Gas Storage Regulatory Goals for the State of California

Understanding Gas Migration Pathways & Mechanisms

March 09, 2016

PSE Healthy Energy
Physicians Scientists & Engineers

Outline

- Critical Concepts
- Gas Migration & Leaks
  - Overview
  - Wellbore Integrity
  - Cap Rock Stability
- Other Sources of Surface Gas (i.e. leaks)

Appendices

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2. Case Studies
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   - Playa del Rey
   - Aliso Canyon
3. Regulatory Recommendations
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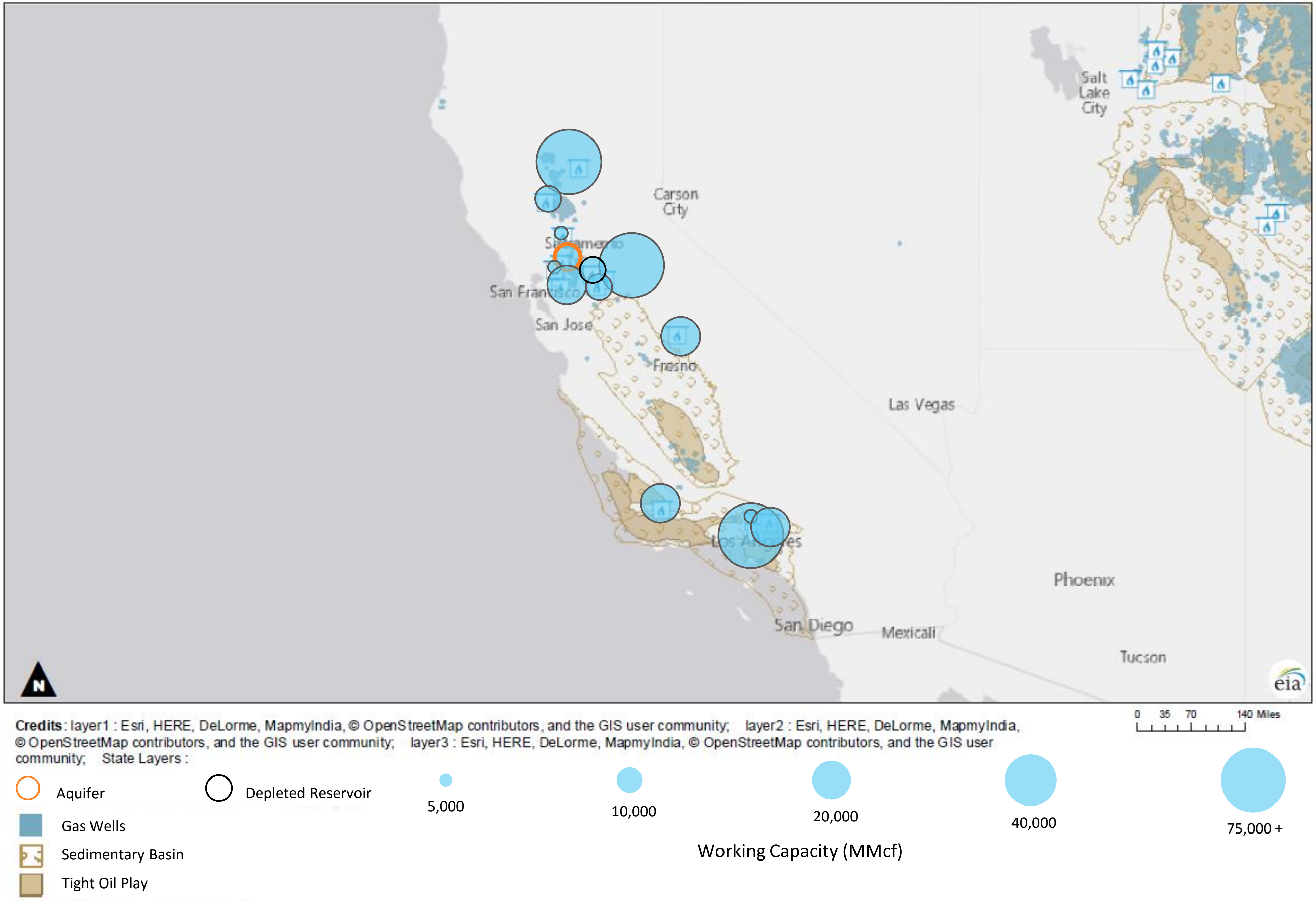
   - Wellbore Construction & Recycling
   - Safety Devices
   - Monitoring & Reporting
   - Emergency Response Plans
   - Safety Training
   - Additional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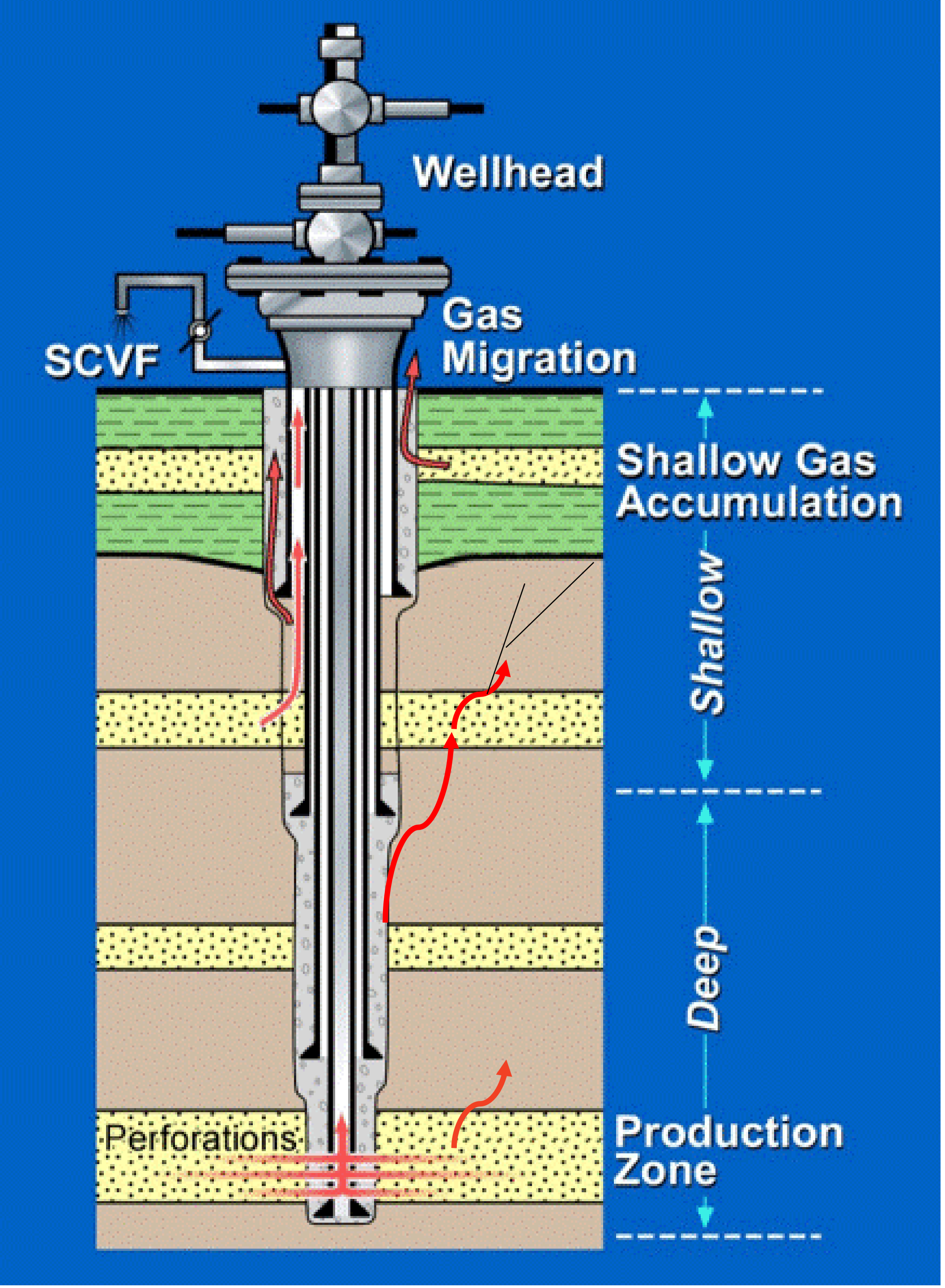
Aquifer
Depleted Reservoir
Gas Wells
Sedimentary Basin
Tight Oil Play
5,000
10,000
20,000
40,000
75,000 +
Working Capacity (MMcf)

Critical Concepts

- Gas Migration - a generic term referring to all possible routes stray gas entry and propagation through and around the cement sheath, an unprotected casing string, or from a fractured/incompetent reservoir. **Majority of CA storage problems are gas migration issues**
- Cap rock – a laterally continuous layer impermeable to gas/fluids which traps formation fluids within the permeable and porous *reservoir* below it. **Permeability can altered by seismic activity and pressure changes (i.e. production or injection/withdrawal cycles)**
- Base gas – minimum volume of gas remaining in the cavern required to maintain sufficient pressure to adequately protect integrity of the subsurface. **This is typically native raw gas, so any storage leak will be a mixture of raw gas species (e.g. higher hydrocarbons, BTEX, CO, H2S)**



Gas Migration

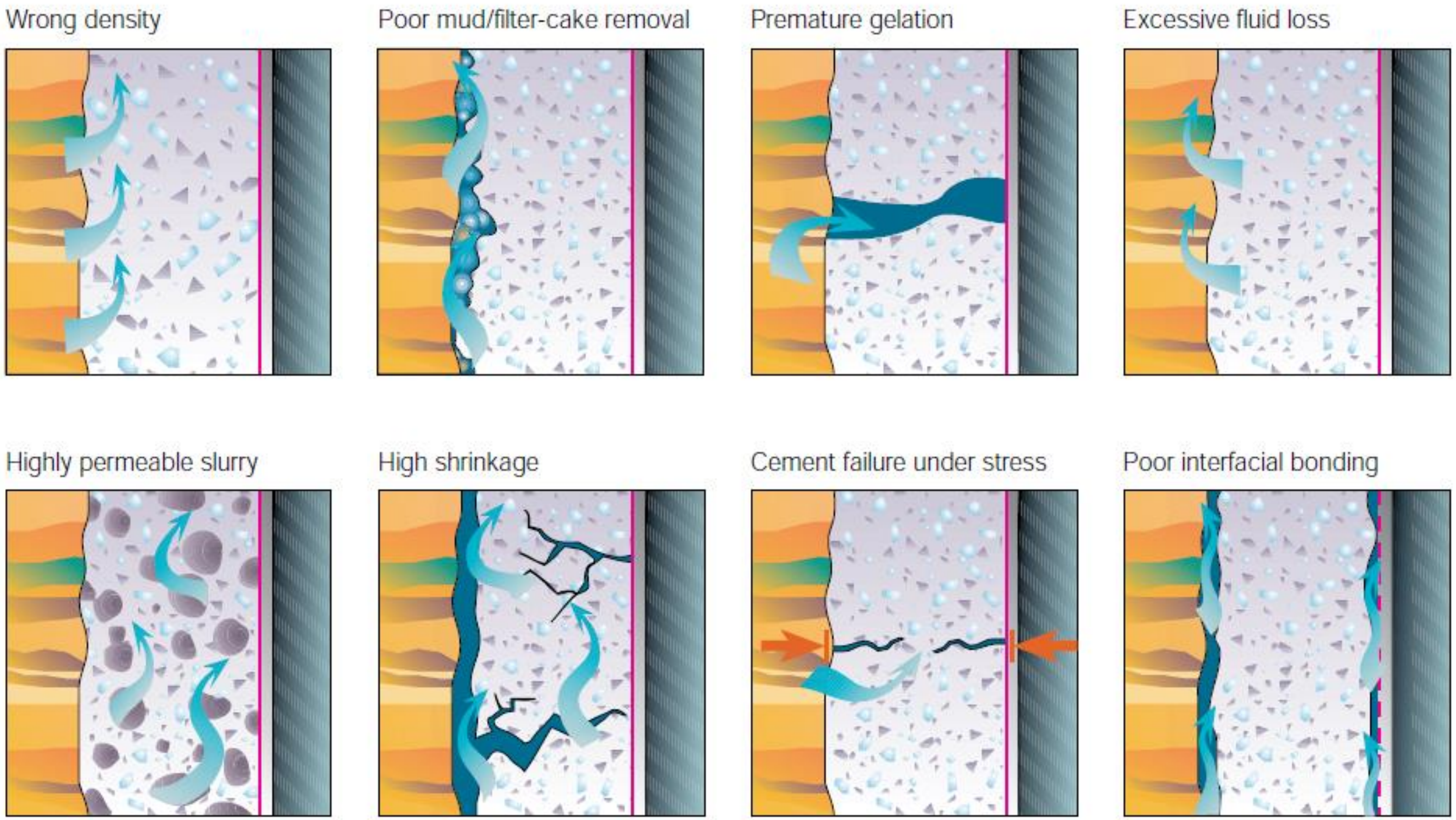
- Fluids/gas under pressure will flow to lower pressure areas
- Any opening to atmospheric pressure or a lower pressure provides a conduit for rapid fluid/gas flow, laterally or vertically
  - Abandoned wellbores
  - Newly drilled wellbores
  - Naturally occurring fault lines & fracture networks
  - Induced fracturing
  - Pilings to stabilize buildings (problematic in Playa del Rey)
- Annular flows of gas at the surface - often signaled by pressure buildup or bubbling at the surface and confirmed by gas readings - can indicate barrier problems anywhere in the well
- **Risks associated with geologic storage in California are particularly high**
  - **Highly petroliferous, developed in young sedimentary rocks**
  - **Long history of development**
    - **many undocumented wells**
    - **aging infrastructure**
  - **Urban development**
  - **Complex geology!**

Potential Pathways

1. Loss of wellbore integrity
   - Cement
     - Faulty primary cement
     - Mechanical stress
   - Casing
     - Inadequate casing design
     - Inadequate casing strength
   - Cascade effects
   - Damage to the well from compaction/subsidence
   - Aging wells
     - Drilled prior to modern standards
     - Degradation of casing and/or cement barriers over time

2. Loss of reservoir's ability to hold gas/fluids – fracturing
   - Induced pressures
   - Seismic activity

Faulty Primary Cement

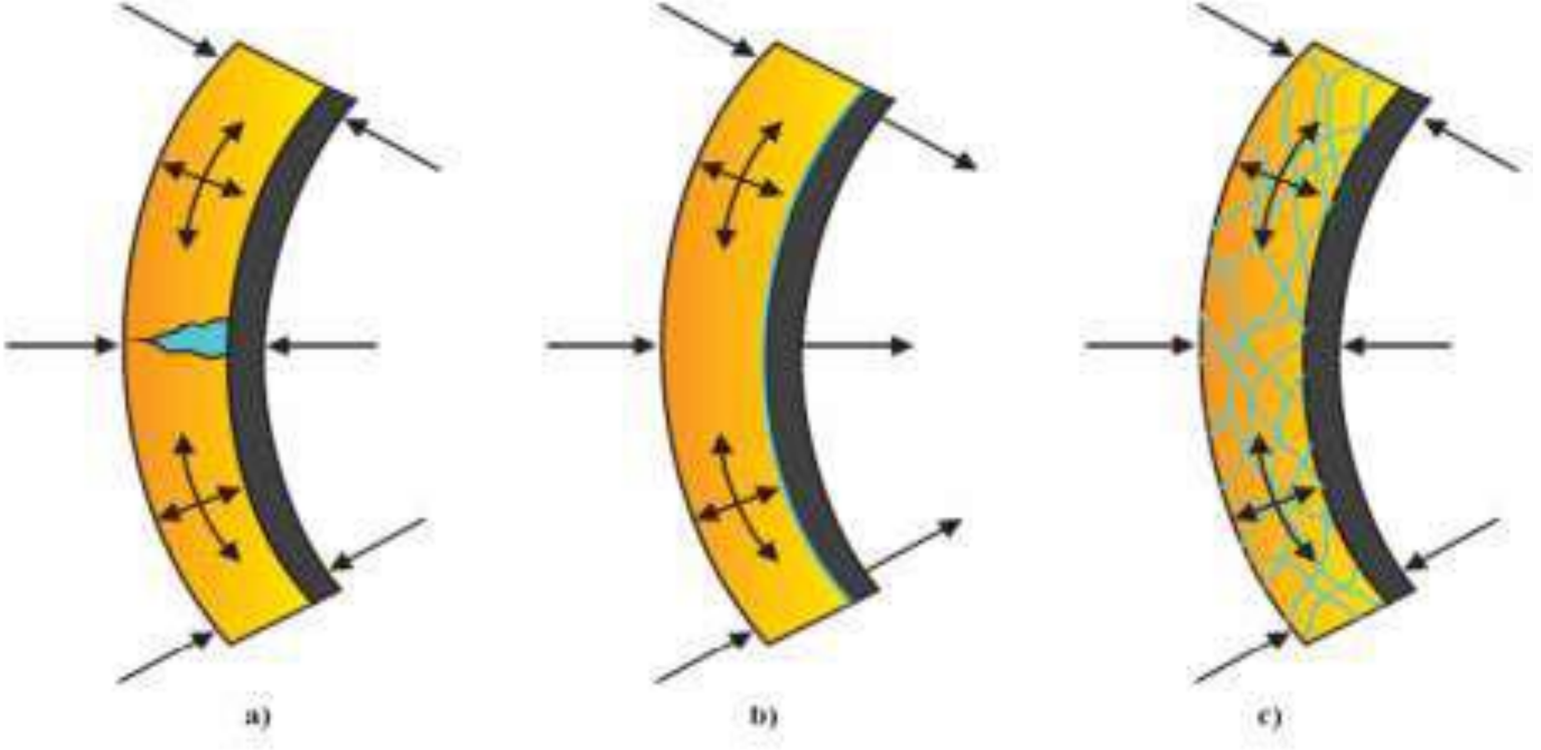


Bonnett & Parfitis 1996

- Formation damage during drilling <u>or cementing</u>
- Cement eccentricity caused by casing not centralized properly
- Poor mud displacement
- Poor bonding due to slurry/formation incompatibility
- Change in slurry composition due to mud contaminations of formation influx
- Water loss in the slurry (ex. high pressure gradient from wellbore to permeable formation)

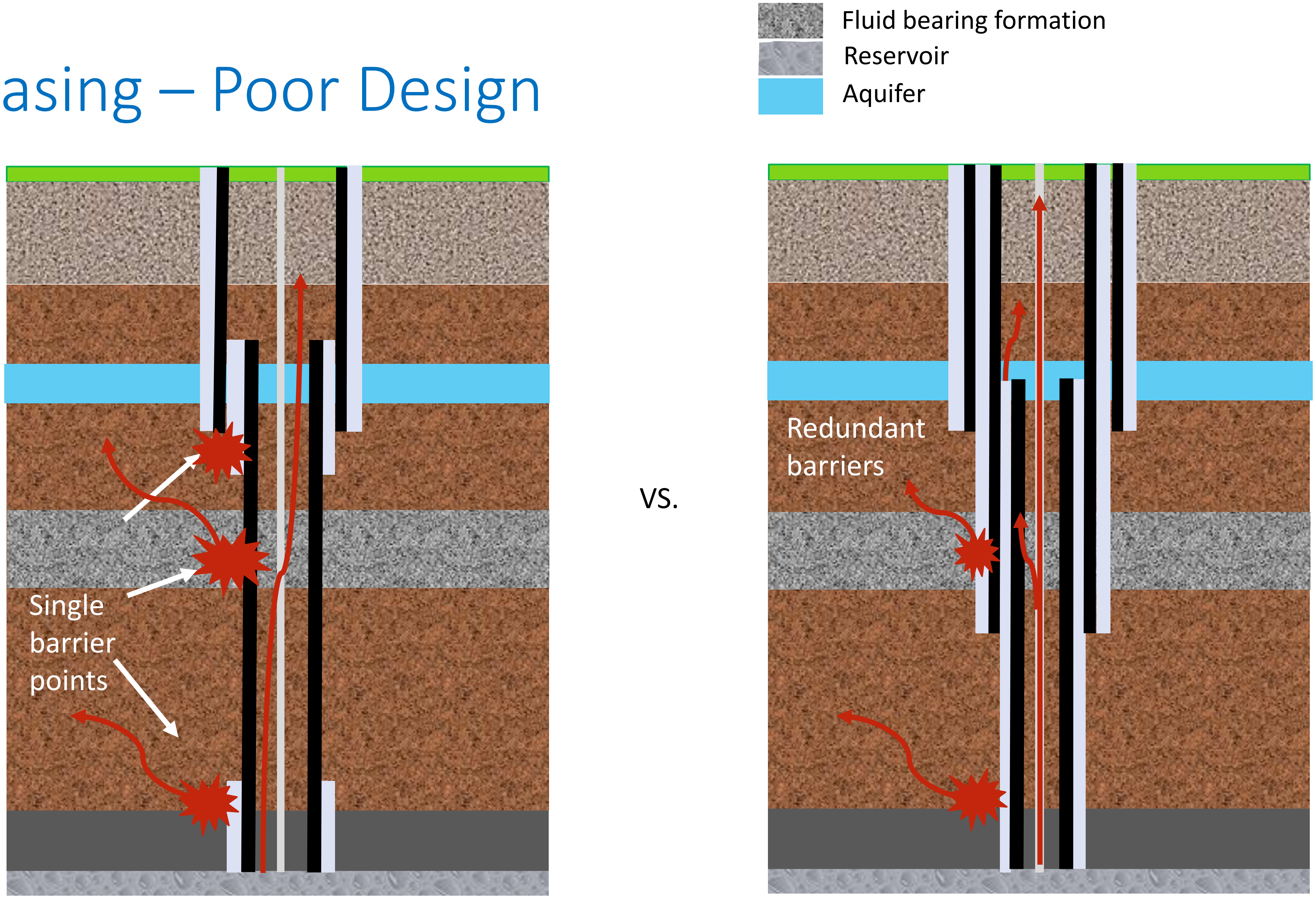
A good primary cement job may deteriorate post well construction/completion due to mechanical stress

Induced pressures (e.g. operation cycles, seismic activity) may stress cement barriers resulting in micro-annuli, cracking (a), de-bonding at the cement/casing or casing/formation interface (b), or shear failure (c)



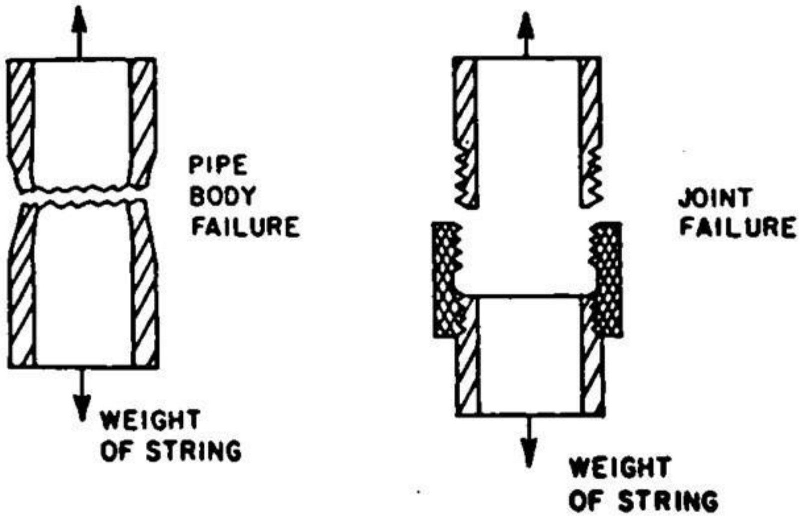
Teodoriu et al. 2012

Casing – Poor Design



Casing - Inadequate Strength

- Collapse (external pressure)
- Tension (pressure exerted by the weight of attached strings)
- Burst (internal pressure)

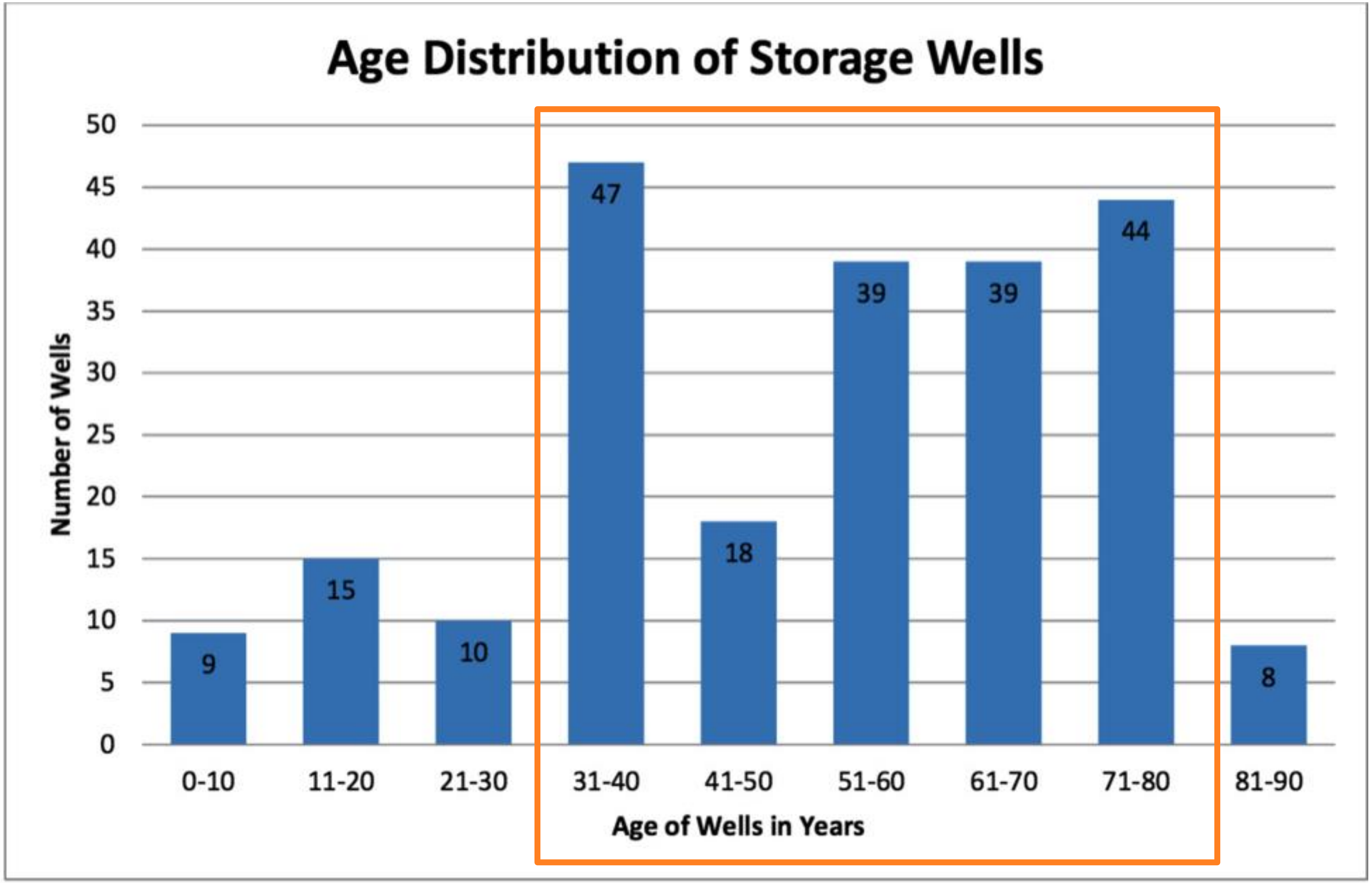


Cascade Effects - Impairment in one barrier can lead to additional impairments

- Cement with even minor impairments is more vulnerable to stresses of thermal/pressure cycles, vibrations.
- Impaired cement may expose casing to corrosive fluids, leading to casing impairment.
- Bleeding an annulus too often may increase the size of a leak.
- Venting through casing shoe may over-pressurize the formation

SPE no. 108698

Aging Wells – e.g. SoCal Gas

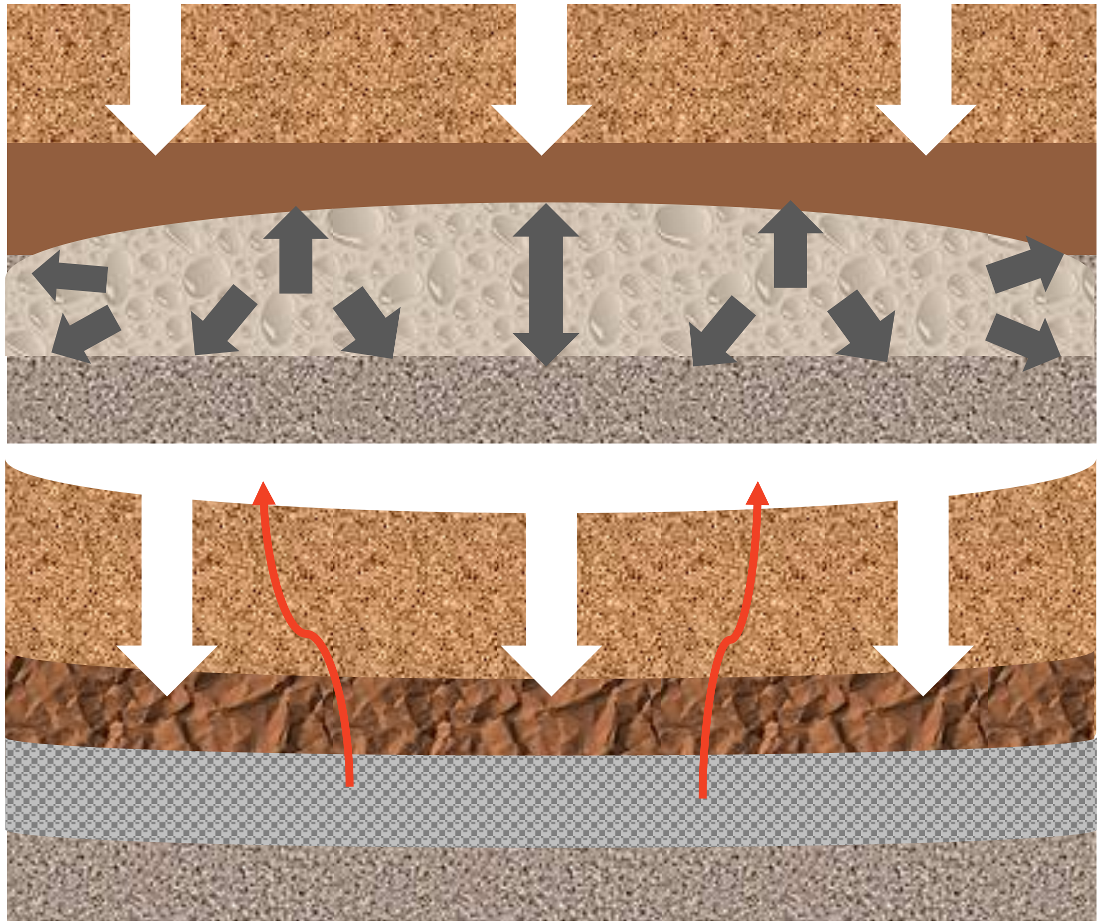


SoCal well inventory
Source: SCPR.org

Cap rock competency - Compaction & Subsidence

- Decreased volume of the reservoir due to reduced pressure/fluids production
  - May have occurred during production history
  - May result from storage operations
- Well documented in California production & storage fields
  - Salt Lake Oilfield
  - Inglewood Oilfield: 0.9 m
  - Wilmington: 8.5 m
  - Playa del Rey (1920-1970): 0.6 m
  - Torrence-Redondo (1956 - 1988): 0.6 m
- Often results in casing/cement damage

Effective Stress = Applied stress – Pore-Fluid support



Effective stress increases with overburden pressure unchanged and loss of supporting pore pressure, potentially increasing permeability of the cap rock

Other Sources of Gas

- Surface Equipment
  - Compressors
  - Site processing
  - **Pipelines!**
- Requires well planned and executed monitoring and leak detection programs
  - Ideally continuous monitoring integrated with warning systems
  - Requires regular testing schedule and documented plan for dealing with leaks

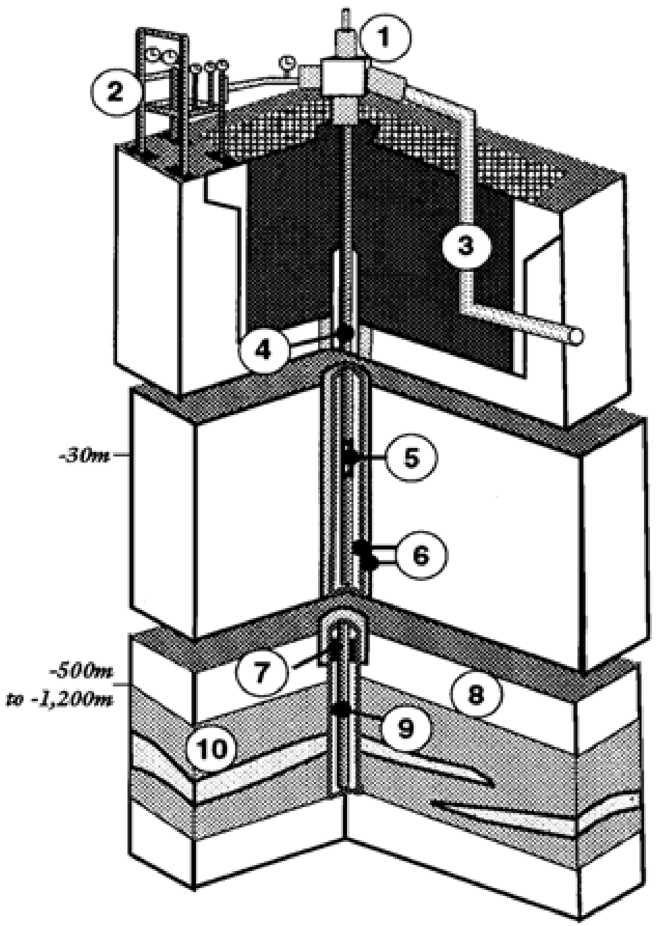
Helpful knowledge for submitting comments

- Slides 25-31 should be referred to for more detailed information about specific issues regarding:
  - Project data requirements (characterization of site geology and land use)
  - Well construction standards for storage wells
  - Mechanical standards for safety devices
  - Testing and monitoring standards
  - Other risk mitigation protocols
  - Standards for emergency response

Thank You.

Appendix 1: Important Aspects of Porosity Storage Options

Depleted Reservoir



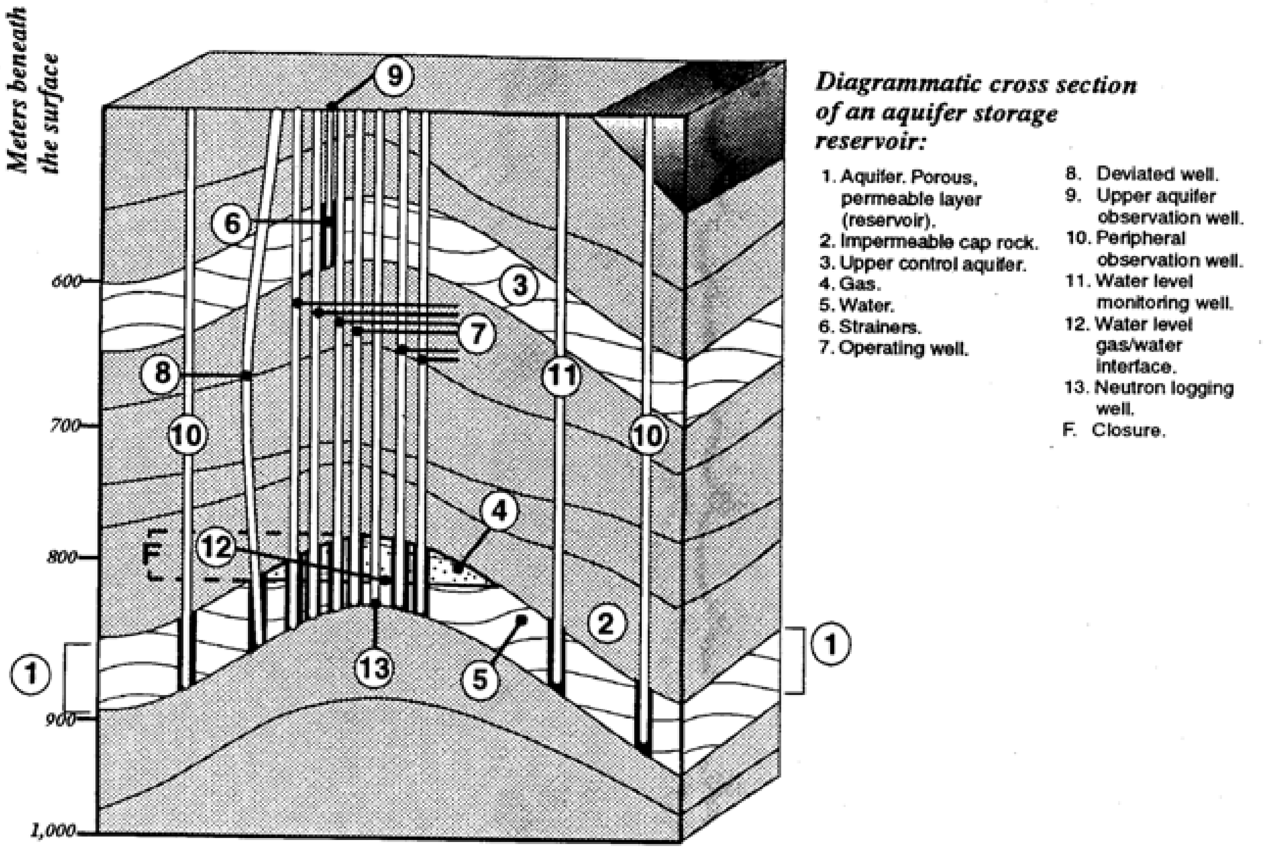
Cross Section of a Storage Well:

1. Wellhead.
2. Safety Valve Control.
3. Connection Pipe.
4. Flow Tubing String.
5. Automatic Safety Valve.
6. Cemented Casing.
7. Packer.
8. Caprock.
9. Strainers(-500 to -1,200m).
10. Reservoir.

Source: Gaz de France, "Underground Storages Facilities" (June 1992): Recreated by Energy Information Administration, Office of Planning Management, and Information Services.

- Geologic trap
  - Historical conditions generally well-known
  - HOWEVER, changes due to seismic activity and/or production history may have altered competency of trap
- Infrastructure
  - Generally make use of existing wells, site processing, and connection and gathering lines
  - reduced cost
  - **increased** risk

Aquifer Reservoir



Source: Gaz de France, "Underground Storages Facilities" (June 1992): Recreated by Energy Information Administration, Office of Planning, Management, and Information Services.

- Geologic trap
  - Requires extensive geophysical surveys to assess tightness of reservoir ($$$)
- Infrastructure
  - Requires construction of wells and pipelines, and installation of site processing equipment

Appendix 1: Case Studies

California Storage Facilities

Montebello (1950s-2003)

- Long-term gas migration problems & at least 13 homes condemned & residents relocated
  - Inadequate cement plugs in abandoned wells
  - Faulty casing/cements
  - Fracturing caused by high-pressure injections
- Injection ceased in 1986
- Facility abandoned in 2003

Playa del Rey (1950s - 2013)

- 1953 – estimated 25% of injected volume migrated to nearby oilfield
- Ongoing migration issues with bubbling common in adjacent marina, creek, and shallow lakes
  - Faults and fracture systems
  - Old, poorly constructed wells
- 2003 compressor valve malfunction resulting in 25 minute oil spray to residential property.
- 2007 lawsuit related water contamination resulting from over-pressurization
- 2013 vent stack explosion

Aliso Canyon (2015)

- 5 billion cf of methane vented to the atmosphere & more than 2,500 families evacuated
  - 63 yr old well not updated
  - Dual tubing/casing injection employed to increase deliverable volume
  - Casing partially cemented
  - Safety valve removed in 1979

Appendix 2: Regulatory Recommendations

Note, some of these points have already been proposed in DOGGR’s draft of revised regulations

Site characterization

All storage projects shall submit a thorough site characterization of area to be designated as the gas storage reservoir as it currently exists and based on local conditions, including:

- Integrity of the cap rock
    - Reported virgin pressure in target reservoir
    - Current cap rock competency
- Identification and analysis of geologic hazards
    - Faulting
    - Brittle formations
    - Shallow gas shows and their composition
    - Ground movement
        - Seismic activity
        - Compaction/Subsidence
- Inventory and Integrity of existing bore holes – active, properly plugged, improperly plugged, unplugged and abandoned, lost and abandoned, and dry holes
    - that penetrate the portion of the gas reservoir that falls within the area proposed to be designated as the gas storage reservoir
    - that penetrate an area reasonable expected to be influenced by the areas proposed to be designated as the gas storage reservoir based on geologic data
- Active mineral resources and extraction
- Land use
    - Residential
    - Commercial
    - Agricultural
    - Wildlife preserves
    - Public spaces

Well Construction & Conversion

Wells converted from production to storage wells must meet current standards for new well construction or be reconditioned to match current standards

- Comprehensive casing string design sufficient to ensure effective and redundant barriers to inter-zonal flow of subsurface fluids from the reservoir and all intersected fluid-bearing formations
- Casings shall be cemented such that there is sufficient cement filling the annular space outside the casing from the casing shoe to the ground surface, or from the casing shoe to a point at least 200 feet above the shoe of the previous casing string.
- All cement operations shall be carried out in accordance with current API Recommended Practices
- New wells drilled or converted for injection of gases shall be equipped with tubing set on a mechanical packer. Packers shall be set no higher than 200 feet below the known top of cement behind the long string casing but in no case higher than 150 feet below the base of fresh water
- Neither injection nor withdrawal shall be conducted through a casing string
- All wellheads shall be equipped with a pressure observation valve on the tubing and each annulus of the well

Storage wellhead components and casing shall be inspected quarterly for corrosion, cracks, deformations, or other conditions that may compromise integrity and that may not be detected by annual tests

Integrity Testing

- Each gas storage well shall be tested for integrity prior to being placed into service, annually thereafter, and after each workover that involves physical changes to any cemented casing string or safety device.
- The operator shall notify DOGGR at least three days prior to conducting any integrity test to allow a DOGGR representative to witness the test. Testing shall not commence before the end of the 3-day period.
- A complete record of each integrity test shall be filed in duplicate with DOGGR within 30 days after testing is completed. The record shall include a chronology of the test, copies of all downhole logs, storage well completion information, pressure readings, volume measurements, temperature logs and readings, and an explanation of the test results that addresses the precision of the test in terms of a calculated leak rate.
- An operator may request approval of well pressure monitoring as an alternative to integrity testing for non-active storage wells that are out of gas storage service. Alternatives to testing the tubing-casing annulus pressure may be monitored and monitoring results described in the annual monitoring report required for continuous monitoring of pressures and gas metering, provided that there is no indication of problems with the well

Safety Devices

- All storage wells shall have an installed and functioning surface-controlled subsurface safety valve (SSSV) or approved alternative safety device that automatically closes when there is a loss of pneumatic or hydraulic pressure on, or power to, the valve or when the maximum operating pressure is exceeded and can be activated on-site and remotely
  - Each SSSV shall be fitted with a failure warning system that is audible and visible in the control room and at any remote control center
  - Each SSSV shall be closed and opened at least monthly
  - Each SSSV system shall be tested at least twice each calendar year at intervals not to exceed 7 months. The test shall consist of activating the actuation devices, checking the warning system, and observing the valve closure
- All storage wells shall have an installed and functioning leak or fire detection system
  - Integrated with warning systems that are audible and visible in the control room and at any remote control center. The circuitry shall be designed so that failure of a detector to function will activate the warning.
  - Tested twice each calendar year at intervals not to exceed 7 months and, when defective, repaired or replaced within 10 days

Monitoring & Reporting

Well record - Within 30 days after the completion, conversion, or recompletion of a gas storage well, the operator shall file a complete record of the well construction and completion

Continuous Data Recording - Installed and functioning equipment to electronically record all operating data at a frequency of at least once per minute mandatory on all storage wells

- Wellhead pressure
- Flow (injection/withdrawal) volumes and rates
- Leak detection

Records Retention

- Operators shall retain for the life of the facility documents and records pertaining to the drilling, mining, completion, repair and workover of storage wells and the testing of storage well integrity, and shall transfer all such documents and records to any new owner and/or new operator of the facility.
- Electronic records of wellhead pressures, gas metering, and leak detector test results shall be retained by the operator for at least five years
- Extension during investigation. The operator shall retain beyond the prescribed retention period any documents or records that contain operational data pertaining to the resolution of any pending regulatory enforcement proceedings until the resolution of such proceedings.

Reporting of leaks - The operator shall report the discovery of any pressure changes or other monitoring data that indicate the presence of leaks in the well or the lack of confinement of the injected gases to the gas storage reservoir. Such report shall be made orally as soon as practicable following the discovery of the leak, and shall be confirmed in writing within five working days.

Emergency Response Plan standards

Each operator shall submit a safety plan specific to the residential, commercial, and public land use in proximity of the gas storage project and based upon existing safety measures at the facility. Copies of the plan shall be available at the storage facility and at the company headquarters

- emergency response procedures
- provisions to provide security against unauthorized activity
- gas release detection and prevention

Each operator shall prepare and implement a plan to train and test each employee at each gas storage project on operational safety and emergency response procedures to the extent applicable to the employee's duties and responsibilities. The plan shall be incorporated into the plan addressing the requirements of the United States Department of Transportation and Occupational Safety and Health Administration.

Each operator shall hold a safety meeting with each contractor prior to the commencement of any new contract work at a gas storage project. Emergency measures specific to the contractor's work shall be explained in the contractor safety meeting.

Each operator shall conduct an annual drill that tests response to a simulated emergency and is witness by DOGGR and emergency response coordinator/authorities. The operator shall file a written evaluation of the drill and plans for improvements with DOGGR and the county emergency management coordinator within 30 days after the date of the drill.

Additional Recommendations

- Increase in operating pressure above the maximum pressure originally permitted shall require a new permit
- Operation pressure shall not exceed the virgin pressure of the reservoir
- DOGGR must be adequately staffed in number and expertise to effectively oversee storage facility safety