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中澳二氧化碳地质封存国际合作
The China Australia Geological Storage of CO₂ Project

CO₂ Geological Storage of Target Area Scale Selection and Evaluation Method

二氧化碳地质封存 目标区级别评价与筛选方法

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China Australia Geological Storage of CO₂

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OUTLINE



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目标与任务 Project Goals and Objectives

- 任务1：建立二氧化碳地质封存目标区级别评价指标体系与评价方法。
- 任务2：开展四川盆地目标区级调查评价，选定一批适宜的目标区，编制目标区级别评价成果图；在四川盆地内选择1-2处典型目标区开展案例研究。
- 任务3：选取评价指标体系中的构造圈闭、水文地质条件、储层非均质性关键指标进行专题研究。
- Task1: Establish selection method and indicator system of the target area scale of CO₂ geological sequestration.
- Task2: Carry out the investigation and evaluation of target area scale in Sichuan basin, and select a number of appropriate target areas, compile target area scale evaluation achievement map; Choose one or two typical target areas to carry out case study in Sichuan basin.
- Task 3: Select key indicators to carry out specific study.



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成果进展 Achievements of Research



- 二氧化碳地质封存目标区级别评价指标体系
- Target scale selection and evaluation index system of CO₂ geological storage
- 四川盆地目标区级评价案例
- Case of target evaluation of Sichuan Basin
- 沉积体系及其沉积相对CO₂地质封存适宜性的影响
- Effects of depositional system and sedimentary on CO₂ geological storage suitability



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CO₂地质封存目标区级别评价指标体系

Target scale selection and evaluation index system of CO₂ geological storage



China Australia Geological Storage of CO₂

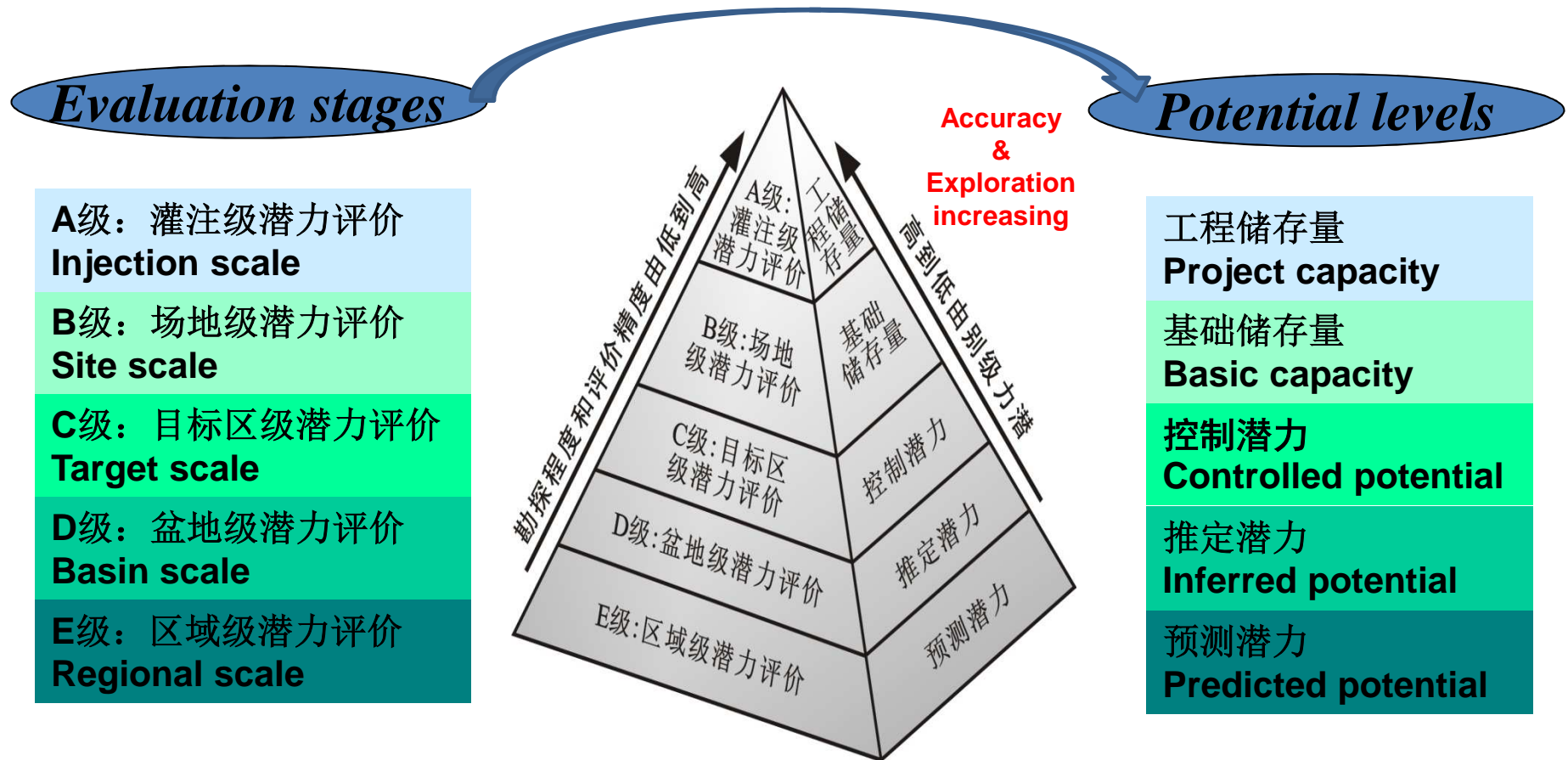
中澳二氧化碳地质封存



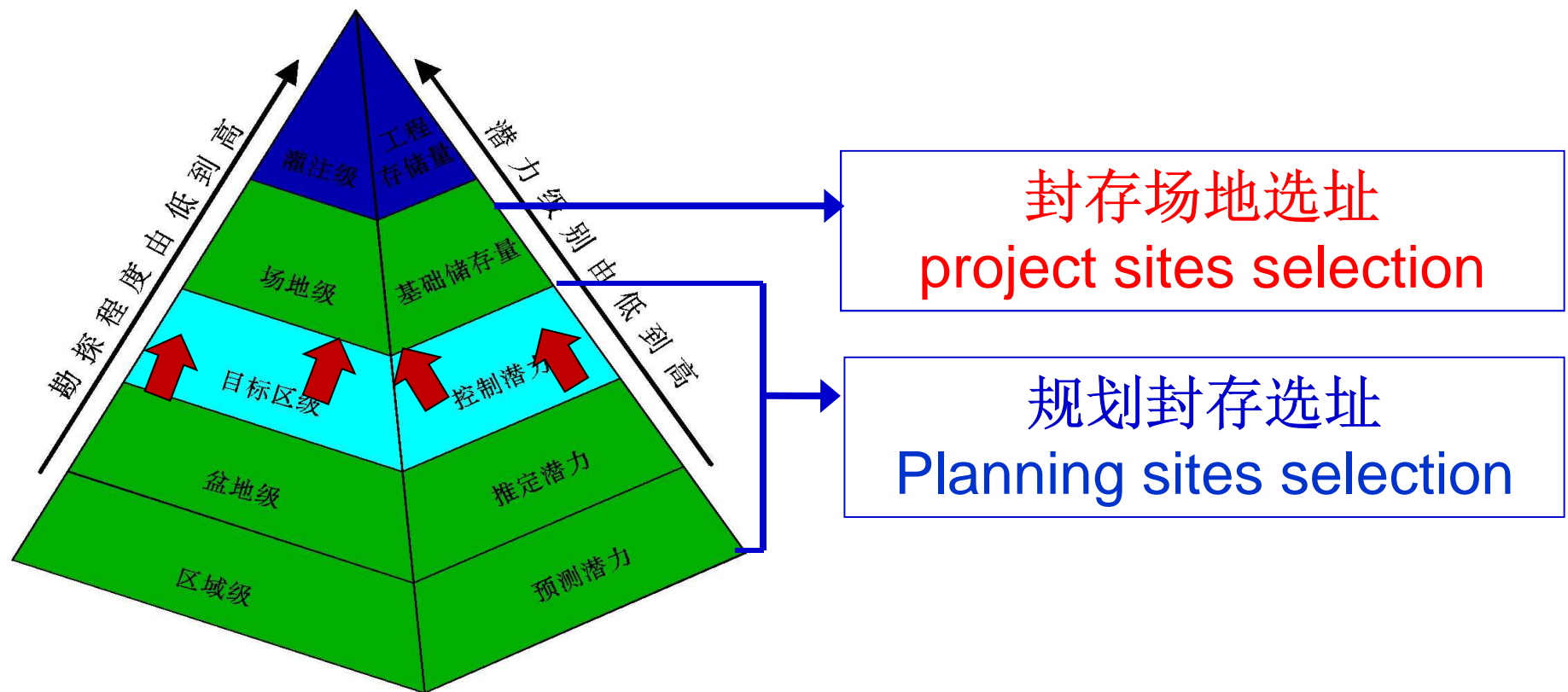
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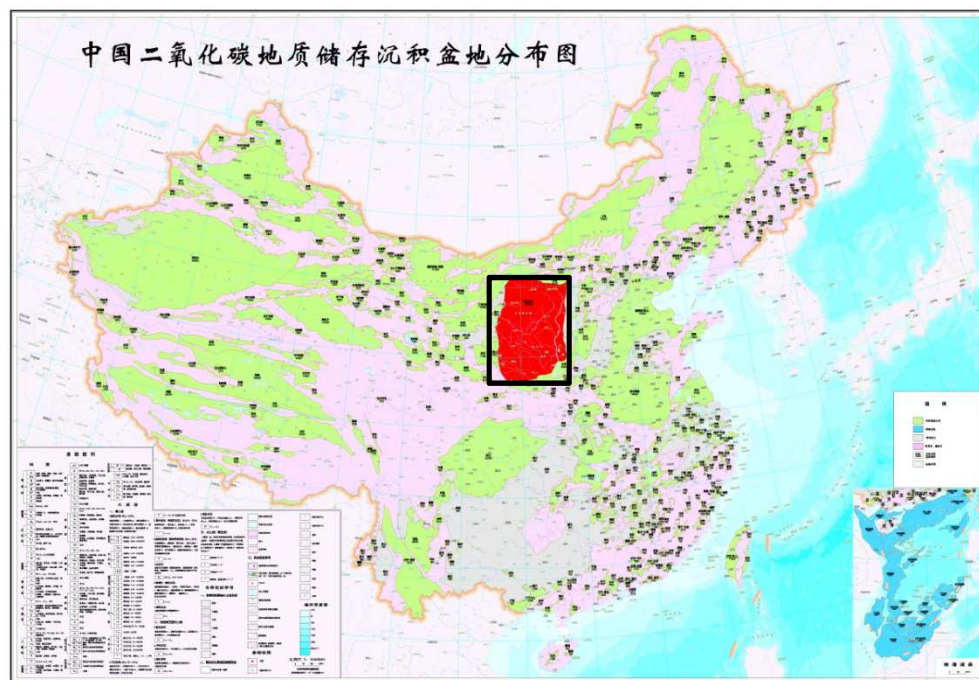
CHEGS Based on the potential evaluation scales divided by Carbon Sequestration Leadership Forum (CSLF) and hydrogeological exploration experiences, we divided the potential evaluation scales into the following 5 stages.

中国地质调查局水文地质环境地质调查中心借鉴碳封存领导人论坛和地下水、矿产勘查经验，将我国二氧化碳地质储存潜力评价分为五个阶段。

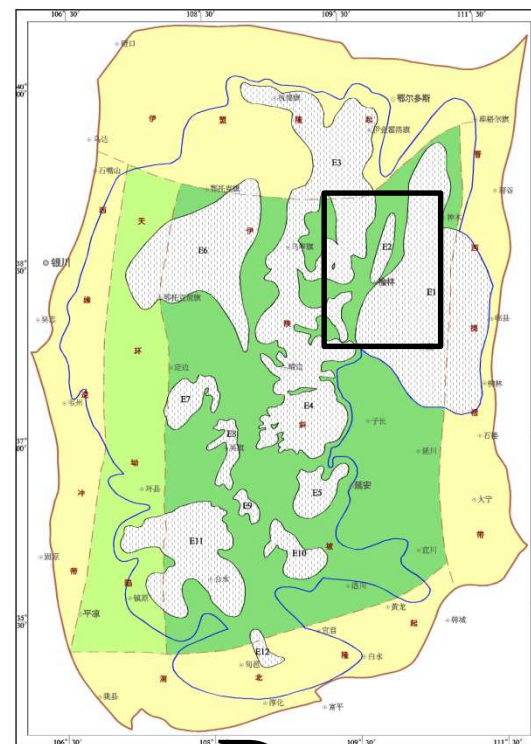


- 目标区筛选与评价具有承上启下的作用。一方面，“目标区”是全国盆地级二氧化碳地质封存潜力与适宜性评价得出的，有进一步开展选址研究价值的地区；另一方面，“目标区”是CO₂地质封存工程选址的起点和主要依据。
- The target area assessment served as a transition. On the one hand, “the target area” is result from Basin potential and suitability assessment, and is of value to study on the site selection; on the other hand, “the target area” is the origin and primary reason of the demo-project site selection.

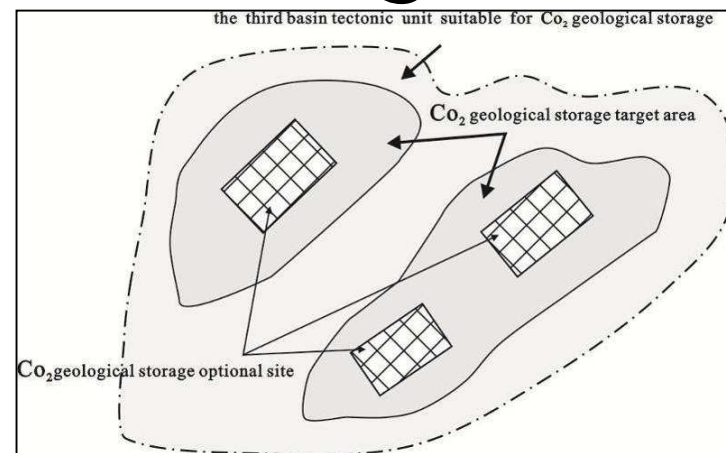




E → **D**



D ↓ **C**



B ← **C**



目标区级别评价基本原则

Basic principle for Target scale selection and evaluation

- 1.安全性原则;
- 2.目标储层有效封存量大的原则;
- 3.经济原则;
- 4.符合一般建设项目环境保护选址条件,不受外部不良地质因素影响的原则。

- 1. Safety ;
- 2. Most effective storage capacity in reservoir
- 3. Economic suitable;
- 4. In line with environmental protection general construction project site conditions, not influenced by geological factors of external adverse principle



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中澳二氧化碳地质封存



二氧化碳地质储存目标靶区评价主要指标构成简表

| 指标层 | 指标亚层 | 指 标 组 成 |
|--------|---------------|---|
| 安全性 | 1、区域地壳稳定性 | ①地震动峰值加速度；②目标靶区地震安全性；③周边25km半径范围内是否有活动断层 |
| | 2、盖层宏观特征 | ①主力盖层的埋深；②盖层岩性；③主力盖层的单层厚度；④盖层分布的连续性；⑤渗透率；⑥主力盖层之上的二次截留能力；⑦盖层微观封闭性指数 |
| | 3、断裂泄露通道 | ①断裂和裂缝的发育情况；②目标靶区范围内是否有其他深度大于800 m的钻井及废弃井；③现有技术条件下未被发现的断裂 |
| | 4、水文地质条件 | ①水动力作用；②深部咸水层水头状态 |
| 储层规模 | 1、储层特征 | ①埋深；②厚度；③沉积环境；④地层组合与砂厚比；⑤矿化度；⑥地层压力系数；⑦有效储层长宽比 |
| | 2、储层物性参数 | ①孔隙度；②渗透率 |
| | 3、地热地质特征 | ①地温梯度；②大地热流值；③地表温度 |
| | 4、储层储存前景 | ①有效储存量；②使用年限； |
| 社会环境风险 | 1、社会环境 | ①人口密度；②与城市的距离；③土地利用现状 |
| | 2、地质环境 | ①地质灾害易发性；②是否在采矿塌陷区、岩溶塌陷区、地面沉降区、沙漠活动区、火山活动区；③是否低于江河湖泊、水库最高水位线或洪泛区 |
| | 3、所在地区的性质 | ①是否符合城市和区域发展总体规划、是否在农业保护区、自然保护区、风景名胜区、文物保护区、生活饮用水源保护区与供水远景规划区、矿产资源储备区和其他需要特别保护的区域；②植被状况 |
| | 4、与饮用水源的关系和距离 | ①CO ₂ 储层上部是否有可供工农业利用的地下水含水层；②是否在饮用地下水主要补给区内；③距离河流、水库等地表饮用水水源的距离 |
| 经济适宜性 | 1、内部环境 | ①碳源规模；②碳源距离；③CO ₂ 运输方式；④蕴矿状况 |

Criteria of Target Selection for CO₂ geological storage in deep saline aquifer

| Layer | Sub-layer | Indicators |
|---|---------------------------------|---|
| Safety | 1.Crustal stability | ①Motion peak acceleration of earthquake;②Earthquake;③Active faults within 25km |
| | 2.Caprock | ①Depth; ②Rock;③Single thick; ④Continuity; ⑤Permeability; ⑥Quality and quantity of sub-cover; ⑦ Microscopic closed index |
| | 3.Faults and Leak | ①Fracture development situation; ②If there are other drilling and abandoned wells deeper than 800 m in the target range; ③Unknown faults under the existing technical conditions |
| | 5. Hydrogeology | ①Hydrodynamics; ②Water head of deep saline aquifers |
| Reservoir | 1. Reservoir feature | ①Depth;②Thickness;③Sedimentary environment;④Stratigraphic combination and sand percent;⑤ Mineralization;⑥Formation pressure coefficient;⑦aspect ratio of effective reservoir |
| | 2.Physical properties | ①Porosity;②Permeability |
| | 3.Geothermal | ①Geothermal gradient;②Terrestrial heat flow;③Surface temperature |
| | 4.Store prospect | ①Effective storage;②service life |
| Socio-economic and environmental conditions | 1.Reservoirs around | ①Occasion to happen geological disasters;②Mining subsidence area, karst subsidence area;③Subsidence zone;④Desert activity;⑤Volcanic activity;⑥Lower than the highest water level of Rivers, lakes and reservoirs / flood storage;⑦Topography of perfusion site |
| | 1. Social Environment | ①population density;②The distance to city;③Land use |
| | 2. Geological environment | ①Geological disasters;②Whether in mining subsidence area, karst subsidence area, ground subsidence area, activity area desert, volcanic activity area;③Whether lower than highest water level of the rivers,lakes and reservoirs, or in floodplains |
| | 3.Character of site | ①City and regional development planning, Agricultural reserve, nature reserves, Scenic spot, cultural relics (archaeological) reserves, Life drinking water reserves, Water supply planning vision, mineral resources reserve districts and other zones that need special protection (Whether in special protection area) ;②Vegetation status |
| | 4.Safe distance to drink source | ①Whether there is groundwater aquifers for industrial or agricultural use in the upper of CO ₂ reservoir;② Whether in the main supply drinking groundwater area;③Distance to surface water source for drinking |
| Economical suitability | | ①Carbon source;②Carbon source distance;③Mode of CO ₂ transportation;④Mineral deposits |

● 地质安全性评价指标层

包括区域地壳稳定性、盖层封闭性特征、可能的CO₂泄漏通道和水文地质条件
4个评价指标亚层，16个评价指标

| 评价指标 | | 评价等级 | 好 | 一般 | 差 |
|-------------------------|---|------|--------------------------|------------------------------|--------------------------|
| 区域地壳稳定性 | 地震动峰值加速度/g | | <0.05 | 0.10~0.15 | >0.2 |
| | 目标靶区地震安全性 | | 安全 | 中等 | 较危险 |
| | 目标靶区25km半径范围内是否有活动断层 | | 无活动断裂，且其外围25km范围内不存在活动断层 | 目标靶区内无活动断裂，但其外围25km范围内存在活动断层 | 目标靶区内及其外围是否发育有活动断裂迄今尚不明确 |
| 盖层封闭性 | 主力盖层的埋深/m | | 800~1200 | 1200~1700 | >1700 |
| | 盖层岩性 | | 蒸发岩类 | 泥质岩类 | 页岩和致密灰岩 |
| | 主力盖层单层厚度/m | | >100 | 100~50 | <50 |
| | 盖层分布的连续性 | | 分布连续性，具区域性 | 分布基本连续 | 分布不连续，局限 |
| | 渗透率/10 ⁻³ μm ² | | K<0.01 | 0.01≤K<1 | K>1 |
| | 主力盖层之上的二次截留能力 | | 多套，质量好 | 多套，质量一般 | 一套 |
| | 盖层微观封闭性指数（CRI） ——封气指数H _g /m | | ≥200 | 100~200 | ≤100 |
| 可能的CO ₂ 泄漏通道 | 断裂和裂缝的发育情况 | | 有限的裂缝，无断层 | 裂缝发育中等，无断层 | 大裂缝，发育断层中等 |
| | 目标靶区范围内是否有其他深度大于800m的钻井及废弃井 | | 无 | 无 | 有 |
| | 现有技术条件下未被发现的断裂 | | 无 | 无 | 可能有 |
| 水文地质条件 | 水动力作用 | | 水力封闭作用 | 水力封堵作用 | 水力运移逸散作用 |
| | 深部咸水层水头状态 | | 低于场地地面 | 大体与场地地面一致 | 高于场地地面 |

● Safety

It consist of Crustal stability, Caprock、Faults and Leak and Hydrogeology 4 sub-layer and 16 indicators.

| Sub-layer | Indicators | Rank | | |
|-------------------|---|--|---|---|
| | | Good | Medium | Poor |
| Crustal stability | Motion peak acceleration of earthquake / (10 m/s^2) | <0.05 | $0.10 \sim 0.15$ | >0.2 |
| | Earthquake | Safe | Medium | Danger |
| | Active faults within 25km | No active faults in target and within 25 km range around | No active faults in target, but within 25 km range around | Whether the target and its peripheral targets are developed active faults is not clear so far |
| Caprock | Depth of Caprock /m | $800 \sim 1\ 200$ | $1\ 200 \sim 1\ 700$ | $>1\ 700$ |
| | Lithology of Caprock | Evaporites | Mudstone | Shale or Dense limestone |
| | Single thick of caprock /m | >100 | $100 \sim 50$ | <50 |
| | Continuity of caprock | With regional continuity distribution | Substantially continuous distribution | Distribution is not continuous, limitations |
| | Permeability / $10^{-3} \mu\text{m}^2$ | $K < 0.01$ | $0.01 \leq K < 1$ | $K > 1$ |
| | Quality and quantity of sub-cover | Multiple sets with good quality | Multiple sets with general quality | Only one set |
| | Microscopic closed index H_g/m | ≥ 200 | $100 \sim 200$ | ≤ 100 |
| Faults and Leak | Fracture development situation | Limited fractures, no fault | Moderate fractures, no fault | Large fractures, faults moderate growth |
| | If there are other drilling and abandoned wells deeper than 800 m in the target range | No | No | Yes |
| | Unknown faults under the existing technical conditions | No | No | Maybe |
| Hydrogeology | Hydrodynamics | Hydraulic closed role | Hydraulic sealing action | Water transport fugitive role |
| | Water head of deep saline aquifers | Below Ground | Consistent with the ground | Above ground |

● 封存规模指标层

包括储层特征、储层物性参数、地热地质特征和储层封存前景4个评价指标亚层，14个评价指标

| 评价指标 | | 评价等级 | 好 | 一般 | 差 |
|--------|--------------------------------------|------|-------|------------|--------|
| 储层特征 | 储集岩的岩性 | | 碎屑岩 | 碎屑岩、碳酸盐岩混合 | 碳酸盐岩 |
| | 主力储层的厚度/m | | >80 | 80~30 | <30 |
| | 有效储层长宽比 | | <1:3 | 1:3~1:5 | >1:5 |
| | 层间非均质性（砂体连续性）/m | | >1200 | 600~1200 | <600 |
| | 储层压力系数 | | <0.9 | 0.9~1.1 | >1.1 |
| | 地层水矿化度/g/L | | 10~50 | 3~10 | <3、>50 |
| 储层物性参数 | 孔隙度/% | 砂岩 | >15 | 15~10 | <10 |
| | | 碳酸盐岩 | >12 | 12~4 | <4 |
| | 渗透率/ $10^{-3}\mu\text{m}^2$ | 砂岩 | >50 | 50~10 | <10 |
| | | 碳酸盐岩 | >10 | 10~5 | <5 |
| 地热地质特征 | 地热流值/ mW/m^2 | | <50 | 50~70 | >70 |
| | 地温梯度/ $^{\circ}\text{C}/100\text{m}$ | | <2 | 2~3 | >3 |
| | 地表温度/ $^{\circ}\text{C}$ | | <3 | 3~25 | >25 |
| 储层封存前景 | 有效封存量/ 10^4 t | | >900 | 900~300 | <300 |
| | 使用年限/a | | >30 | 30± | <30 |

● Reservoir

It consist of Reservoir feature, physical properties、 Geothermal and Store prospect 4 sub-layer and 16 indicators.

| Sub-layer | Indicators | | Rank | | |
|---------------------|---|-----------|---------|-----------------------------------|-----------------|
| | | | Good | Medium | Poor |
| Reservoir feature | Lithology | | Clastic | Mixed clastic and carbonate rocks | carbonate rocks |
| | Thickness /m | | >80 | 80~30 | <30 |
| | aspect ratio of effective reservoir | | <1:3 | 1:3~1:5 | >1:5 |
| | Heterogeneity between Stratum /m | | >1 200 | 600~1 200 | <600 |
| | Reservoir pressure coefficient | | <0.9 | 0.9~1.1 | >1.1 |
| | Mineralization of groundwater / (g/L) | | 10~50 | 3~10 | <3、 >50 |
| Physical properties | Porosity /% | Sandstone | >15 | 15~10 | <10 |
| | | Carbonate | >12 | 12~4 | <4 |
| | Permeability / $10^{-3} \mu\text{m}^2$ | Sandstone | >50 | 50~10 | <10 |
| | | Carbonate | >10 | 10~5 | <5 |
| Geothermal | Terrestrial heat flow / (mW/m^2) | | <50 | 50~70 | >70 |
| | Geothermal gradient / ($10^{-2} \text{ }^\circ\text{C}/\text{m}$) | | <2 | 2~3 | >3 |
| | Surface temperature / $^\circ\text{C}$ | | <3 | 3~25 | >25 |
| Store prospect | Effective storage / 10^4 t | | >900 | 900~300 | <300 |
| | Service life of reservoir /a | | >30 | 30 \pm | <30 |

● 社会环境风险指标层

包括社会环境、地质环境、所在地区的性质、与饮用水源的关系与安全距离的影响4个评价指标亚层11个评价指标

| 评价指标 | | 评价等级 | 好 | 一般 | 差 |
|-------------|--|-------------|---------------|--------------|-------------------|
| 社会环境 | 人口密度/人/km | | <25, 极端稀疏区 | 26~50, 绝对稀疏区 | >51, 相对稀疏区 |
| | 与居民点的距离/m | | >1200 | 800~1200 | <800 |
| | 土地利用现状 | | 沙漠等未利用土地 | 牧草地、林地、耕地、园地 | 居民点及工矿用地、交通用地、水域等 |
| 地质环境 | 地质灾害易发性 | | 不易发 | 低—中易发 | 高易发 |
| | 是否在采矿塌陷区、岩溶塌陷区、地面沉降区、沙漠活动区、火山活动区 | 否 | 否, 但可能存在影响 | 是 | 是 |
| | 是否低于江河湖泊、水库最高水位线或洪泛区 | | | | |
| 所在地区的性质 | 是否符合城市和区域发展总体规划 | 符合 | 符合 | 不符合 | 不符合 |
| | 是否在农业保护区、自然保护区、风景名胜区、文物(考古)保护区、生活饮用水源保护区、供水远景规划区、矿产资源储备区和其他需要特别保护的区域, 是否在特别需要保护的区域 | 不在, 且 >10km | 不在, 但可能存在影响 | 在 | 在 |
| | 植被状况(有无重点保护植物) | 无、低 | 少、一般 | 多、高 | 多、高 |
| | | | | | |
| 与饮用水源的关系与距离 | CO ₂ 储层上部是否有可供工农业利用地下水含水层 | 无 | 有, 但下伏有良好的隔水层 | 有, 下伏无良好的隔水层 | 有, 下伏无良好的隔水层 |
| | 是否在饮用地下水主要补给区内 | 不在 | 不在, 但可能存在影响 | 在 | 在 |
| | 距离河流等地表饮用水源的距离/km | >3 | 3~1 | <1 | <1 |

● Socio-economic and environmental conditions

It consists of social environment, geological environment、character of target and safe distance to drink source 4 sub-layer and 11 indicators.

| Sub-layer | Indicators | Rank | | |
|-------------------------------|---|------------------------------|--|---|
| | | Good | Medium | Poor |
| Social Environment | population density / (人/km) | <25,Extremely sparse areas | 26~50,Absolute sparse areas | >51,Relatively sparse area |
| | Distance to resident /m | >1 200 | 800~1 200 | <800 |
| | Land use | Desert and other unused land | Pasture, woodland, Farmland, garden | Residential, industrial land, transportation land, Waters, etc. |
| Geological environment | Occasion to happen geological disasters | Not prone | Low or medium prone | High prone |
| | Whether in mining subsidence area, karst subsidence area, ground subsidence area, activity area desert, volcanic activity area; | No | No,But may impact | Yes |
| | Lower than the highest water level of Rivers, lakes and reservoirs / flood storage | No | No,but may impact | Yes |
| Character of Target | City and regional development planning | Accord | Accord | Not accord |
| | Agricultural reserve, nature reserves, Scenic spot, cultural relics (archaeological) reserves, Life drinking water reserves, Water supply planning vision, mineral resources reserve districts and other zones that need special protection | No,and>10 km | No,but may impact | Yes |
| | Vegetation status | No | A few | Many |
| Safe distance to drink source | Whether there is groundwater aquifers for industrial or agricultural use in the upper of CO ₂ reservoir | No | Yes,but there is good underlying impermeable layer | Yes,and there is no good underlying impermeable layer |
| | Whether in the main supply drinking groundwater area | No | No,but may impact | Yes |
| | Distance to surface water source for drinking | >3 | 3~1 | <1 |

● 经济适宜性指标层

包括碳源规模、碳源距离、运输方式和蕴矿状况等4个指标

| 评价等级 评价指标 | 好 | 一般 | 差 |
|------------------|--------|--------------|-------|
| 碳源规模/ 10^4 t/a | >100 | $100\sim 50$ | <50 |
| 碳源距离/km | <20 | $20\sim 50$ | >50 |
| 运输方式 | 管道 | 公路、铁路 | 船舶 |
| 蕴矿状况 | 不压覆矿产 | 有矿产，但互不影响 | 压覆矿产 |

● Economical suitability

It consist of Amount of carbon , Carbon source distance 、 Mode of CO₂ transportation and Mineral deposits 4 sub-layer.

| Indicators | Rank | | |
|--|-----------------------|---|-------------------|
| | Good | Medium | Poor |
| Amount of carbon / (10 ⁴ t/a) | > 100 | 100~50 | < 50 |
| Carbon source distance /km | < 20 | 20~50 | > 50 |
| Mode of CO ₂ transportation | Pipeline | Road, rail | Shipping |
| Mineral deposits | Not Overlaid Minerals | There are minerals, but independently of each other | Overlaid Minerals |

评价方法 Evaluation Method

- 在目标靶区评价指标的科学化选取后，对各因子层和单要素的权重赋值采用专家评分法和层次分析法综合评判。通过相互之间重要性对比，建立重要性成对比较判断矩阵。
- After selecting target indexes target, determine the weights of each factor floor and each factor with using expert scoring method and AHP. Each index value is got by contrasting the importance of each index. Based on CO₂ geological storage target evaluation index evaluation

二氧化碳地质封存适宜性评价指标权重排序表

| 排序 | 评价指标 | 权重 | 排序 | 评价指标 | 权重 |
|----|-----------------------------|--------|----|---|--------|
| 1 | 地震动峰值加速度/g | 0.1077 | 23 | 地质灾害易发性 | 0.0114 |
| 2 | 目标靶区地震安全性 | 0.1077 | 24 | 有效储层长宽比 | 0.0108 |
| 3 | 储集岩的岩性 | 0.0835 | 25 | 蕴矿状况 | 0.0103 |
| 4 | 主力储层的厚度 | 0.0731 | 26 | 土地利用现状 | 0.0099 |
| 5 | 目标靶区25km半径范围内是否有活动断层 | 0.0538 | 27 | 地热流值 | 0.0084 |
| 6 | 主力盖层的埋深 | 0.0471 | 28 | 地温梯度 | 0.0084 |
| 7 | 盖层岩性 | 0.0393 | 29 | 主力盖层之上的二次截留能力 | 0.0082 |
| 8 | 断裂和裂缝的发育情况 | 0.0356 | 30 | 是否符合城市和区域发展总体规划 | 0.0079 |
| 9 | 孔隙度 | 0.0344 | 31 | 使用年限 | 0.007 |
| 10 | 储层渗透率 | 0.0344 | 32 | 盖层微观封闭性指数（CRI）——封气指数 | 0.0058 |
| 11 | 盖层渗透率 | 0.0305 | 33 | 深部咸水层水头状态 | 0.0057 |
| 12 | 盖层分布的连续性 | 0.0276 | 34 | 碳源距离 | 0.0055 |
| 13 | 人口密度 | 0.026 | 35 | 运输方式 | 0.0055 |
| 14 | 储层压力系数 | 0.0242 | 36 | 现有技术条件下未被发现的断裂 | 0.0052 |
| 15 | 与居民点的距离 | 0.0227 | 37 | 是否在采矿塌陷区、岩溶塌陷区、地面沉降区、沙漠活动区、火山活动区 | 0.0049 |
| 16 | 地层水矿化度 | 0.0222 | 38 | 地表温度 | 0.0042 |
| 17 | 碳源规模 | 0.0179 | 39 | 距离河流等地表饮用水源的距离 | 0.0038 |
| 18 | 水动力作用 | 0.0171 | 40 | 是否在农业保护区、自然保护区、风景名胜区、文物（考古）保护区、生活饮用水源保护区、供水远景规划区、矿产资源储备区和其他需要特别保护的区域，是否在特别需要保护的区域 | 0.0032 |
| 19 | 层间非均质性（砂体连续性） | 0.0171 | 41 | CO ₂ 储层上部是否有可供工农业利用地下水含水层 | 0.0031 |
| 20 | 主力盖层单层厚度 | 0.0163 | 42 | 是否在饮用地下水主要补给区内 | 0.0024 |
| 21 | 有效封存量 | 0.014 | 43 | 是否低于江河湖泊、水库最高水位线或洪泛区 | 0.0013 |
| 22 | 目标靶区范围内是否有其他深度大于800m的钻井及废弃井 | 0.0136 | 44 | 植被状况（有无重点保护植物） | 0.0013 |

Weights of evaluation indexes

| Sequence | Index | Weight | Sequence | Index | Weight |
|----------|---|---------|----------|---|---------|
| 1 | Motion peak acceleration of earthquake | 0.107 7 | 23 | Occasion to happen geological disasters | 0.011 4 |
| 2 | Earthquake | 0.107 7 | 24 | aspect ratio of effective reservoir | 0.010 8 |
| 3 | lithology of Reservoir | 0.083 5 | 25 | Mineral deposits | 0.010 3 |
| 4 | Thickness of Reservoir | 0.073 1 | 26 | Land use | 0.009 9 |
| 5 | Active faults within 25km | 0.053 8 | 27 | Terrestrial heat flow | 0.008 4 |
| 6 | Depth of Caprock | 0.047 1 | 28 | Geothermal gradient | 0.008 4 |
| 7 | lithology of Caprock | 0.039 3 | 29 | Quality and quantity of sub-cover | 0.008 2 |
| 8 | Fracture development situation | 0.035 6 | 30 | City and regional development planning | 0.007 9 |
| 9 | Porosity of Reservoir | 0.034 4 | 31 | Service life of reservoir | 0.007 |
| 10 | Permeability of Reservoir | 0.034 4 | 32 | Microscopic closed index | 0.005 8 |
| 11 | Permeability of Caprock | 0.030 5 | 33 | Water head of deep saline aquifers | 0.005 7 |
| 12 | Continuity of caprock | 0.027 6 | 34 | Carbon source distance | 0.005 5 |
| 13 | population density; | 0.026 | 35 | Mode of CO2 transportation | 0.005 5 |
| 14 | Reservoir pressure coefficient; | 0.024 2 | 36 | Unknown faults under the existing technical conditions | 0.005 2 |
| 15 | The distance to resident | 0.022 7 | 37 | Whether in mining subsidence area, karst subsidence area, ground subsidence area, activity area desert, volcanic activity area; | 0.004 9 |
| 16 | Mineralization of groundwater | 0.022 2 | 38 | Surface temperature | 0.004 2 |
| 17 | Amount of carbon | 0.017 9 | 39 | Distance to surface water source for drinking | 0.003 8 |
| 18 | Hydrodynamics | 0.017 1 | 40 | Agricultural reserve, nature reserves, Scenic spot, cultural relics (archaeological) reserves, Life drinking water reserves, Water supply planning vision, mineral resources reserve districts and other zones that need special protection | 0.003 2 |
| 19 | Heterogeneity between Stratum | 0.017 1 | 41 | Whether there is groundwater aquifers for industrial or agricultural use in the upper of CO2 reservoir | 0.003 1 |
| 20 | Single thick of caprock | 0.016 3 | 42 | Whether in the main supply drinking groundwater area | 0.002 4 |
| 21 | Effective storage | 0.014 | 43 | Lower than the highest water level of Rivers, lakes and reservoirs / flood storage | 0.001 3 |
| 22 | If there are other drilling and abandoned wells deeper than 800 m in the target range | 0.013 6 | 44 | Vegetation status | 0.001 3 |



四川盆地目标区级评价案例

Case of target evaluation of Sichuan Basin



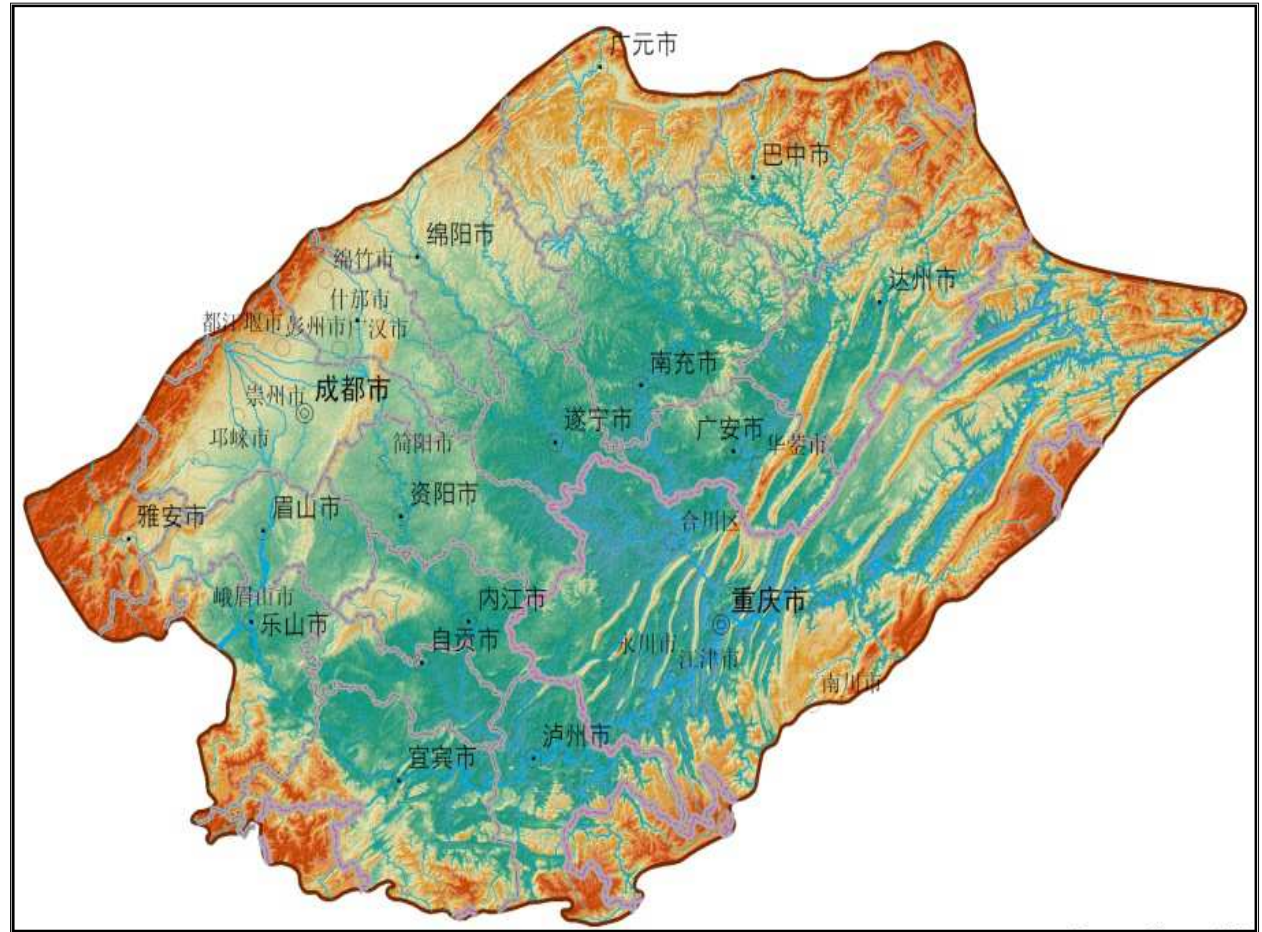
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中澳二氧化碳地质封存



背景 Background

- 四川盆地处于川渝地区，总面积约26万km²。是具有典型意义的沉积盆地。
- Sichuan Basin is located in Sichuan and Chongqing area, the total area is about 260000 km². Is a typical sedimentary basin.

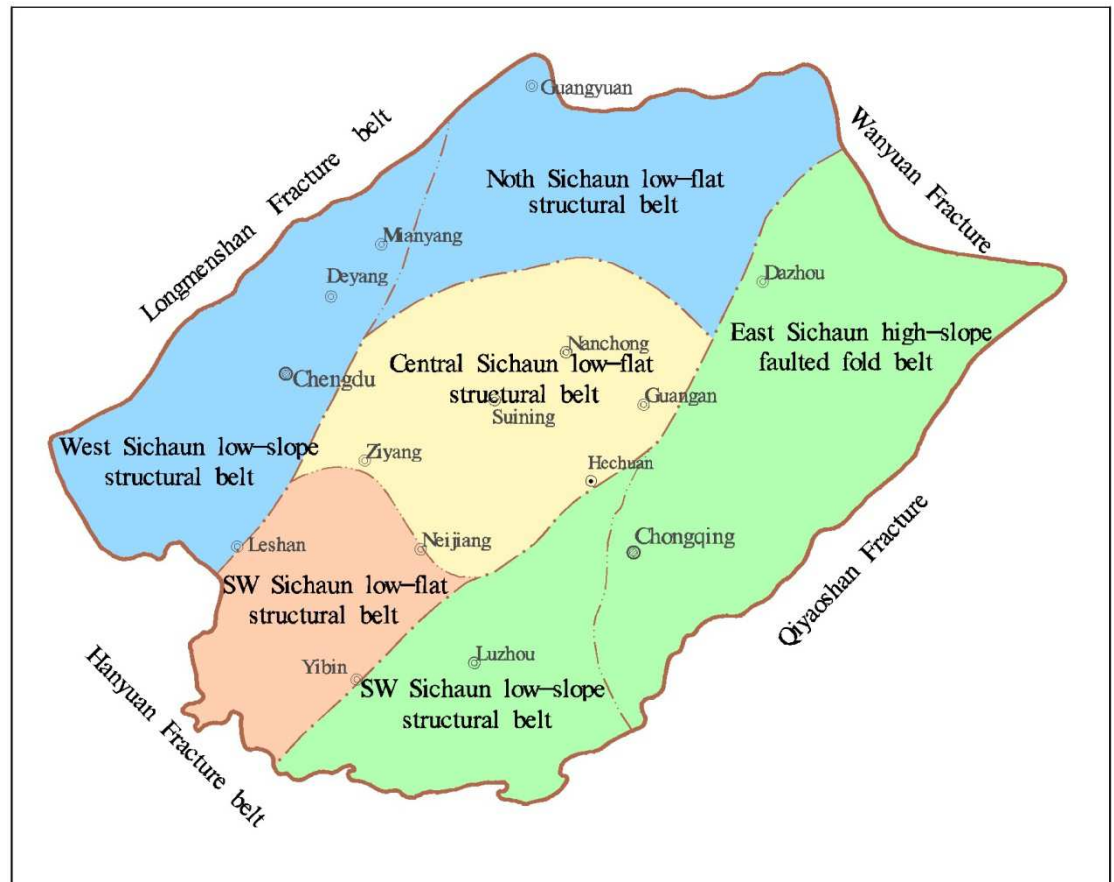


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◆ 构造单元划分 Division of Geotectonic Units

| 编号 No. | 构造单元 Geotectonic Units | 面积 Area (km ²) |
|------------------|--|----------------------------------|
| I | 川东南高褶区 High fold region in Southeastern Sichuan | 76000 |
| I ₁ | 川东高陡褶带 High fold region in Southeastern Sichuan | 50000 |
| I ₂ | 川南低陡褶带 Low-steep fold belt in Southern Sichuan | 26000 |
| II | 川中低缓隆起区 Low-gentle uplifts in the middle of Sichuan | 58000 |
| II ₁ | 川中平缓褶带 Flat fold belt in the middle of Sichuan | 37000 |
| II ₂ | 川西南低陡褶带 Low-steep fold belt in Southwestern Sichuan | 21000 |
| III | 川西北坳陷区 Depressions in Northwestern Sichuan | 66000 |
| III ₁ | 川北低平褶带 Low-flat fold belt in Northern Sichuan | 34000 |
| III ₂ | 川西低陡褶带 Low-steep fold belt in Western Sichuan | 32000 |



Division of Geotectonic Units in Sichuan Basin



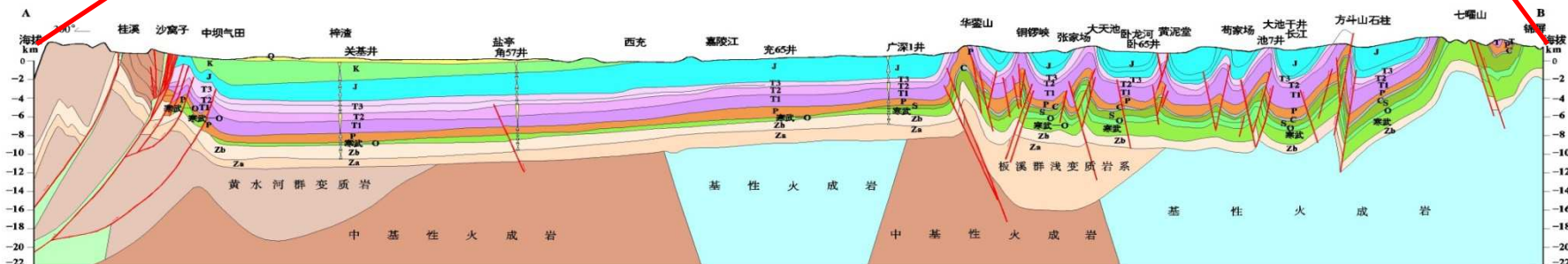
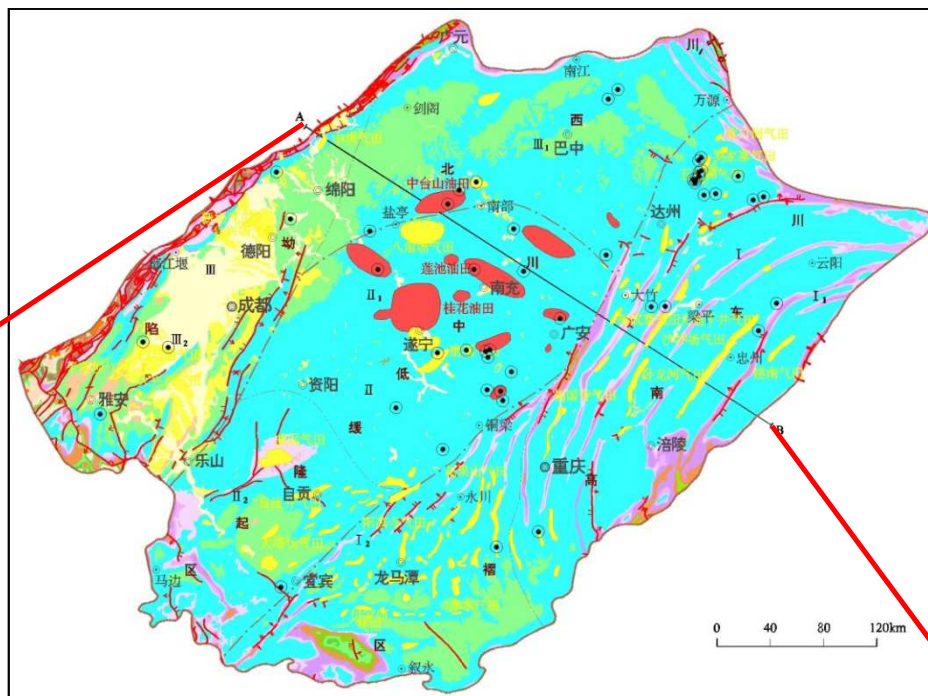
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◆ 地质条件 Geological Conditions

| 系 | 统 | 组 | 厚度 | 剖面 | 储盖组合 |
|------|----|--------------|----------|----|------|
| 侏罗系 | 上统 | 蓬莱镇组 | 400-1800 | | |
| | | 遂宁组 | 200-600 | | |
| | 中统 | 沙溪庙组 | 550-2340 | | |
| | | 千佛崖组 | 0-300 | | |
| | 下统 | 白田坝组 | 200-450 | | |
| 三叠系 | 上统 | 须家河组 | 400-3000 | | |
| | | 小塘子组 马鞍塘组 | 0-500 | | |
| | 中统 | 雷口坡组 | 0-1000 | | |
| | | 嘉陵江组 | 100-1040 | | |
| | 下统 | 飞仙关组 | 300-770 | | |
| 二叠系 | 上统 | 长兴组 | 20-300 | | |
| | | 龙潭组 | 40-222 | | |
| | 中统 | 茅口组 | 100-353 | | |
| | | 栖霞组 | 80-220 | | |
| | 下统 | | | | |
| 石炭系 | | | 0-544 | | |
| 泥盆系 | | | 0-7243 | | |
| 志留系 | | | 337-1962 | | |
| 奥陶系 | | | 70-1030 | | |
| 寒武系 | | | 424-2319 | | |
| 震旦系 | 上统 | | 528-3000 | | |
| | 下统 | | | | |
| 前震旦系 | | | | | |

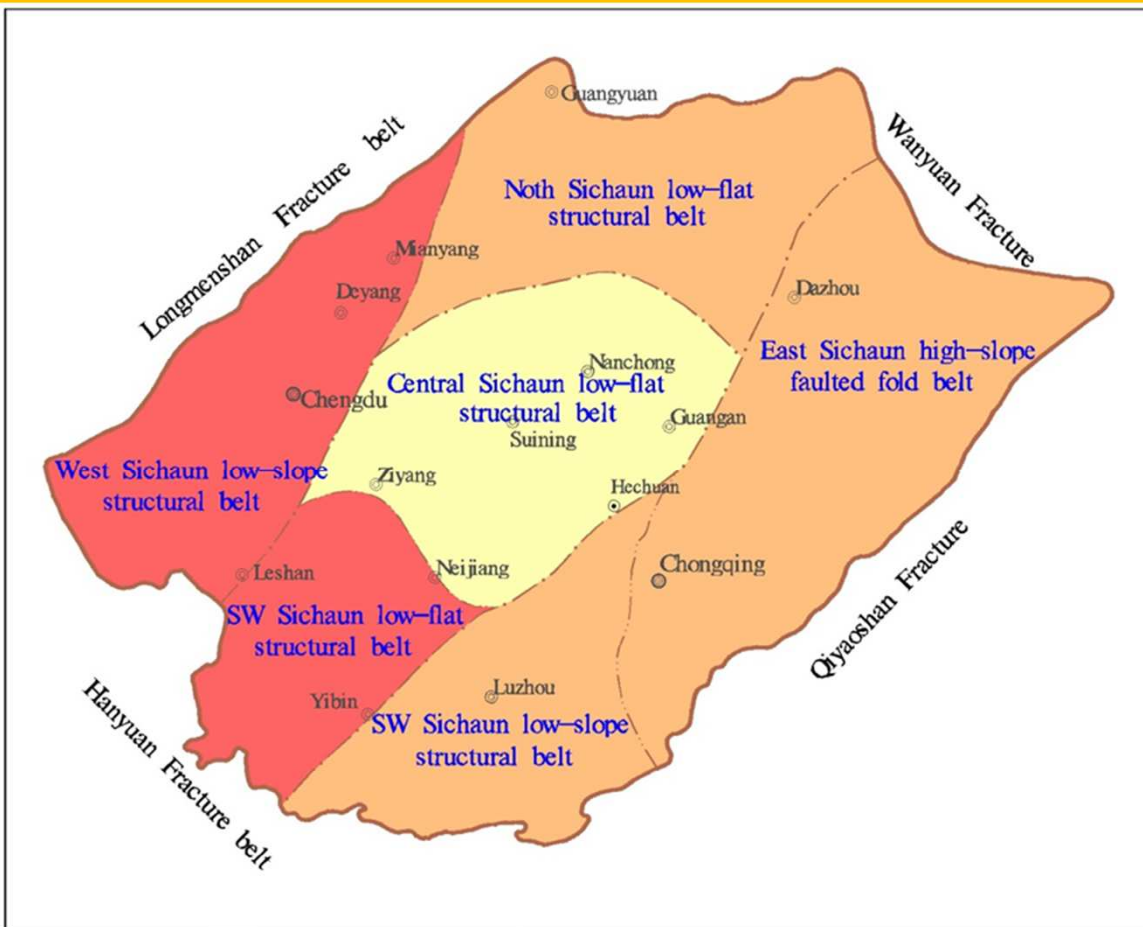
- 四川盆地是一个中、新生代和古生代复合的沉积盆地，沉积总厚度约6000~12000m。
- Sichuan Basin is complex with 6000 ~ 12000m sedimentary thickness of Mesozoic, Cenozoic and Paleozoic strata.



◆ 盆地级评价结果

◆ Basin scale CO₂ geological storage suitability evaluation

| | |
|--|-------------------|
| 川东高陡褶皱带 High fold region in Southeastern Sichuan | 较不适宜 Unlikely |
| 川南低陡褶皱带 Low-steep fold belt in Southern Sichuan | 较不适宜 Unlikely |
| 川中平缓褶皱带 Flat fold belt in the middle of Sichuan | 一般适宜 Possible |
| 川西南低陡褶皱带 Low-steep fold belt in Southwestern Sichuan | 不适宜 Unsuitable |
| 川北低平褶皱带 Low-flat fold belt in Northern Sichuan | 较不适宜 Unlikely |
| 川西低陡褶皱带 Low-steep fold belt in Western Sichuan | 不适宜 Unsuitable |



Sichuan Basin potential and suitability evaluation map

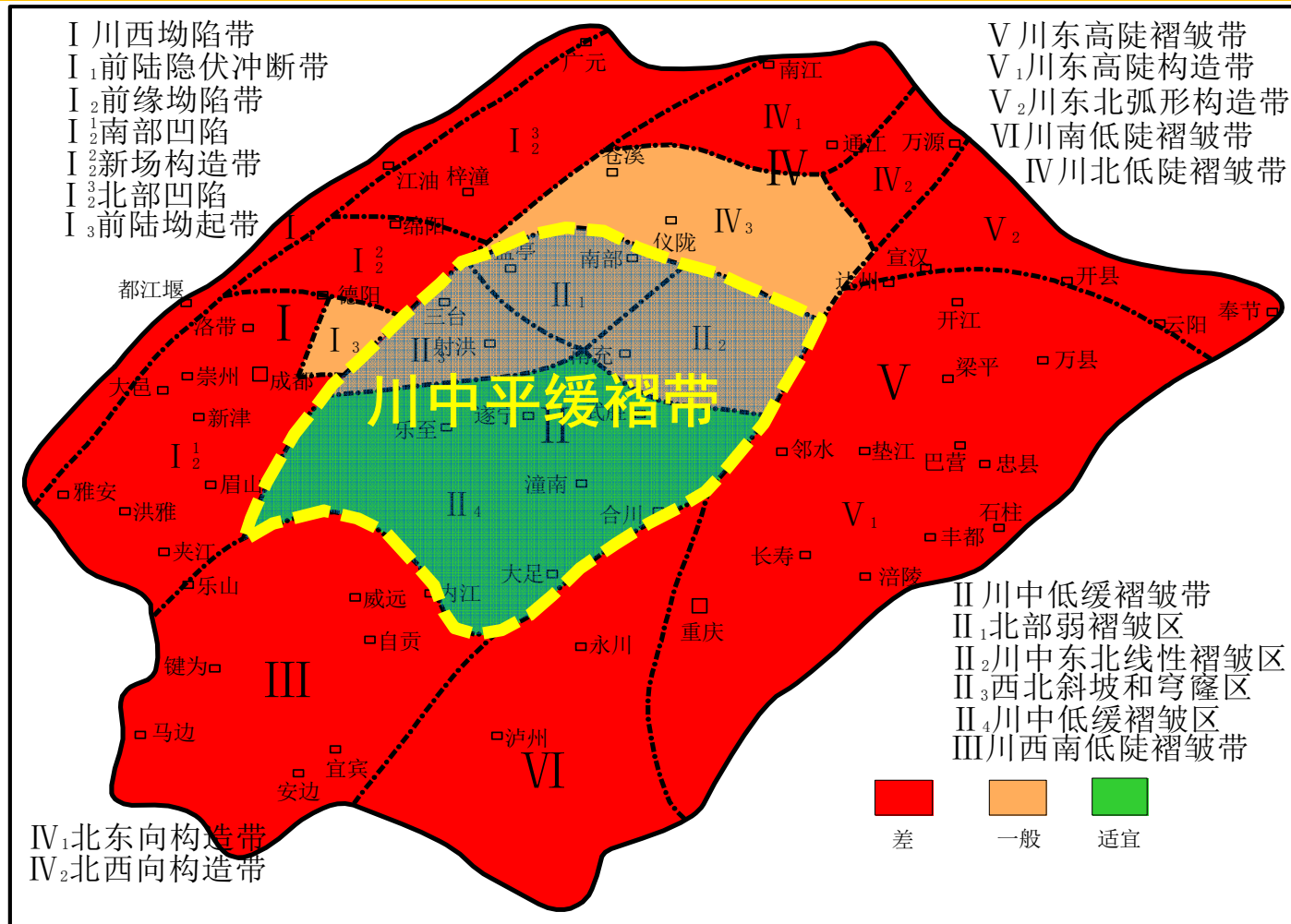


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◆ 目标区级评价

◆ Target scale CO₂ geological storage suitability evaluation



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 中澳二氧化碳地质封存



◆川中平褶皱带三级构造单元评价

◆ Third Tectonic Units Evaluation

北部弱褶皱区:

描述：褶皱强度较弱，面积较大，断裂、裂缝有所发育；压力系数1.6，异常高压区；主要储集层为须一段、须四、须二、须六，物性一般，有效储层厚度小，大安寨为孔隙裂缝性储层，埋深2800米，物性较差；

评价等级：一般适宜

川中东北线性褶皱区:

描述：褶皱较强，断裂及裂缝发育；压力系数大于1.2；须家河组须4段储层砂体大于80米，雷口坡、嘉陵江组等碳酸盐岩储层不发育

评价等级：一般适宜

西北斜坡和穹隆区:

描述：主要储集层为大安寨孔隙
裂缝性储层，物性差，埋深2600
米左右，有效储层大于12米；压
力系数1.3-1.8，压力系数高；临
近川西坳陷，地壳稳定性差。

评价等级：一般适宜

川中低缓褶皱区

描述：储集层主要为须家河组须2段，储层厚度大，物性一般；雷口坡组、嘉陵江组裂缝发育，物性较好；须家河组2段和须5段发育多套泥岩、页岩盖层，分布稳定；雷口坡组、嘉陵江组储集层之上膏盐发育，延伸稳定，封盖系数高；处于盆地较低压力区，压力系数1.1-1.4；断层不发育。

评价等级：适宜

◆ 有利靶区初步筛选

◆ Favorable Target Preliminarily Screening

◆ A: 合川-武胜目标区

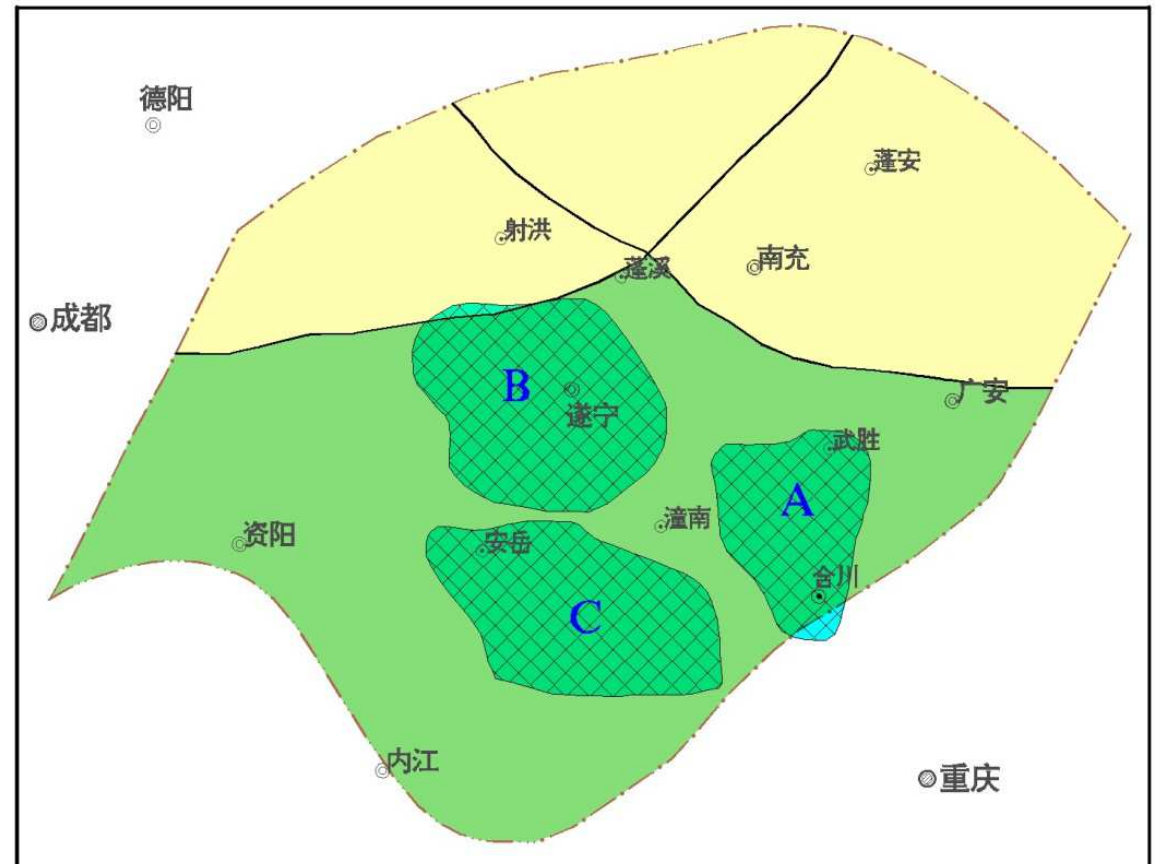
◆ B: 遂宁目标区

◆ C: 安岳-潼南目标区

◆ A: Hechuan-Wusheng-Target

◆ B: Suining Target

◆ C: Anyue-Tongnan Target



川中低缓褶皱区目标靶区分布图

Distribution of targets in Middle Low Folded region

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目标靶区评价结果表

| 指标层 | 指标亚层 | 具体指标 | 合川-武胜目标区 | | 隧宁目标靶区 | | 安岳-潼南目标靶区 | |
|-------|-------------------------|-----------------------------|----------|----|--------|----|-----------|----|
| | | | 评价等级 | 得分 | 评价等级 | 得分 | 评价等级 | 得分 |
| 地质安全性 | 区域地壳稳定性 | 地震动峰值加速度 | 好 | 9 | 好 | 9 | 好 | 9 |
| | | 目标靶区地震安全性 | 好 | 9 | 好 | 9 | 好 | 9 |
| | | 目标靶区25km半径范围内是否有活动断层 | 一般 | 5 | 好 | 9 | 一般 | 5 |
| | 盖层封闭性 | 主力盖层的埋深 | 差 | 1 | 差 | 1 | 差 | 1 |
| | | 盖层岩性 | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | | 主力盖层单层厚度 | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | | 盖层分布的连续性 | 好 | 9 | 好 | 9 | 好 | 9 |
| | | 渗透率 | 好 | 9 | 好 | 9 | 好 | 9 |
| | | 主力盖层之上的二次截留能力 | 好 | 9 | 好 | 9 | 好 | 9 |
| | | 盖层微观封闭性指数（CRI）——封气指数 | 好 | 9 | 好 | 9 | 好 | 9 |
| | 可能的CO ₂ 泄漏通道 | 断裂和裂缝的发育情况 | 一般 | 5 | 好 | 9 | 一般 | 5 |
| | | 目标靶区范围内是否有其他深度大于800m的钻井及废弃井 | 差 | 1 | 差 | 1 | 差 | 1 |
| | | 现有技术条件下未被发现的断裂 | 一般 | 5 | 好 | 9 | 一般 | 5 |
| | 水文地质条件 | 水动力作用 Hydrodynamics | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | | 深部咸水层水头状态 | 差 | 1 | 差 | 1 | 差 | 1 |
| 储存规模 | 储层特征 | 储集岩的岩性 | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | | 主力储层的厚度 | 好 | 9 | 好 | 9 | 好 | 9 |
| | | 有效储层长宽比 | 好 | 9 | 好 | 9 | 好 | 9 |
| | | 层间非均质性（砂体连续性） | 好 | 9 | 好 | 9 | 好 | 9 |
| | | 储层压力系数 | 一般 | 5 | 差 | 1 | 差 | 1 |
| | | 地层水矿化度 | 差 | 1 | 差 | 1 | 差 | 1 |
| | 储层物性参数 | 孔隙度 | 差 | 1 | 差 | 1 | 差 | 1 |
| | | | 一般 | 5 | 差 | 1 | 一般 | 5 |
| | | 渗透率 | 差 | 1 | 差 | 1 | 差 | 1 |
| | | | 差 | 1 | 差 | 1 | 差 | 1 |
| | 地热地质特征 | 地热流值 | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | | 地温梯度 | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | | 地表温度 | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | 储层储存前景 | 有效储存量 | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | | 使用年限 | 一般 | 5 | 一般 | 5 | 一般 | 5 |

目标靶区评价结果表

| 指标层 | 指标亚层 | 具体指标 | 合川-武胜目标区 | | 隧宁目标靶区 | | 安岳-潼南目标靶区 | |
|--------|-------------|---|----------|----|--------|----|-----------|----|
| | | | 评价等级 | 得分 | 评价等级 | 得分 | 评价等级 | 得分 |
| 社会环境风险 | 社会环境 | 人口密度 | 差 | 1 | 差 | 1 | 差 | 1 |
| | | 与居民点的距离 | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | | 土地利用现状 | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | 地质环境 | 地质灾害易发性 | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | | 是否在采矿塌陷区、岩溶塌陷区、地面沉降区、沙漠活动区、火山活动区 | 好 | 9 | 好 | 9 | 好 | 9 |
| | | 是否低于江河湖泊、水库最高水位线或洪泛区 | 好 | 9 | 好 | 9 | 好 | 9 |
| | 所在地区的性质 | 是否符合城市和区域发展总体规划 | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | | 是否在农业保护区、自然保护区、风景名胜区、文物（考古）保护区、生活饮用水源保护区、供水远景规划区、矿产资源储备区和其他需要特别保护的区域，是否在特别需要保护的区域 | 好 | 9 | 好 | 9 | 好 | 9 |
| | | 植被状况（有无重点保护植物） | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | 与饮用水源的关系与距离 | CO ₂ 储层上部是否有可供工农业利用地下水含水层 | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | | 是否在饮用地下水主要补给区内 | 一般 | 5 | 一般 | 5 | 一般 | 5 |
| | | 距离河流等地表饮用水源的距离 | 好 | 9 | 好 | 9 | 好 | 9 |
| 经济适宜性 | 碳源规模 | | 好 | 9 | 好 | 9 | 好 | 9 |
| | 碳源距离 | | 一般 | 5 | 一般 | 5 | 好 | 9 |
| | 运输方式 | | 好 | 9 | 好 | 9 | 好 | 9 |
| | 蕴矿状况 | | 一般 | 5 | 一般 | 5 | 一般 | 5 |

◆ 评价结果

◆ Evaluation Result

- 隧宁目标靶区最为适合开展二氧化碳地质储存，其次为合川-武胜靶区，最次为安岳-潼南目标靶区。
- 三个靶区的适宜性都处于一般等级，总体来说并不十分理想。
- Suining target is most suitable to carry out CO₂ geological storage, followed by Hechuan-Wusheng target, the last is Anyue-Tongnan target.
- Three target suitability are at the general level, in general, is not very satisfactory.



China Australia Geological Storage of CO₂
中澳二氧化碳地质封存





沉积体系及其沉积相对CO₂地质封存适宜性的影响

Effects of depositional system and sedimentary on CO₂ geological storage suitability



China Australia Geological Storage of CO₂

中澳二氧化碳地质封存



- 本次研究分析了冲（洪）积沉积体系、河流沉积体系、湖泊沉积体系、沼泽沉积体系、三角洲沉积体系、滨海碎屑沉积体系、浅海碎屑沉积体系、碳酸盐岩沉积体系对CO₂地质封存的储盖层有利相带的影响
- Analyze alluvial sedimentary system, fluvial system, lacustrine depositional system, marsh sedimentary system, delta system, coastal clastic depositional systems, shallow marine clastic depositional systems, carbonate depositional system for CO₂ geological storage reservoir cap the impact of favorable facies



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沉积体系及其沉积相对CO₂地质封存适宜性的影响分析表

| 沉积体系 | 类型 | 沉积亚相 | 储盖层有利相带分析 | 代表性盆地或地区 |
|-----------|--------------------------|----------------------------------|---|--|
| 冲（洪）积沉积体系 | 干旱扇 湿地扇 | 扇根 扇中 扇端 侧缘 | 扇根和扇中亚相封存条件较好； 冲（洪）积扇砂砾岩体岩性粗、物性较好，只要有较好的封闭条件就可以作为CO ₂ 地质封存储集层。 | 陆相沉积盆地三叠纪（如克拉玛依含油层）、晚侏罗世、白垩纪、第三纪、第四纪发育广泛 |
| 河流沉积体系 | 平直河 曲流河 辫状河 网状河 | 河道 溢岸 | 泥质岩分布都很零散，侧向不连续，相对来说垂向封堵能力较差；河流相砂体发育，尤其是主流河道，发育CO ₂ 地质封存的良好储集体。 | 渤海湾盆地新近系馆陶组，长庆油田是典型的古河道砂岩体储层油田 |
| 三角洲沉积体系 | 曲流河三角洲 辫状河三角洲 扇三角洲 | 三角洲平原 三角洲前缘 前三角洲 | 三角洲前缘沉积物相对较粗，发育较好储集层。 | 华北盆地石炭—二叠世海陆交互相沉积；大庆长垣三角洲 |
| 沼泽沉积体系 | 河漫沼泽 湖成沼泽 滨海沼泽 | | 层厚的沼泽相沉积具有良好的连续性和封闭性，是CO ₂ 地质封存的良好盖层。 | 含煤盆地广泛发育，如四川盆地、鄂尔多斯盆地等 |
| 湖泊沉积体系 | 淡水湖 半盐水湖 盐水湖 | 滨湖相 浅湖相 半深湖相 深湖相 湖湾相 | 理想的湖泊沉积模式，基本上是呈环带状分布的，即湖滩砾石外带—砂质沉积带—粉砂质、泥灰沉积内带—湖中心软泥沉积带，形成了储—盖理想组合。 同时，深湖区的浊积砂体也是重要的储集层。 | 大港部分油田的产层属于古近系滨海湖滩砂岩体（沿岸砂坝），下辽河盆地和泌阳盆地部分油田的储层属于湖底扇砂岩体。 |
| 滨海碎屑沉积体系 | 无障壁海岸 | | 以砂砾海滩相为主，可发育较好的碎屑岩储集层。 | 我国中、晚元古代、寒武纪及泥盆纪等的滨海沉积中，多发育此类沉积体系 |
| | 障壁海岸 | 泻湖 潮坪 障壁岛（滩） | 由泻湖—潮坪—障壁岛（滩）组成，属于陆海过渡型沉积体系，可发育储—盖—储组合。 | 为海陆交互相沉积体系，华北盆地石炭—二叠世多发育此类沉积体系。 |
| 浅海碎屑沉积体系 | | 过渡带 滨外陆棚带 | 过渡带以粘土质粉砂至粉砂为主。 | |
| | | | 以粉细砂和粘土为主，砂砾成分极少。 | |
| 碳酸盐岩沉积体系 | 陆表海碳酸盐沉积 | | 以发育碳酸盐岩天然气储层为特征，常发育较好的储集层。 | 塔里木、鄂尔多斯和四川等大型克拉通盆地。 |

Effects of Depositional system and sedimentary on CO₂ geological storage suitability

| Depositional system | Type | Subfacies | Favorable reservoir facies analysis on reservoir and caprock | Representative basin or region |
|---|---|---|--|--|
| Alluvial (flood) deposition system | Arid alluvial fan Alluvial wetland | Alluvial fan root Middle alluvial fan Alluvial fan end Alluvial fan side | Storage conditions on root and middle are better; Glutenite on alluvial (flood) fan have good lithology, good physical property, as long as there is a better confinement can be set as the CO ₂ geological storage sealing layer. | Continental sedimentary basins (such as Karamay oil layer) on Triassic, Late Jurassic, Cretaceous, Tertiary |
| Fluvial system | Straight River Meandering river Braided river Mesh River | Watercourse Overbank | Argillaceous rocks are scattered distribution, lateral discontinuous, relatively poor vertical sealing capacity; fluvial sands development, especially in the mainstream of the river, have good reservoir development CO ₂ geological storage. | Neogene Guantao on Bohai Bay Basin, Changqing Oilfield is typical of ancient river oil reservoir sandstone body |
| Delta system | Meandering river delta Braided river delta Fan delta | Delta plain Delta front Predelta | Delta front sediments is relatively thick, well-developed reservoir. | North Basin Carboniferous - Permian paralic deposition; Daqing Changyuan Delta |
| Marsh sedimentary system | River Swamp Man Lake into swamp Coastal marshes | | Marsh sediments with good continuity and closure are thick, are good geological storage of CO ₂ cap. | Widely developed coal basins, such as the Sichuan Basin, the Ordos Basin |
| Lacustrine depositional system | Freshwater Brackish lake Lagoon | Lakeside phase Shallow lacustrine Semi-deep lake Deep lake Bay phase | Ideal lake depositional model is basically showed zonal distribution, that is packed gravel lake beach - sandy sedimentary belt - silt, deposited with the marl - Lake Centre ooze deposition zone, forming a reservoir - Cover ideal combination. Meanwhile, deep lake turbidite sandstone reservoirs are also important. | Producing layer Dagang Oilfield part belongs Paleogene coastal lake beach sand body (coastal sand dam), Liaohe Basin and the lower reservoir basin portion oilfield BIYANG fan sandstone body belongs to the lake. |
| Coastal clastic depositional systems | No barrier coast | | To gravel beach facies, can develop better clastic reservoirs. | In China, Late Proterozoic, Cambrian and Devonian and other coastal sediments, and more development of these depositional systems |
| | Barrier coast | Lagoon Tidal flat Barrier island (beach) | By the lagoon - tidal - barrier island (beach), belonging to the transitional land and sea sedimentary system, can develop the reservoir - cap - storage combination. | To paralic depositional systems, North China Basin Carboniferous - Permian sedimentary and more development of such system. |
| Shallow marine clastic depositional systems | | Transition Waterfront outer shelf belt | Transition to clayey silt to silt. | |
| | | | Mainly with fine sand and clay, gravel component is minimal. | |
| Carbonate sedimentary system | Epicontinental carbonate deposition | | Developmental characteristics of carbonate reservoirs of natural gas, often better reservoir development. | Tarim, Ordos and Sichuan large cratonic basins. |

Conclusions



- 该目标区级别评价指标体系包括地质安全性、储存规模、社会环境风险、经济适宜性四个方面，基本涵盖了目标区级别评价所能涉及的因素。
- **Target scale selection and evaluation index system consists of Safety, Reservoir, Socio-economic and environmental conditions, Economical suitability, nearly cover factors for CO₂ geological storage in Target scale**



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Conclusions



- 指标的分级借鉴了油气开采、环境地质、地质灾害、社会经济等多个领域，结合已有的二氧化碳地质封存的实践，具有一定的普遍性；
- **Index grading draw a number of areas of oil and gas exploration, environmental geology, geological disasters, socio-economic, etc., combined with the existing practice of CO₂ geological storage, with a certain universality;**



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Conclusions



- 在不同地区的地质、环境、社会经济条件存在较大差异，决策者对于不同评价因子重要性的认知也存在较大差异，指标体系在保证基本普适性的条件下，还要根据不同地区的情况有针对性的调整，而不能一成不变。
- **Because of difference of geology, environmental, social and economic conditions in different areas , and the different perception of the importance of evaluation factors of policy-makers, the index system will have targeted adjustments according to different regions the situation.**



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Thanks for your attention!

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