铀矿等类型的重要钻孔资料，通过整理、扫描、数据类型转换、录入和集成，建成钻孔数据库，实现了对多源钻孔数据的统一管理，为东胜地区煤田钻孔资料的“二次开发、快速找铀”提供可靠数据支撑。

(2) 利用三维建模软件，基于已建立的钻孔数据库，可实现连井剖面、含煤含铀目的层的顶底板标高、地层等厚图、砂体等厚图及含砂率图等重要基础地质图件的快速生成。通过精细构建不同尺度、不同类型的三维地质模型，进而实现多角度展示不同成矿地质要素与铀矿化在三维空间的配置关系，为东胜地区砂岩型铀矿成矿规律研究及勘查工作部署提供可靠的模型支撑。

致谢：中国地质大学 (武汉) 吴立群副教授及孙玉函博士、内蒙古地质调查院杨才教授级高工等人一起参加了三维地质建模工作，中国地质调查局天津地质调查中心王惠初研究员、辛后田教授级高工、李承东研究员、赵凤清研究员给予了诸多宝贵建议，在此一并致谢。

参考文献

Jiao Y Q, Wu L Q, Wang M F, Xu Z C. 2005. Forecasting the occurrence of sandstone-type uranium deposits by spatial analysis: an example from the northeastern Ordos Basin, China. In: Mao JW, Bierlein, FP (Eds.), Mineral Deposit Research: Meeting the Global Challenge[M]. Springer-Verlag, Berlin Heidelberg, 273–275.

Jiao Y Q, Wu L Q, Rong H. 2016. The relationship between Jurassic Coal Measures and Sandstone-Type Uranium Deposits in the Northeastern Ordos Basin, China[J]. Acta Geologica Sinica (English Edition), 90(6): 2117−2132.

Jin R S, Yu R A, Yang J, Zhou X, Teng X M, Wang S B, Si Q H, Zhu Q, Zhang T F. 2019. Paleo-environmental constraints on uranium mineralization in the Ordos Basin: evidence from the color zoning of U-bearing rock series[J]. Ore Geology Reviews, 104(2019): 175−189.

Jin R S, Teng X M, Li X G, Si Q H, Wang W. 2020. Genesis of sandstone-type uranium deposits along the northern margin of the Ordos Basin, China[J]. Geoscience Frontiers, 11(1): 215−227.

Liu C Y, Zhao H G, Zhao J F, Wang J Q, Zhang D D, Yang MH. 2008. Temporospatial coordinates of evolution of the ordos basin and its mineralization responses[J]. Acta Geologica Sinica (English Edition), 82(6): 1229−1243.

Liu C Y, Zhao H G, Sun Y H. 2009. Tectonic background of Ordos Basin and its controlling role for basin evolution and energy mineral deposit[J]. Energy Exploration & Exploitation, 27(1): 15−27.

Li S T, Yang S G, Tomasz J. 1995. Upper Triassic-Jurassic foreland sequences of the Ordos Basin in China stratigraphic, evolution of foreland basins[J]. SEPM Special Publication, 52: 233−241.

陈路路, 汤超, 李建国, 钟延秋, 谷社峰, 魏佳林, 肖鹏, 徐增连, 曾辉, 刘华建, 陈印. 2018. 松辽盆地大庆长垣南端四方台组含铀砂岩岩石学特征及地质意义 [J]. 地质调查与研究, 41(1): 33−39, 66.

吕志成, 庞振山, 薛建玲, 耿林, 张志辉, 甄世民, 陶文, 贾儒雅, 陈辉, 姚磊. 2018. 2012—2014 年老矿山深部和外围找矿成果数据集 [J]. 中国地质, 45(S1): 45−65.

冯晓曦, 滕雪明, 何友宇. 2019. 初步探讨鄂尔多斯盆地东胜铀矿田成矿作用研究若干问题 [J]. 地质调查与研究, 42(2): 96−103.

焦养泉, 吴立群, 杨生科, 吕新彪, 杨琴, 王正海, 王敏芳. 2006. 铀储层沉积学: 砂岩型铀矿勘查与开发的基础 [M]. 北京: 地质出版社, 1–323.

焦养泉, 吴立群, 荣辉, 彭云彪, 万军伟, 苗爱生. 2012. 铀储层结构与成矿流场研究: 揭示东胜砂岩型铀矿床成矿机理的一把钥匙 [J]. 地质科技情报, 31(5): 94−104.

焦养泉, 吴立群, 彭云彪, 荣辉, 季东民, 苗爱生, 里宏亮. 2015. 中国北方古亚洲构造域中沉积型铀矿形成发育的沉积–构造背景综合分析 [J]. 地学前缘, 22(1): 189−205.

焦养泉, 吴立群, 荣辉, 张凡, 乐亮, 陶振鹏, 孙钰函. 2018. 铀储层地质建模: 揭示成矿机理和应对“剩余铀”的地质基础 [J]. 地球科学, 43(10): 3568−3583.

金若时, 程银行, 李建国, 司马献章, 苗培森, 王少轶, 奥琮, 里宏亮, 李艳锋, 张天福. 2017. 中国北方晚中生代陆相盆地红−黑岩系耦合产出对砂岩型铀矿成矿环境的制约 [J]. 中国地质, 44(2): 205−223.

金若时, 谭志安. 2013. 中国北方含煤盆地砂岩型铀矿找矿模式层序研究 [J]. 地质调查与研究, 36(2): 81−84.

鲁超, 焦养泉, 彭云彪, 吴立群, 苗爱生, 荣辉, 谢惠丽. 2018. 大营地区古层间氧化带识别与空间定位预测 [J]. 中国地质, 45(6): 1228−1240.

苗培森, 李建国, 汤超, 金若时, 程银行, 赵龙, 肖鹏, 魏佳林. 2017. 中国北方中新生代盆地深部砂岩铀矿成矿条件与找矿方向 [J]. 地质通报, 36(10): 1830−1840.

汤超, 金若时, 谷社峰, 李建国, 钟延秋, 苗培森, 司马献章, 魏佳林. 2018. 松辽盆地北部四方台组工业铀矿体的发现及其意义 [J]. 地质调查与研究, 41(1): 1−8, 32.

魏佳林, 汤超, 徐增连, 肖鹏, 刘华健, 曾辉, 陈路路, 赵丽君, 郭虎, 张超, 朱强, 李艳锋. 2018. 大庆长垣南部四方台组砂岩型铀矿化特征研究 [J]. 地质调查与研究, 41(1): 9−17.

杨俊杰, 裴锡古. 1996. 中国天然气地质学 [M]. 北京: 石油工业出版社, 3–20.

俞礽安, 司马献章, 金若时, 苗培森, 彭胜龙. 2020. 鄂尔多斯盆地东北缘发现大型砂岩型铀矿床 [J]. 中国地质, 47(3): 883−884.

张天福, 孙立新, 张云, 程银行, 李艳峰, 马海林, 鲁超, 杨才, 郭根万. 2016. 鄂尔多斯盆地北缘侏罗纪延安组、直罗组泥岩微量元素、稀土元素地球化学特征及其古沉积环境意义 [J]. 地质学报, 90(12): 3454−3472.

张天福, 张云, 苗培森, 俞礽安, 李建国, 金若时, 孙立新. 2018. 鄂尔多斯盆地西缘中晚侏罗世地层化学蚀变指数 (CIA) 研究及其意义 [J]. 地质调查与研究, 41(4): 258−262.

张天福, 张云, 程银行, 苗培森, 奥琮, 金若时, 段连峰, 段宵龙. 2019. 利用露头、井震及地球化学综合厘定层序界面—以鄂尔多斯盆地东北缘侏罗系为例 [J]. 煤田地质与勘探, 47(1): 40−48.

张天福, 张云, 金若时, 俞礽安, 孙立新, 程银行, 奥琮, 马海林. 2020a. 鄂尔多斯盆地东北缘侏罗系层序界面特征及其时空属性对砂岩型铀矿成矿环境的制约 [J]. 中国地质, 47(2): 278−299.

张天福, 张云, 孙立新, 马海林, 程银行. 2020b. 鄂尔多斯盆地北部东胜地区侏罗系−白垩系钻孔数据 [DB/OL]. 地质科学数据出版系统. (2020-06-30). DOI:10.35080/data.H.2020.P20

张云, 孙立新, 张天福, 马海林, 鲁超, 李艳峰, 程银行, 杨才, 郭佳城, 周晓光. 2016. 鄂尔多斯盆地东北缘煤铀岩系层序地层与煤铀赋存规律研究 [J]. 地质学报, 90(12): 3424−3440.

周小希, 陈安蜀, 邓凡, 杨君, 王心华. 2016. 北方重要盆地铀矿钻孔数据库设计及实现 [J]. 地质调查与研究, 39(3): 231−236.

周小希, 邓凡, 万林, 杨君. 2019. 铀矿大数据综合管理信息平台设计与实现 [J]. 煤田地质与勘探, 47(1): 6−14.

doi: 10.12029/gc2020Z120

Article Citation: Zhang Tianfu, Zhang Yun, Cheng Xianyu, Sun Lixin, Cheng Yinhang, Zhou Xiaoxi, Wang Shaoyi, Ma Hailin, Lu Chao. 2020. Borehole Databases and 3D Geological Model of Jurassic-Cretaceous Strata in Dongsheng Area, North Odors Basin[J]. Geology in China, 47(S1):310−324.

Dataset Citation: Zhang Tianfu; Zhang Yun; Sun Lixin; Ma Hailin; Cheng Yinhang. Borehole Databases and 3D Geological Model of Jurassic-Cretaceous Strata in Dongsheng Area, North Odors Basin(V1). Tianjin Center, China Geological Survey; Laboratory of Non-Fossil Energy Minerals, Tianjin Center, China Geological Survey; Geological Survey Institute of Inner Mongolia Autonomous Region; 208th Team of the China National Nuclear Corporation[producer], 2015. National Geological Archives of China[distributor], 2020-06-30. 10.35080/data.H.2020.P20; http://dcc.cgs.gov.cn/en//geologicalData/details/doi/10.35080/data.H.2020.P20

Received: 07-04-2020
Accepted: 31-05-2020

Fund Project:
jointly funded by the National Key R&D Program of China (No.: 2018YFC0604203; 2018YFC0604206), geological survey project initiated by the China Geological Survey (No.: DD20190813), the International Geoscience Program (ICGP 675, *Supergene Fluid Ore-forming Process of Sandstone Uranium Deposits*), and the National Program on Key Basic Research Project of China (973 Program, No.: 2015CB4530006)

Borehole Databases and 3D Geological Model of Jurassic-Cretaceous Strata in Dongsheng Area, North Odors Basin

ZHANG Tianfu [1,2], ZHANG Yun [1,2], CHENG Xianyu [1,2], SUN Lixin [1,2], CHENG Yinhang [1,2], ZHOU Xiaoxi [1,2], WANG Shaoyi [1,2], MA Hailin [3], LU Chao [4]

(1. *Tianjin Center*, *China Geological Survey*, *Tianjin* 300170, *China*; 2. *Laboratory of Non-Fossil Energy Minerals*, *Tianjin Center*, *China Geological Survey*, *Tianjin* 300170, *China*; 3. *Geological Survey Institute of Inner Mongolia Autonomous Region*, *Hohhot* 010000, *China*; 4. *208th Team of the China National Nuclear Corporation*, *Baotou* 014000, *China*)

Abstract: The integrated application of existing borehole data has become an urgent need with further prospecting of sandstone-hosted uranium deposits. In this paper, a comprehensive borehole database of Jurassic–Cretaceous strata in Dongsheng area (also referred to as the Database) was established under the guidance of the new ideas and methods of "secondary development and utilization of existing coalfield borehole data" and "coal-uranium joint exploration". In detail, the borehole attributes of Dongsheng area were collected. Then key borehole data related to coalfields and uranium deposits were successively collated, scanned, converted into desired data types, input into data tables, and integrated into databases according to unified standards and requirements. As a result, the Database was established, achieving unified management of borehole data from multiple sources. The Database consists of three Access databases and corresponding result maps. Each of the Access databases contains eight data tables, namely *Basic information of a borehole*, *Beds based on comprehensive histograms*, *Beds based on lithologic description*, *Names and codes of strata*, *Data from logging curves*, *Configuration of logging curves*, *Bending degree measurement of boreholes*, etc. These data tables respectively contain detailed data of the lithology from geologic records, beds, rock colors, logging curves, hydrogeological beds, borehole sampling, and bending degree measurement. According to application and practices, the Database enables a quick generation of critical basic geologic maps such as well profiles and the isoline maps of the elevations of roofs and floors, stratum thickness, sand-body thickness, and sand content of

About the first author: ZHANG Tianfu, male, born in 1985, assistant researcher, mainly engages in geological and mineral survey and research; E-mail: tianfuzhang85@163.com.

target strata bearing coal and uranium. This will increase the data utilization efficiency and provide critical data for the exploration and research of uranium deposits.
Key words: Borehole dataset; 3D geological model; sandstone-hosted uranium deposit; uranium deposit exploration; Dongsheng; Odors Basin
Data service system URL: http://dcc.cgs.gov.cn

1 Introduction

The geological surveys of coalfields and oilfields in the Dongsheng area in northeast Odors Basin (also referred to as the study area) started in the 1950s–1960s, covering oil, geology and minerals, and coal. The geological survey of the uranium deposits in Odors Basin began in the 1950s. However, no breakthrough was made during prospecting of uranium deposits in the basin until the early 21st century, when several large–superlarge sandstone-hosted uranium deposits were successively discovered, such as Daying, Nalinggou, and Zaohuohao deposits. Since 2010, the Tianjin Center of China Geological Survey have organized and implemented the program titled *Geological Survey of Multiple Minerals such as Coal and Uranium in Major Basins of China*, the project titled *Determination of Exploration Areas of Uranium Deposits in the Middle West Odors Basin*, and the project named *Survey Engineering of Sandstone-Hosted Uranium Deposits in North China* based on the unconventional concept of spanning exploration. As a result, a series of important prospecting breakthroughs were made in the basins of North China and 14 newly-discovered uranium deposits were initially reported (Jin RS and Tan ZA, 2013; Miao PS et al., 2017; Jin RS et al., 2017; Chen LL et al., 2018; Tang C et al., 2018; Wei JL et al., 2018; Feng XX et al., 2019; Jin RS et al., 2019, 2020). Meanwhile, under the guidance of metallogenic theory of in-situ leachable sandstone-hosted uranium deposits, an innovative idea of "quick uranium exploration based on secondary development of existing borehole data" was proposed according to geological background and conditions for mineralization (Jin RS and Tan ZA, 2013; Miao PS et al., 2017; Jin RS et al., 2017; Zhang TF et al., 2016, 2018, 2019).

The integrated application of existing borehole data has become an urgent need with further prospecting of sandstone-hosted uranium deposits (Zhang Y et al., 2016; Zhou XX et al., 2016, 2019; Lyu ZC et al., 2018; Zhang TF et al., 2016, 2018, 2019). Three-dimensional models allow more accurate expression of various geological phenomena than traditional 2D presentation of geological data, and borehole data serve as the most intuitive and accurate means to obtain 3D geological information. Furthermore, massive coal-oil-uranium borehole data and logging data of the study area have been accumulated, providing credible data for the building of borehole databases and 3D geological models of this area (Jiao YQ et al., 2006; 2018; Lu C et al., 2018). Most importantly, high-density exploration well network and abundant borehole data were achieved in this area as two large uranium deposits named Nalinggou and Daying, which are newly discovered. Therefore, the study area is qualified for the establishment the borehole databases and underground 3D geological models (Zhang TF et al., 2016, 2019). To this end, in the aforementioned project titled *Survey Engineering of*

Sandstone-Hosted Uranium Deposits in North China in 2015–2018, the pilot work was deployed to establish borehole databases of uranium deposits in the study area and to conduct 3D geological modeling based on the borehole data (Yu RA et al., 2020; Zhang TF et al., 2020a). This project was conducted based on previous borehole data of coalfields and uranium deposits in the study area, during which the borehole attributes were comprehensively acquired on a large scale for the first time. Then key borehole data related to coalfields and uranium deposits were successively collated, scanned, converted into desired data types, input into data tables, and integrated into databases according to unified standards and requirements. As a result, the Database was established. This will provide data and information technology for the survey of uranium deposits and the metallization research of sandstone-hosted uranium deposits. Furthermore, it is greatly significant for subsequent utilization of borehole data based on secondary development of the data. The brief metadata table of the Database (Zhang TF et al., 2020b) is shown in Table 1.

The geologic setting of the study area is as follows. The magmatic activities are undeveloped and the outcrops mainly include Mesozoic and Cenozoic strata (Fig. 1a; Liu CY

Table 1 Metadata Table of Database (Dataset)

Items	Description
Database (dataset) name	Borehole Database of Jurassic–Cretaceous Strata in Dongsheng Area, North Odors Basin
Database (dataset) authors	Zhang Tianfu, Tianjin Center, China Geological Survey Zhang Yun, Tianjin Center, China Geological Survey Sun Lixin, Tianjin Center, China Geological Survey Ma Hailin, Inner Mongolia Geological Investigation Institute Cheng Yinhang, Tianjin Center, China Geological Survey
Data acquisition time	2015–2017
Geographic area	Dongsheng area, Odors City, Inner Mongolia
Data formats	.xls and.mdb for the databases;.bwi and.jpg for the atlas
Data size	2.99 GB
Data service system URL	http://dcc.cgs.gov.cn
Fund projects	Jointly funded by a project initiated by the China Geological Survey (No.: DD20190813), the National Key R&D Program of China (No.: 2018YFC0604200), the National Program on Key Basic Research Project of China (973 Program, No.: 2015CB453000), and the International Geoscience Program (IGCP675)
Language	Chinese
Database (dataset) composition	This Database contains three Access databases. Each of the Access databases contains eight data tables, namely *Basic information of a borehole, Beds based on comprehensive histograms, Beds based on lithologic description, Names and codes of strata, Data from logging curves, Configuration of logging curves, Bending degree measurement of boreholes*, etc. These data tables respectively contain detailed data of lithology from geologic records, beds, rock colors, logging curves, hydrogeological beds, borehole sampling, and bending degree measurement. The result maps mainly include the isoline maps of stratum thickness, sand-body thickness, burial depth of roofs and floors, and sand content of target strata.

et al., 2008, 2009; Jiao YQ et al., 2012; 2015). The Triassic and Jurassic strata in this area are mostly distributed on the margin of Odors Basin, and the outcrops are mostly visible in the Dongsheng and Jungar areas on the northeast margin of Odors Basin (Li ST et al., 1995; Jiao YQ et al., 2005, 2016). The Cretaceous strata are mostly distributed in the left of the basin (Fig. 1b). The Middle–Lower Jurassic Yan'an Formation ($J_{1\text{-}2}y$) and Middle Jurassic Zhiluo Formation (J_2z) serve as the focus of this study, with relatively complete stratigraphic sequences (Fig. 1c).

2 Methods for Data Acquisition and Processing

2.1 Data Acquisition

Borehole attributes are critical data in the Database. However, the attribute structures differ a lot owing to different sources, long time span, and different data standards of borehole data acquired. The boreholes involved include not only the ones drilled for verification in recent years but also the ones drilled and documented on paper in earlier years. Thus, it is necessary to massively digitalize previous borehole data recorded on paper. Only by this way, can the data be input into databases. Therefore, massive scanning and intellectual digitalization are required in retrospective building of the Database. Most especially, high-accuracy digitalization of logging curves cannot be acquired manually but should be traced and identified automatically using machines.

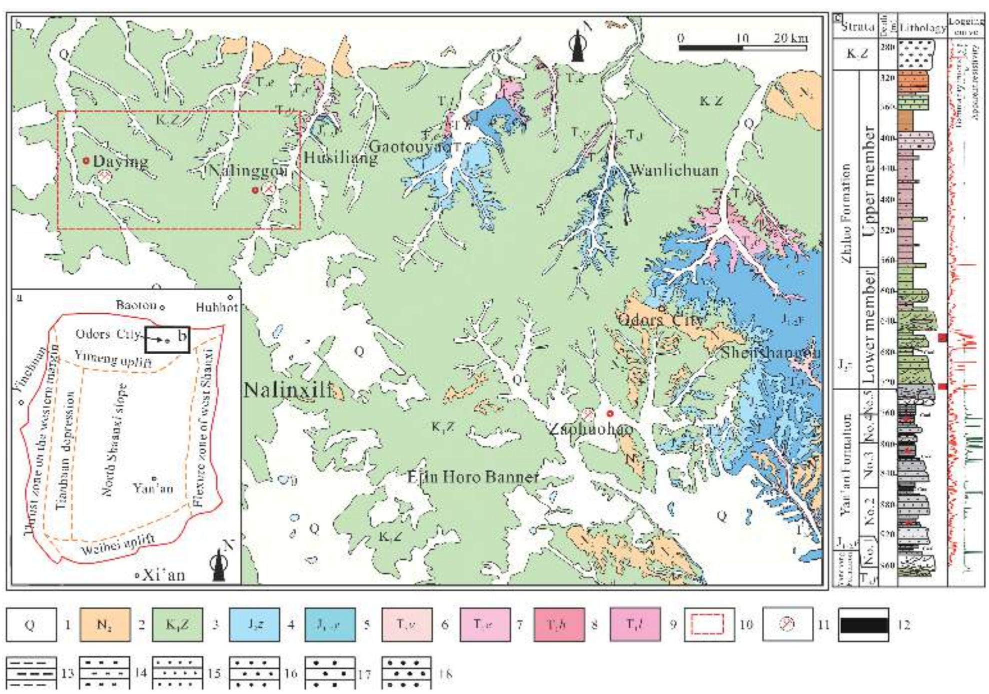

Fig. 1 Tectonic location map (a, modified after Yang JJ and Pei XG, 1996), generalized geological map (b), and borehole histogram (c) of the northeastern margin of Odors Basin

1—Quaternary; 2—Neogene Pliocene; 3—Lower Cretaceous Zhidan Group; 4—Middle Jurassic Zhiluo Formation; 5—Mid–Lower Jurassic Yan'an Formation; 6—Upper Triassic Yanchang Formation; 7—Middle Triassic Ermaying Formation; 8—Lower Triassic Heshanggou Formation; 9—Lower Triassic Liujiagou Formation; 10—The study area; 11—Sandstone-hosted uranium deposit; 12—Coal seam; 13—Mudstone; 14—Siltstone; 15—Fine-grained sandstone; 16—Medium-grained sandstone; 17—Coarse-grained sandstone; 18—Conglomerate

According to analysis of the histograms of different types of boreholes, the Database was mainly built retrospectively to achieve comprehensive histograms of boreholes as result maps. The observed and interpreted entity data used in building the Database were determined according to related drilling specifications and standards and comparative analysis of massive borehole data. The observed entity data include lithology data from geologic records, beds, rock colors, logging curves, hydrogeological beds, borehole sampling, and bending degree measurement; geophysical exploration records of cores (γ and $\gamma+\beta$); images of cores (minerals), and other attributes (such as important alteration and bedding). The interpreted entity data include lithologic data from logging interpretation, logging interpretation results, and basic chemical analysis results. After the entities and their relationships were determined, the relationship mode was converted in the stage of logical structure design, and as a result, all relationships between observed and interpreted entities were incorporated into the entities at the other corresponding ends (Zhou XX et al., 2016). Eight data tables were finally designed for building a coalfield borehole database (Fig. 2) and a maximum of 18 data tables were designed for retrospective acquisition of data from boreholes in sandstone-hosted uranium deposits (Fig. 3). The main fields in the borehole attribute data tables and the logical structure of the data tables are shown in Fig. 3. The borehole data were acquired using a database application system and data for logging curves were obtained using digital software. The Tianjin Center of China Geological Survey developed a database application system based on

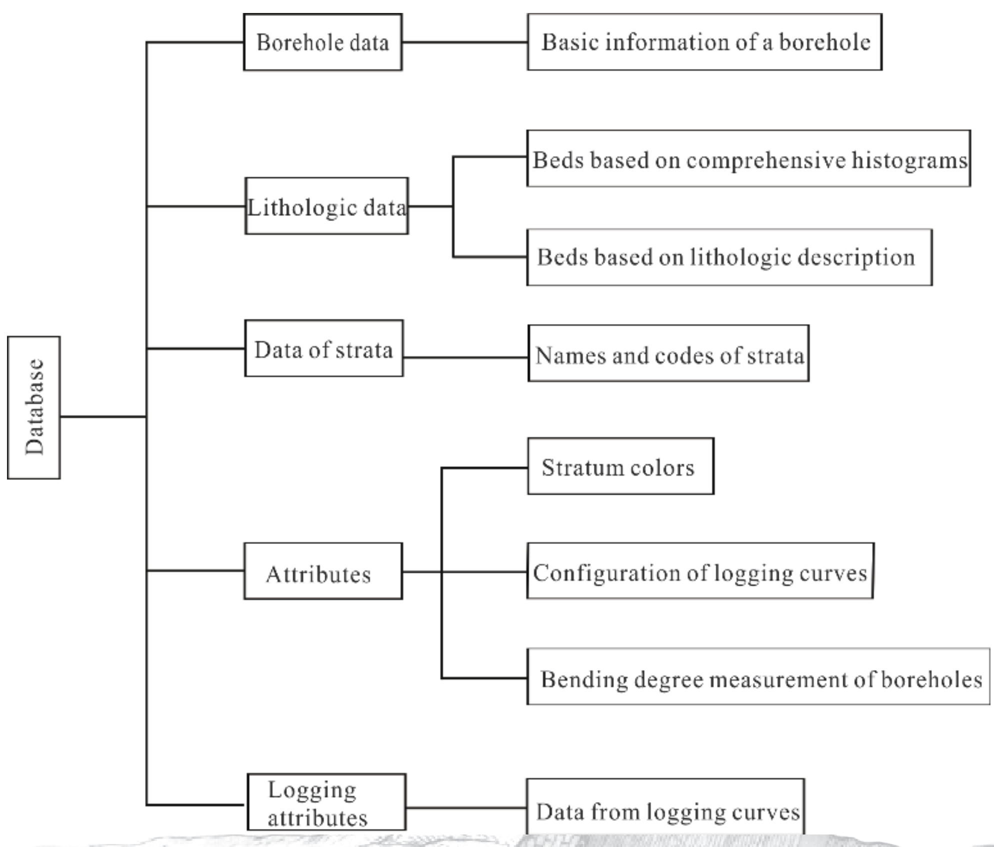

Fig. 2 Data acquired for the Database

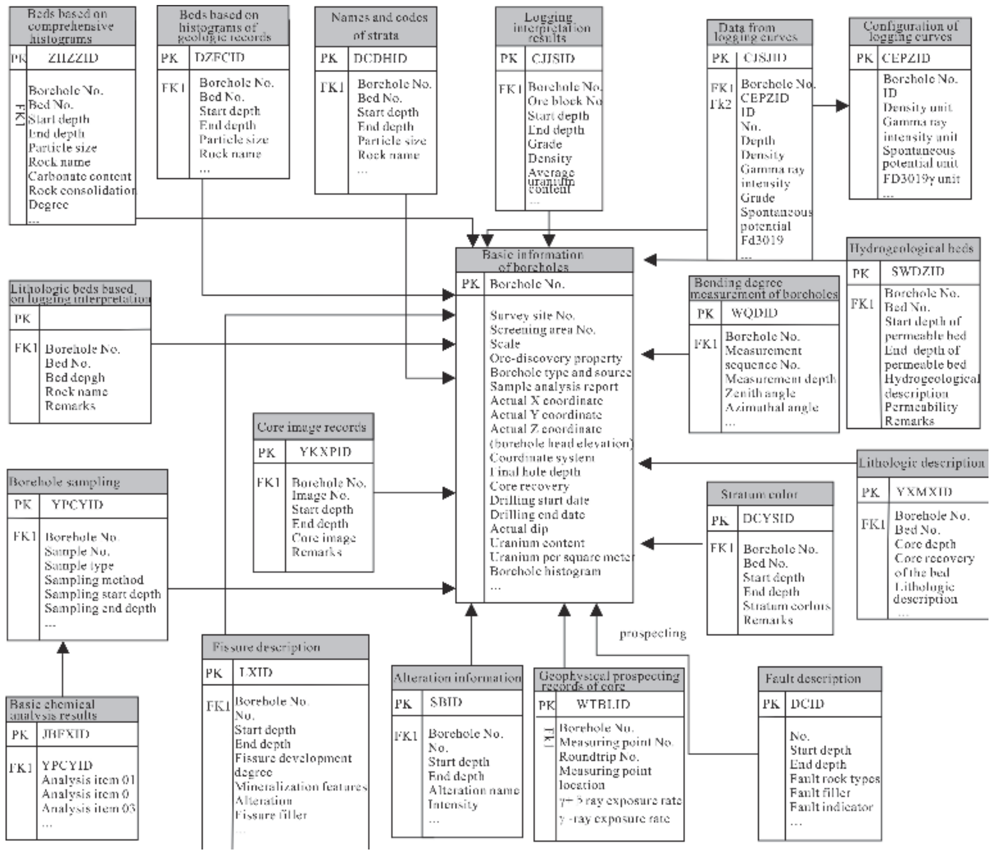

Fig. 3 Logical structure of borehole attribute data tables (modified after Zhou XX et al., 2016)

C/S architecture for borehole data acquisition. A series of functions were provided in this system, including data inputting, data editing, batch data importing and exporting in customized formats, data query, and conversion of MapGIS maps, thus allowing users to easily and quickly import data into the Database (Zhou XX et al., 2016).

The borehole data in the Database originated from the *Reconnaissance Survey Report of the Coal in Nalinxili Minefield, Dongsheng Coalfield, Inner Mongolia,* and the 195 boreholes were drilled by Inner Mongolia Coal Construction Engineering (Group) Corporation. In this study, only the eight data tables (Fig. 2) were filled with the data acquired while other data tables are empty owing to limited original borehole data.

2.2 Data Inputting into Database

During borehole data acquisition, data for each borehole was recorded in one complete Excel file. Each Excel file contains a maximum of 18 tables, and eight tables were filled with the data acquired in this study. Access databases are traditional relational databases. They are lightweight and adopt file-level storage, and are easy to use and suitable for the building of distributed databases. Therefore, in this study, Access databases were adopted to summarize the Excel files of borehole data, and data for 195 boreholes drilled in the Daying–Nalinggou area were used to build the databases. 195 Excel files of borehole data were generated and were integrated into three Access databases. These databases have been successfully applied in metallogenic research and 3D geological modeling of sandstone-hosted uranium deposits.

2.3 Description of Data Samples

Coalfield borehole data of the study area were stored in Excel tables and Access databases, including 195 Excel files and three Access databases. The Excel files were designated by “work area code (121 201 150 137 012) + borehole No.” in a united manner. Each Excel file (Fig. 2) corresponds to a borehole and contains eight tables of borehole attributes, such as the basic information of the borehole, lithologic description from geological records, strata division, rock colors, and logging curves. Each table has a unique code in the databases, and are comprised of the first letter of Chinese pinyin of the table name. For example, the code of the table *Basic information of a borehole* is “TABLE_ZKJC” since the Chinese pinyin of the table name is “zuan kong ji ben xin xi”, and similarly, the code of the table *Beds based on lithologic description* is “TABLE_YXMSFC”. The resulting maps of rock series bearing coal and uranium are in the format of *.bwi, and mainly include three kinds of map layers, namely borehole location, isoline, and human geographical features. The map layers of the borehole location mainly include the locations of the boreholes to be mapped and related attributes. The isoline map layers were plotted according to the acquired borehole attributes. The human geographical features refer to the point locations on the ground and names of geographical features such as habitations at levels of towns and counties. Different map layers can be presented either separately or after being incorporated with other map layers. The 3D geologic structural model is in the format of the Eclipse model data (*.txt) after being exported. It can intuitively display the landform shapes of various strata, the thickness distribution and lefts of sediments, and paleo-uplift denudation zones (Fig. 4).

3 Application of the Database

3.1 Preparation of 2D Maps

The 2D maps can be quickly developed based on the borehole databases by using the plan data management module and mapping module of the software Gxplorer developed in China,

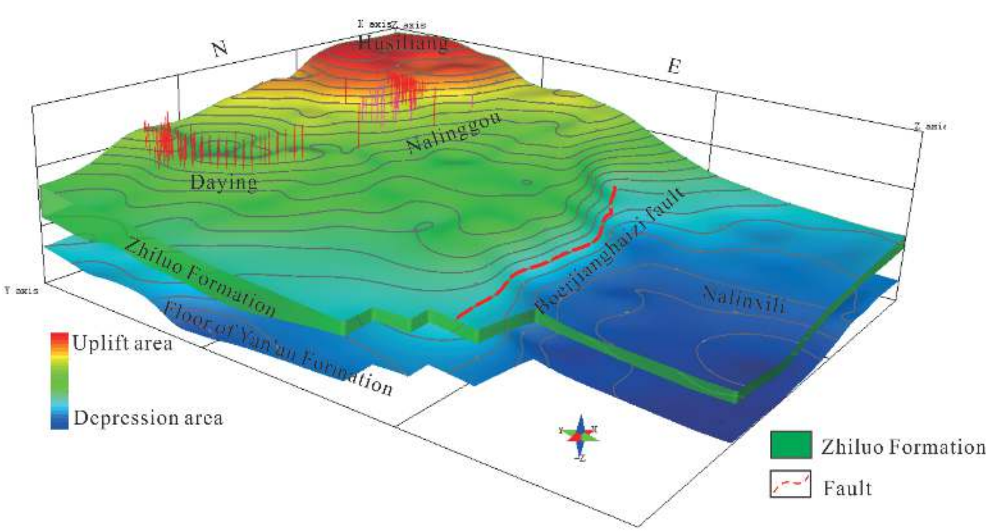

Fig. 4 3D spatial distribution morphology of the strata and paleo-landform of middle Jurassic Zhiluo Formation in the Husiliang–Daying–Nalinxili area, northeast Odors Basin

including the regional borehole distribution maps, stratum thickness isoline map (Fig. 5), tectonic maps of roofs and floors of target strata, and the maps of physical properties of reservoirs (such as lithology, porosity, permeability, and saturation). Superimposition and comparison between map layers can be achieved using different gridding algorithms and variation models.

3.2 Preparation of Profiles

Well profiles, sand-body comparison profiles, and the fence-shaped well profiles in any direction (Fig. 6) can be quickly developed based on borehole databases, thus facilitating the comparative analysis of strata and reservoirs.

3.3 3D Geological modeling

The study area features weak tectonism in general, with fault structures not developing and stratigraphic attitude gently inclining. Therefore, the 3D geological modeling of this area can be achieved using an automated modeling module of the software Gxplorer. In detail, the 3D geological models of different types and scales can be precisely built based on the borehole databases. In this way, the 3D spatial distribution relationship between different geological metallogenic factors and uranium mineralization can be further presented.

Three-dimensional visualization of the structures of regional geological bodies and the restored paleo-landforms can be obtained at a small scale (Fig. 4), while 3D models of uranium reservoirs and mineralized bodies can be achieved on a large scale. As for the 3D modeling, a series of maps in temporal dimensions and profiles on different scales in spatial dimensions were combined, and the attribute restrictions of the 3D modeling include structures of the roofs and floors of target strata, the regional well profiles, sand-body data revealed by boreholes, data from logging curves, and 2D seismic data. In this way, the 3D models were precisely

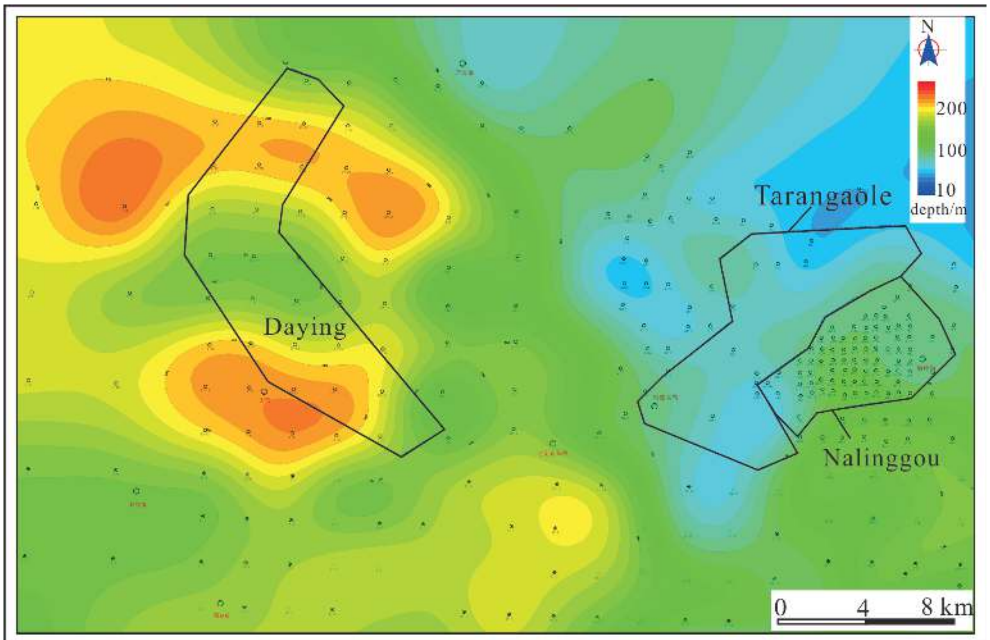

Fig. 5 Stratum thickness isoline map of middle Jurassic Zhiluo Formation in the Daying–Nalinggou area

characterized. After users select lithologic data to be analyzed, Gxplorer can automatically divide profile data into different groups by different regions and angles and then combine the profiles in each group by applying 3D visualization technology. As a result, the discrete 3D lithologic models (Fig. 7) and longitudinal profiles in different directions (Fig. 8) are

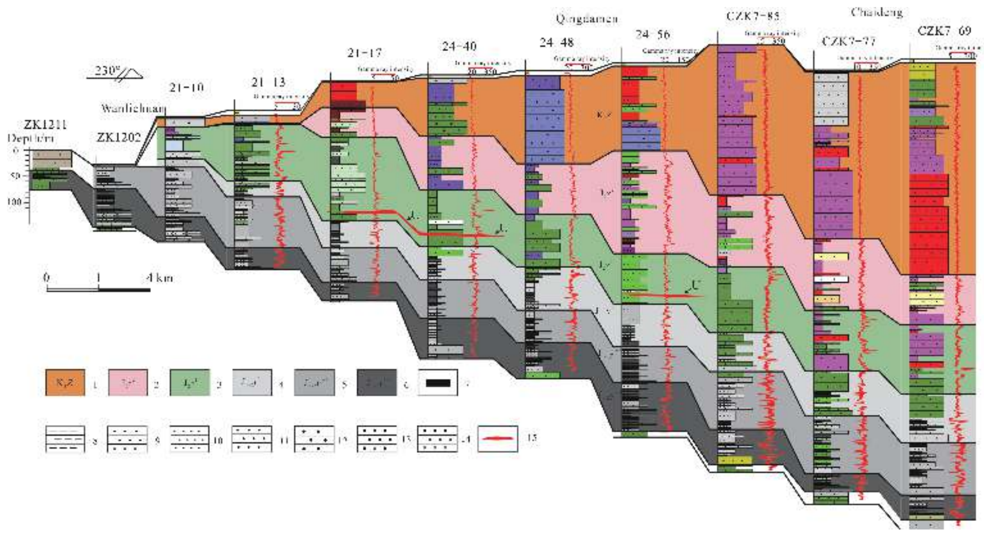

Fig. 6 Comparison profile of Jurassic–Lower Cretaceous strata in the Wanlichuan–Chaideng area on the northeastern margin of Odors Basin

1—Lower Cretaceous Zhidan Group; 2—Upper member of Middle Jurassic Zhiluo Formation; 3—Lower member of Middle Jurassic Zhiluo Formation; 4—Member No. 5 of Mid-Lower Jurassic Yan'an Formation; 5—Members Nos. 3-4 of Mid-Lower Jurassic Yan'an Formation; 6—Members Nos. 1-2 of Mid-–Lower Jurassic Yan'an Formation; 7—Coal seam; 8—Mudstone; 9—Siltstone; 10—Fine-grained sandstone; 11—Medium-grained sandstone; 12—Coarse-grained sandstone; 13—Pebbly coarse-grained sandstone; 14—Conglomerate; 15—Stratum bearing Uranium deposit. *Note*: the colors of lithologic patterns in the stratigraphic histogram denote the colors of core

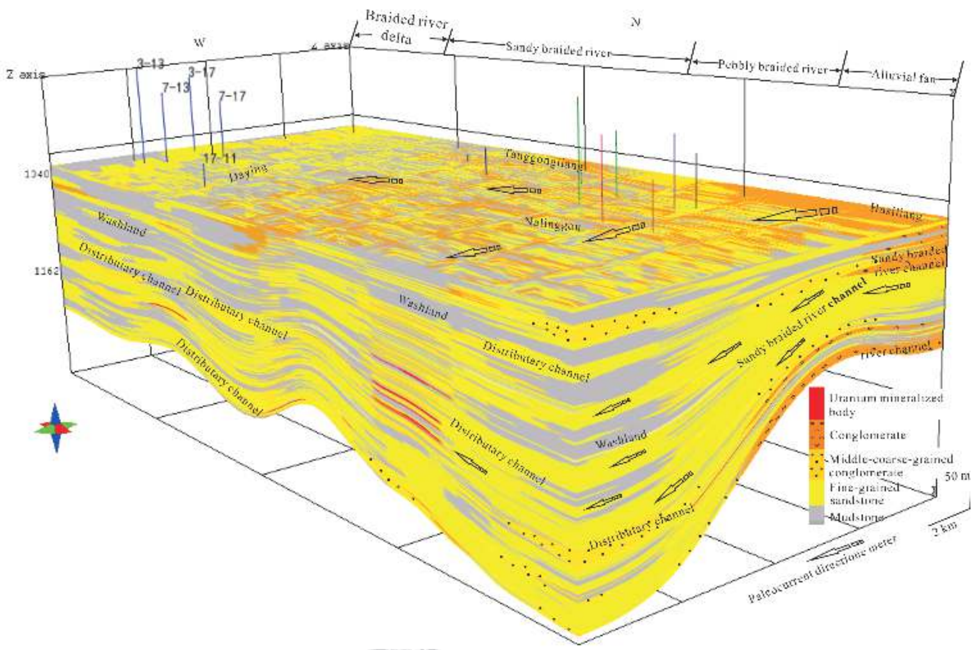

Fig. 7 Relationship of the 3D attribute model of lithology and grain size to uranium mineralization in the lower member of middle Jurassic Zhiluo Formation in the Daying–Nalinggou mining area

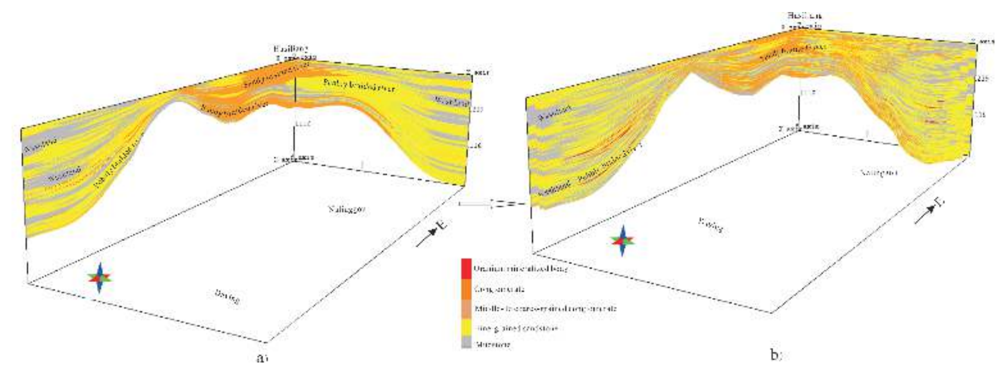

Fig. 8 Relationship of 3D spatial distribution of skeleton sand bodies and sedimentary systems with uranium mineralized bodies in the Daying–Nalinggou area

Notes: there exists regional transition of sedimentary facies in the Daying–Nalinggou area. The sedimentary system transits orderly from pebbly braided river facies to sandy braided river facies and further to braided river delta facies toward west and south from the Husiliang area. The uranium mineralization in the Daying area (red) is mainly developed in the lithologic transition interface between the braided river sand bodies and the braided river delta

generated. They can be used to analyze the discrete relationship of lithology and grain sizes. The atlas developed can be used to intuitively analyse the lithologic distribution in the study area in 3D space from multiple angles, thus providing credible models for the metallogenic rule research and exploration deployment of the sandstone-hosted uranium deposits in the area.

4 Data Quality Control

4.1 Quality Control of Borehole Data

All of the borehole data were acquired in accordance with the uniform standard *Technical Requirements for the Building of Borehole Database of Sandstone-hosted Uranium Deposits in Major Basins of North China (Trial)* to ensure that the data were authentic, accurate, logically consistent, standardized, and integral. All necessary modifications and changes were fully demonstrated by the project team, with corresponding records and reasonable explanations being kept. The data quality control and the review and acceptance check of the databases were sufficiently performed from the project team to the organization responsible for the project. The self-check rate and mutual check rate were both 100%, the inspection rate at the project level was 60%, and the rate of the spot check conducted by higher-level organizations was 15%. In the case where problems occurred during the inspection or check, the reasons were quickly found and the problems carefully rectified. In this way, the error rate of the database data reported was less than 0.3%. Meanwhile, the inspection records and modification explanations of the database were kept. In summary, strict quality control was implemented both in the stage when the data were collected and input into the database and in the stage of data processing, thus ensuring high quality of data.

4.2 Quality Assessment of Atlas and 3D Geological Models

All of the borehole data used to develop the result maps and 3D geological models originated from boreholes used to build the borehole databases. Therefore, they are credible. The borehole databases involve an area of about 420 km^2 and 195 boreholes were used in modeling. The boreholes are evenly distributed in general, mostly with a grid density of 2 km × 2 km. Meanwhile, the reasonability of stratigraphic boundaries was examined by preparing the well profiles of many strata, comparison profiles of skeleton sand-bodies, and the fence-shaped well profiles, as well as logging curves and seismic sections. Once unreasonable strata division was discovered, it was modified based on demonstration, and then the borehole databases were updated accordingly. The result maps were automatically corrected based on the updated databases, thus guaranteeing accurate comprehensive maps. In addition, the 2D well profiles and sand-body profiles can also be involved in the 3D modeling as restrictions. In mid-December, 2018, the Tianjin Center of China Geological Survey organized experts to review the database, building and 3D geological modeling of the Dongsheng area, and as a result, field acceptance was passed.

5 Data Value

The Database built in this study enables unified management of borehole data of the study area, thus increasing the efficiency of the integrated application of the data. Furthermore, automated mapping of the borehole data, based on the borehole databases, was achieved by using the 3D modeling software Gxplorer. In this way, massive borehole attributes can be presented more quickly and intuitively. They can be rapidly expressed in a 3D visual way and quickly queried according to multiple conditions. All these will provide data and information technology for the exploration of uranium deposits and the integration of exploration results, and also offer a good reference for the building of borehole databases and 3D modeling of other areas. The Access borehole databases built in this study are traditional relational databases. They are lightweight and adopt file-level storage, easy to use. Additionally, they feature good compatibility and can be directly used in other 3D modeling software.

6 Recommendations on Data Usage

In this study, the databases are in.mdb format and the atlas is in.bwi and according.jpg formats. The result maps and the 3D models were developed using the 3D modeling software Gxplorer developed by Xi’an Shiwen Software Co. Ltd., in which the Ezwell module was used for data processing and interpretation, as well as result analysis.

The Ezwell module features object-oriented operation style, making comprehensive interpretation of single-well logging data and the editing of map faces intuitive, flexible, and efficient. Meanwhile, aesthetically pleasing single-well result maps in various forms with rich contents can be generated. The operations of the Ezwell module are simple, fast, and easy to learn, including adding map tracks, editing map tracks, editing curves, and setting filling and displaying ways. The Ezwell module is equipped with strong drawing template technology. The style being used can be saved as a template and added into the template library in order to be used for other boreholes. The templates can be changed anytime into new image formats when necessary. Meanwhile, the template technology enables the quick generation of multiple types of result maps. Data pre-processing functions are also very strong in the module, including curve editing, curve depth correction, curve splicing, curve filtering, deviated well straightening, data preview, data calculating, data analysis and statistics, and core location. Two- or three-dimensional cross-plots can be generated using these functions. In addition, images can be saved into abundant formats in this module. Various result maps (such as comprehensive histograms of strata, typical curves, composite diagrams of core, comprehensive interpretation maps, and cross-plots) can be saved as vector diagrams (such as EMF, CGM, DXF, and PDF) and bitmaps (BMP, JPEG, JPG, GIF, TIF, and TIFF).

7 Conclusion

(1) The Database was developed based on previous borehole data of coalfields and uranium deposits, during which borehole attributes were comprehensively acquired on a large scale for the first time. Key borehole data related to coalfields and uranium deposits were collated, scanned, converted into required data types, input into data tables, and integrated into databases according to unified standards and requirements. As a result, the Database was established, achieving unified management of borehole data from multiple sources and providing credible data for the "quick uranium exploration based on secondary development" of existing coalfield borehole data of the Dongsheng area.

(2) Critical basic geological maps can be quickly generated based on the Database by using 3D modeling software, including well profiles and the isoline maps of the elevations of roofs and floors, stratum thickness, sand-body thickness, and sand content of target strata bearing coal and uranium. By precisely building the 3D geological models of different types and scales, the 3D spatial distribution relationship between different geological metallogenic factors and uranium mineralization were presented from multiple angles. This will provide credible models for the metallogenic rule research and exploration deployment of the sandstone-hosted uranium deposits in the study area.

Acknowledgments: Associate Professor Wu Liqun and Dr. Sun Yuhan from China University of Geosciences (Wuhan) and Professorate Senior Engineer Yang Cai from the Geological Survey Institute of Inner Mongolia participated in the 3D geological modeling. Professor Wang Huichu, Professorate Senior Engineer Xin Houtian, Professor Li Chengdong, and Professor Zhao Fengqing from the Tianjin Center of China Geological Survey proposed many valuable suggestions. We hereby would like to extend our sincere appreciation to all of them.

References

Chen Lulu, Tang Chao, Li Jianguo, Zhong Yanqiu, Gu Shefeng, Wei Jialin, Xiao Peng, Xu Zenglian, Zeng Hui, Liu Huajian, Chenyin. 2018. Petrology characteristics of the uranium-bearing layer of Sifantai Formation in Daqing placanticline of Songliao basin and their geological implications[J]. Geological Survey and Research, 41(1): 33−39, 66 (in Chinese with English abstract).

Feng Xiaoxi, Teng Xueming, He Youyu. 2019. Preliminary discussions on the metallogenesis of the Dongsheng uranium orefields in the Ordos basin[J]. Geological Survey and Research, 42(2):

96−103 (in Chinese with English abstract).

Jin R S, Teng X M, Li X G, Si Q H, Wang W. 2020. Genesis of sandstone-type uranium deposits along the northern margin of the Ordos Basin, China[J]. Geoscience Frontiers, 11(1): 215−227.

Jin R S, Yu R A, Yang J, Zhou X, Teng X M, Wang S B, Si Q H, Zhu Q, Zhang T F. 2019. Paleo-environmental constraints on uranium mineralization in the Ordos Basin: evidence from the color zoning of U-bearing rock series[J]. Ore Geology Reviews, 104(2019): 175−189.

Jiao Y Q, Wu L Q, Rong H. 2016. The relationship between Jurassic Coal Measures and Sandstone-Type Uranium Deposits in the Northeastern Ordos Basin, China[J]. Acta Geologica Sinica (English Edition), 90(6): 2117−2132.

Jiao Y Q, Wu L Q, Wang M F, Xu Z C. 2005. Forecasting the occurrence of sandstone-type uranium deposits by spatial analysis: an example from the northeastern Ordos Basin, China. In: Mao JW, Bierlein, FP (Eds.), Mineral Deposit Research: Meeting the Global Challenge[M]. Springer-Verlag, Berlin Heidelberg, 273−275.

Jiao Yangquan, Wu Liqun, Yang Shengke, Lyu Xinbiao, Yang Qin, Wang Zhenghai, Wang Minfang. 2006. Uranium reservoir sedimentology: basis for exploration and development of sandstone uranium deposits[M]. Beijing: Geological Publishing House, 1−323 (in Chinese).

Jiao Yangquan, Wu Liqin, Rong Hui, Peng Yunbiao, Wan Junwei, Miao Aisheng. 2012. Uranium reservoir architecture and ore-forming flow field study: a key of revealing Dongsheng sandstone-type uranium deposit mineralization mechanism[J]. Geological Science and Technology Information, 31(5): 94−104 (in Chinese with English abstract).

Jiao Yangquan, Wu Liqun, Peng Yunbiao, Ronghui, Ji Dongmin, Miao Aisheng, Li Hongliang. 2015. Sedimentary-tectonic setting of the deposition-type uranium deposits forming in the Paleo-Asian tectonic domain, North China[J]. Earth Science Frontiers, 22(1): 189−205 (in Chinese with English abstract).

Jiao Yangquan, Wu Liqun, Rong Hui, Zhang Fan, Yue Liang, Tao Zhenpeng, Sun Yuhan. 2018. Geological Modeling of Uranium Reservoir: The Geological Foundation of Revealing the Metallogenic Mechanism and Solving "Remaining Uranium"[J]. Editorial Committee of Earth Science-Journal of China University of Geosciences, 43(10): 3568−3583 (in Chinese with English abstract).

Jin Ruoshi, Cheng Yinhang, Li Jianguo, Sima Xianzhang, Miao Peisen, Wang Shaoyi, Ao Cong, Li Hongliang, Li Yanfeng, Zhang Tianfeng. 2017. Late Mesozoic continental basin"Red and Black beds"coupling formation constraints on the sandstone uranium mineralization in northern China[J]. Geology in China, 44(2): 205−223 (in Chinese with English abstract).

Jin Ruoshi, Tan Zhian. 2013. Study on the exploration sequence of sandstone-hosted uranium deposits in North China[J]. Geological Survey and Research, 36(2): 81−84 (in Chinese with English abstract).

Li S T, Yang S G, Tomasz J. 1995. Upper Triassic-Jurassic foreland sequences of the Ordos Basin in China stratigraphic, evolution of foreland basins[J]. SEPM Special Publication, 52: 233−241.

Liu C Y, Zhao H G, Zhao J F, Wang J Q, Zhang D D, Yang MH. 2008. Temporospatial coordinates of evolution of the ordos basin and its mineralization responses[J]. Acta Geologica Sinica (English

Edition), 82(6): 1229−1243.

Liu C Y, Zhao H G, Sun Y H. 2009. Tectonic background of Ordos Basin and its controlling role for basin evolution and energy mineral deposit[J]. Energy Exploration & Exploitation, 27(1): 15−27.

Lu Chao, Jiao Yangquan, Peng Yunbiao, Wu Liqun, Miao Aisheng, Rong Hui, Xie Huili. 2018. Paleo-interlayer oxidation zone identification and spatial localization prediction in Daying area[J]. Geology in China, 45(6): 1228−1240 (in Chinese with English abstract).

Lyu Zhicheng, Pang Zhenshan, Xue Jianling, Geng Lin, Zhang Zhihui, Zhen Shimin, Tao Wen, Jia Ruya, Chen Hui, Yao Lei. 2018. Dataset of ore-prospecting results surrounding and beneath the Old Mines from 2012 to 2014[J]. Geology in China, 45(S1): 58−97.

Miao Peisen, Li Jiangguo, Tang Chao, Jin Ruoshi, Cheng Yinhang, Zhao Long, Xiao Peng, Wei Jialin. 2017. Metallogenic condition and prospecting orientation for deep sandstone-hosted uranium deposits in Mesozoic-Cenozoic basins of North China[J]. Geological Bulletin of China, 36(10): 1830−1840 (in Chinese with English abstract).

Tang Chao, Jin Ruoshi, Gu Shefeng, Li Jianguo, Zhong Yanqiu, Miao Peisen, Sima Xianzhang, Wei Jialin. 2018. Discovery and significance of industrial uranium ore in Sifangtai Formation, north Songliao basin[J]. Geological Survey and Research, 41(1): 1−8, 32 (in Chinese with English abstract).

Wei Jialin, Tang Chao, Xu Zenglian, Xiao Peng, Liu Huajian, Zeng Hui, Chen Lulu, Zhao Lijun, Guo Hu, Zhang Chao, Zhu Qiang, Li Yanfeng. 2018. Research on sandstone-hosted uranium mineralization of the Sifangtai Formation in southern Daqing placanticline[J]. Geological Survey and Research, 41(1): 9−17 (in Chinese with English abstract).

Yang Junjie, Pei Xigu. 1996. Natural Gas Geology in China[M]. Beijing: Petroleum Industry Press, 3−20 (in Chinese).

Yu Reng’an, Sima Xianzhang, Jin Ruoshi, Miao Peisen, Peng Shenglong. 2020. Discovery of a large-size uranium deposit in Northeast Ordos Basin[J]. Geology in China, 47(3): 883−884 (in Chinese with English abstract).

Zhang Tianfu, Sun Lixin, Zhang Yun, Cheng Yinhang, Li Yanfeng, Ma Hailin, Lu Chao, Yang Cai, Guo Genwan. 2016. Geochemical Characteristics of the Jurassic Yan'an and Zhiluo Formations in the Northern Margin of Ordos Basin and Their Paleoenvironmental Implications[J]. Acta Geologica Sinica, 90(12): 3454−3472 (in Chinese with English abstract).

Zhang Tianfu, Zhang Yun, Miaopeisen, Yu Reng’an, Li Jianguo, Jin Ruoshi, Sun Lixin. 2018. Study on the chemical index of alteration of the Middle and Late Jurassic Strata in the western margin of Ordos basin and its implications[J]. Geological Survey and Research, 41(4): 258−262 (in Chinese with English abstract).

Zhang Tianfu, Zhang Yun, Cheng Yinhang, Miao Peisen, Ao Cong, Jin Ruoshi, Duan Lianfeng, Duan Xiaolong. 2019. Integrated identification of sequence boundary through outcrop, seismic with logging and geochemistry:A case of Jurassic in northeastern margin of Ordos basin[J]. Coal Geology & Exploration, 47(1): 40−48 (in Chinese with English abstract).

Zhang Tianfu, Zhang Yun, Jin Ruoshi, Yu Reng'an, Sun Lixin, Cheng Yinhang, Ao Cong, Ma Hailin. 2020a. Characteristics of Jurassic sequence boundary surfaces on the northeastern margin of Ordos basin and their constraints on the spatial-temporal properties of sandstone uranium mineralization[J]. Geology in China, 47(2): 278−299 (in Chinese with English abstract).

Zhang Tianfu, Zhang Yun, Sun Lixin, Ma Hailin, Cheng Yinhang. 2020b. Borehole Databases and 3D Geological Model of Jurassic-Cretaceous Strata in Dongsheng Area, North Odors Basin[DB/OL]. Geoscientific Date & Discovery Publishing System. (2020-06-30). DOI: 10.35080/data.H.2020.P20.

Zhang Yun, Sun Lixin, Zhang Tianfu, Ma Hailin, Lu Chao, Li Yanfeng, Cheng Yinhang, Yang Cai, Guo Jiacheng, Zhou Xiaoguang. 2016. Sequence Stratigraphy Study of Coal-Uranium Bearing Rock Series and Occurrence Regularity Coal and Uranium in the Northeastern Margin of Ordos Basin[J]. Acta Geologica Sinica, 90(12): 3424−3440 (in Chinese with English abstract).

Zhou Xiaoxi, Chen Anshu, Deng Fan, Yang Jun, Wang Xinhua. 2016. Design and realization of uranium mine drilling database of the important basins in North China[J]. Geological Survey and Research, 39(3): 231−236 (in Chinese with English abstract).

Zhou Xiaoxi, Deng Fan, Wan Lin, Yang Jun. 2019. Design and implementation of information management platform for big data of uranium[J]. Coal Geology & Exploration, 47(1): 6−14 (in Chinese with English abstract).