An Assessment of the Geologic Storage Capacity of California Sedimentary Basins

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Abstract

An initial assessment of the capacity of sedimentary basins in California to store CO_2 emissions has been carried out as part of the WESTCARB Regional Partnership activities. A preliminary screening of 104 sedimentary basins excluded 77 different areas as possible sequestration sites. Where data were available, depth-to-basement and/or sandstone isopach maps were generated for 20 of the remaining sedimentary basins. For basins containing oil and gas production, a GIS layer of the oil and gas fields was prepared and attributed with detailed data on producing intervals, production, and rock and fluid properties. These data were then used as a basis for preliminary CO_2 storage-capacity estimates. Using API gravity and depth as screening criteria, oil reservoirs were screened for CO_2-Enhanced Oil Recovery (EOR) potential. From this, the CO_2 that could be stored in oil reservoirs associated with EOR was found to be 3.4 Gt. A realistic estimate of the storage capacity of saline formations in the ten largest basins ranged from 146 to 840 Gt CO_2, depending on assumptions about what fraction of the formations are used, what fraction of the pore volume is filled with separate phase CO_2, and salinity. The proximity of potential storage reservoirs to Quaternary faults was also assessed.

1. Introduction

Annual CO_2 emissions in California amount to about 345 Mt (10^6 metric tons) (EPA, 1999). Utility and industrial point source emissions, which could potentially be stored in geologic formations, are about 124 Mt. In determining whether geologic sequestration is an option for CO_2 emissions reduction in California, one of the first steps is to evaluate the subsurface storage capacity. Benson (2001) performed a preliminary assessment of California storage capacity, concluding that the capacity of depleted oil fields was sufficient for 5 to 40 years of current emissions from power generation, and the capacity of saline formations in the Central Valley alone was sufficient for more than 300 years of emissions. Only very coarse-scale information was available for these estimates, including gross oil and gas production figures as well as total areas of major sedimentary basins. This paper presents the results of a more comprehensive study to provide data at a level of detail sufficient for a regional-scale assessment of geologic sequestration opportunities.

2. Geologic Data Assembly

With a geology made complex by its proximity to a convergent continental margin, California contains 11 diverse geomorphic provinces. The first step in estimating storage capacity was to identify and catalog the significant sedimentary basins within these provinces. Basins selected included all large or hydrocarbon producing basins and numerous smaller basins (mostly in the Basin and Range and Mohave Desert provinces) that could be identified from the 1:750,000 scale geologic map of California (Jennings, 1977). This resulted in an inventory of 104 basins, the outlines of which were digitized to produce a California sedimentary basin GIS layer. This layer was combined with a California oil and gas field GIS layer.

The basins were then subjected to preliminary screening criteria to determine suitability for CO_2 sequestration. Preliminary screening involved literature searches and limited analysis of well logs where available. Requisite criteria included the presence of significant porous and permeable strata, thick and widespread seals, and sufficient sediment thickness to provide critical state pressures for CO_2 injection (>800 m). Additionally, basins underlying sensitive lands such as national and state park lands, Indian lands, and military installations were excluded. This preliminary screening resulted in exclusion of 77 basins from further consideration. The screening results were also attributed to the sedimentary basin GIS layer. Figure 1 shows the sedimentary basins, results of the screening, and oil and gas fields.

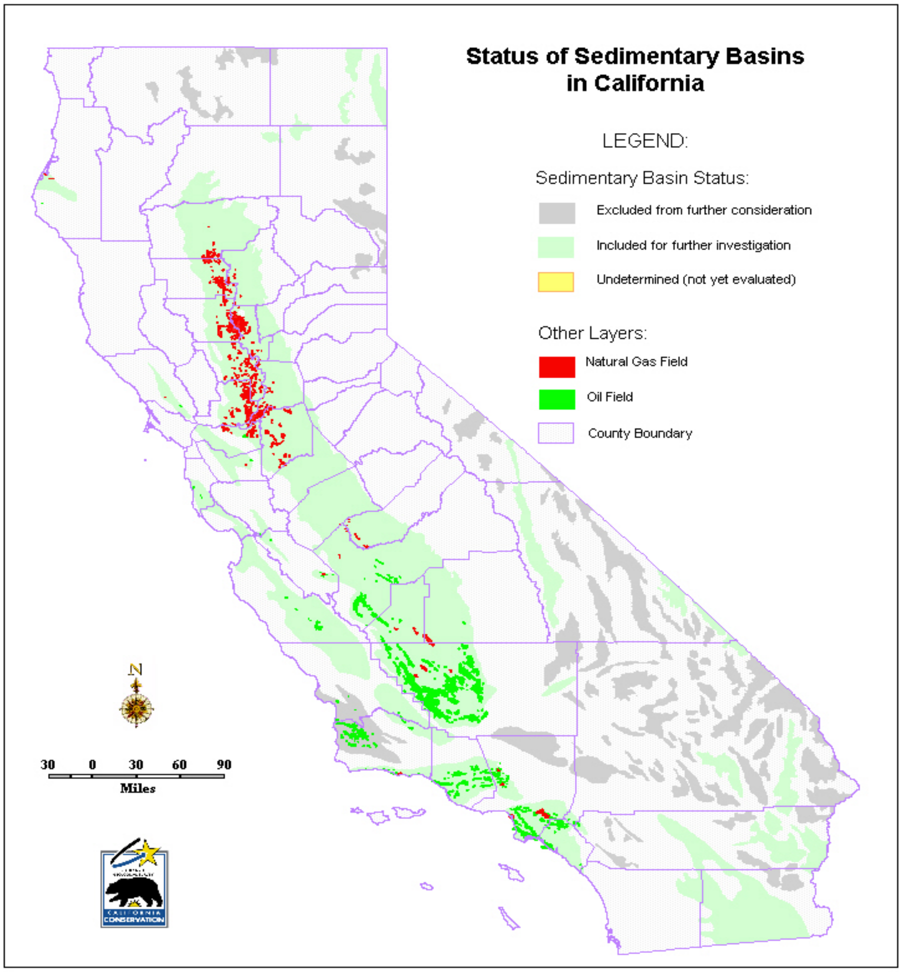

Figure 1. Sedimentary basins in California showing those areas excluded from capacity assessment in light grey. Oil and gas fields are overlain.

To characterize the physical rock and fluid properties of potential sequestration basins, we assembled oil and gas field and reservoir data from publications of the California Division of Oil, Gas, and Geothermal Resources (DOGGR) and other available sources. First, field-scale data were compiled in a database, providing information such as location, depth, field area, cumulative production, and depth to base of fresh water. This information was attributed to the California oil and gas field GIS layer.

Information about the physical rock and fluid properties for each individual producing, abandoned, or shut-in reservoir unit within each field was then also compiled and tabulated in a database. These data included reservoir fluid (oil, gas, water), zone status (producing, abandoned, shut-in), average depth, average thickness, producing area, porosity, permeability, initial pressure and temperature, formation water salinity, seal thickness, trap type (structural or stratigraphic), and history of secondary/tertiary recovery efforts.

Since almost no physical data exist for saline aquifers below 800 m, data from the oil and gas producing zones have been considered as surrogates for brine-filled equivalents downdip of oil and gas accumulations and outside of oil and gas producing areas.

California stratigraphy is frequently distorted or truncated by regional and local angular unconformities, faults, and major submarine canyons. A systematic effort to accurately map the many promising sandstone zones or seals was therefore beyond the scope of this initial screening investigation. Thus we decided to prepare a single gross sandstone-isopach map for each basin for the interval between 800 m (2,625 ft) and 3,050 m (10,000 ft). While this approach lumps many disparate sand bodies in the isopach interval and is not accurate from a rock, time, or sequence-stratigraphic standpoint, it does provide a broad measure from which storage appropriate for a regional assessment can be made. The upper limit represents the minimum depth for critical state CO_2 injection. The lower limit incorporates a reasonable number of deeper well logs, enabling characterization of the larger Sacramento, San Joaquin, Los Angeles, and Ventura basins. A thinner isopach interval was employed for smaller basins lacking deep well control. Depth-to-basement and sandstone-isopach maps were generated for seven major sedimentary basins for which geophysical or well log data were available. Depth-to-basement or sandstone-isopach maps were prepared for 13 additional basins. Examples of the sandstone-isopach and depth-to-basement maps for the Sacramento-San Joaquin basins are shown in Figures 2 and 3.

All information and completed maps, compiled in standard digital and GIS formats, are being made available through the Utah Automated Geographic Reference Center (AGRC) clearinghouse. The Utah AGRC database is, in turn, linked to the NATCARB national geologic sequestration database.

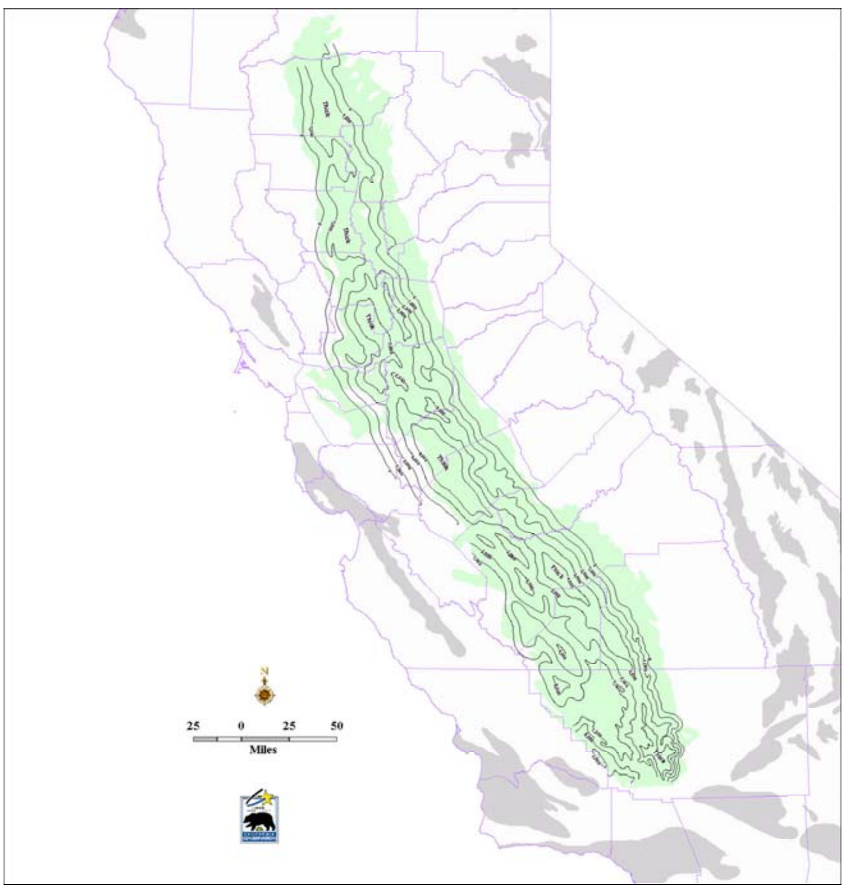

Figure 2. Sacramento and San Joaquin basins—gross sandstone-isopach map for depth interval 2,625–10,000 ft

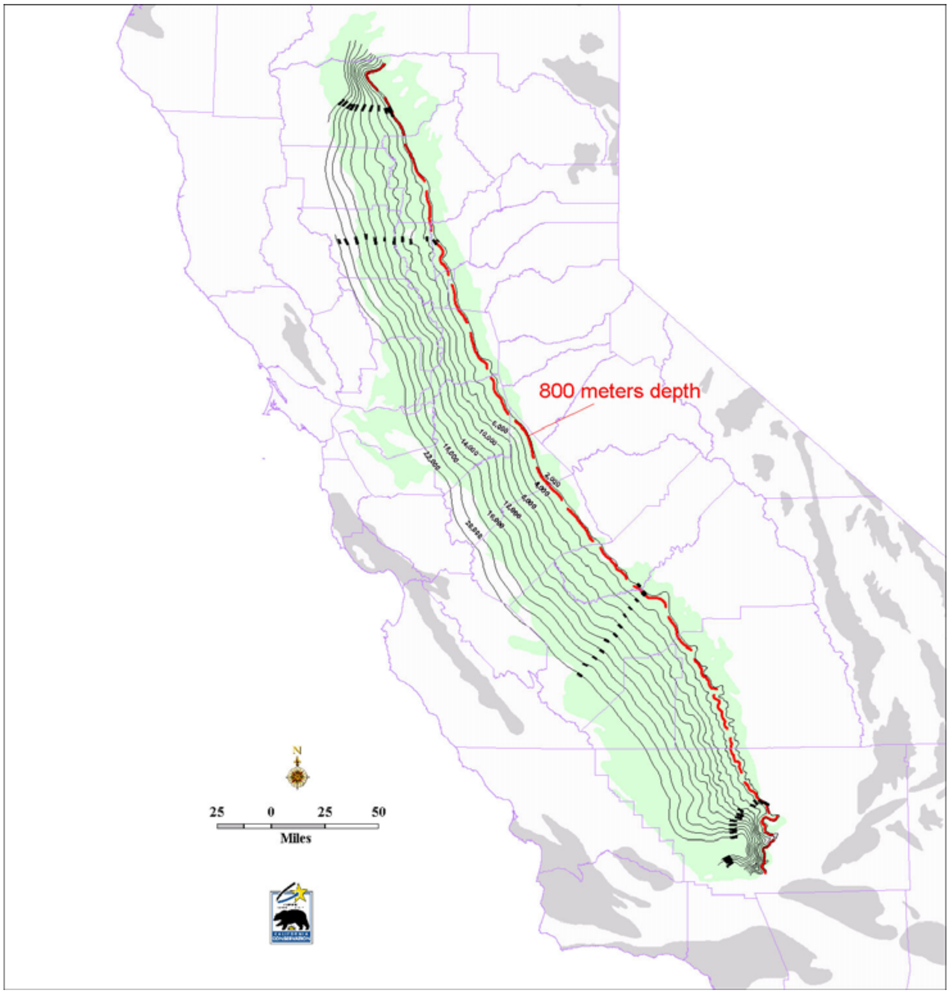

Figure 3. Sacramento and San Joaquin basins—depth-to-basement map

3. Capacity Calculations

The isopach and depth-to-basement maps were used to estimate the total storage capacity in saline formations in the ten largest sedimentary basins in California. Table 1 provides the data used to calculate the total available pore volume in the basins. Only a portion of the total pore volume is available for storage. The storage capacity is determined from the mass of CO_2 trapped in the pore space either as a separate phase or dissolved in the pore water. Many factors affect the percentage of the pore space that could be occupied, including formation heterogeneity, buoyant flow, hydrologic boundary conditions, residual saturation, and other two-phase flow properties. Reservoir modeling studies also suggest that, because of two-phase conditions and diffusion, the pore volume containing dissolved CO_2 will be greater than the pore volume of separate-phase CO_2 (Doughty et al., 2001). Two other factors affecting storage capacity are the density of the in-place CO_2 and the salinity of the pore water. Formation temperature and allowable injection pressures will, in large part, determine the CO_2 density. Salinity of the pore waters is important because CO_2 solubility decreases with increasing salinity.

Figure 4 shows the results of capacity calculations for a range of pore-volume values containing separate-phase and dissolved CO_2. The calculations assumed a single density value of 600 kg/m^3 and a CO_2 dissolved mass fraction of 2.5%. Results show total storage capacity for the 10 basins ranging from 146 Gt to 840 Gt. The low end of this range would provide sufficient capacity for storing over 1,000 years of utility and industrial sector emissions at the current emission rates. Table 1 shows that more than half of this capacity is contained in the Sacramento-San Joaquin basins.

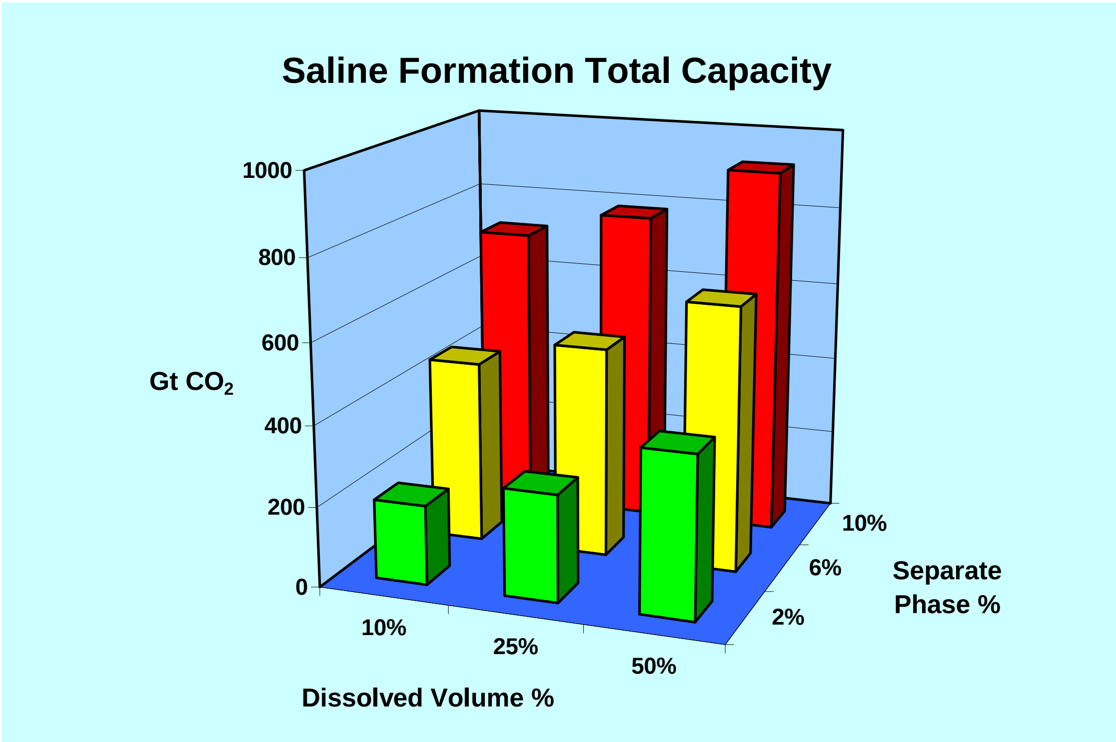

Figure 4. Total sequestration capacity of saline formations in ten largest basins in California

Table 1. Data used for calculation of pore volume of California basins

Volumetric Data for California Basins			
	Area (sq. miles)+	**Estimated Average Thickness (ft.)***	**Estimated Average Porosity****
Sacramento-San Joaquin basins	18,550	2,000	0.25
Los Angeles Basin	1,341	3,000	0.25
Ventura Basin	1,450	3,000	0.24
Salton Trough	2,559	2,000	0.24
Eel River Basin	175	1,500	0.26
Salinas Basin	1,343	1,250	0.28
La Honda Basin	268	1,500	0.25
Livermore Basin	144	800	0.23
Orinda Basin	296	600	0.23
Cuyama Basin	582	3,000	0.27
+Area of basin at depths greater than 2,625 ft. (800 m)			
*Average sands (isopachs) thickness for depth window 2,625 ft (800 m)– 10,000 ft			
**Approx. average porosity for all zones in isopachs window			

Several of the sedimentary basins, notably the Sacramento, San Joaquin, Los Angeles, and Ventura basins, also contain major oil and gas fields, which will likely be the first targets for geologic sequestration. Estimates for the CO_2 storage capacity of California oil and gas fields were based upon production data, using Elewaut et al, 1996:

$$Q_{CO2} = (V_{Uoil} + V_{Ugas}) * \rho_{CO_2} / 1{,}000 \quad (1)$$

where Q_{CO2} = CO_2 storage capacity ($MtCO_2$)
V_{Uoil} = Underground volume of oil produced (M m^3)
V_{Ugas} = Underground volume of gas produced (M m^3)
ρ_{CO_2} = CO_2 density at the reservoir pressure

The underground volume of oil and gas was estimated from:

$$V_{Uoil} = V_{oil(st)} * B_o \quad (2)$$

$$V_{Ugas} = V_{gas(st)} * B_g \quad (3)$$

where $V_{oil(st)}$ = Volume of oil at standard conditions (M m^3)
$V_{gas(st)}$ = Volume of gas at standard conditions (M m^3)
B_o = Oil formation volume factor (FVF)
B_g = Gas formation volume factor (E^{-1})

A default FVF of 1.2 was applied for oil. The gas expansion factor E was calculated with linear relation: E = 4.8P+93.1, where P is the reservoir pressure in MPa. If the original reservoir pressure value were missing, it was calculated from the average depth of the field, assuming a gradient of 10.5 MPa/km.

An estimate of the CO_2 EOR potential for oil fields was made based on API gravity data and depth. Oil fields at depths >3,000 ft and with API gravity more than 25^o were classified as fields with miscible CO_2-EOR potential. Fields at depths >3,000 ft and with API gravity between 17.5^o and 25^o were classified as fields with immiscible CO_2-EOR potential. Fields at depths >3,000 ft and API gravity less than 17.5^o were classified as fields with storage potential but no EOR potential. The attributed GIS database was interrogated using these criteria, yielding 121 fields in California with miscible CO_2 EOR potential and a CO_2 storage capacity of 3.4 Gt. The storage capacity was increased to 3.8 Gt by including the fields in the remaining two categories. Though tiny compared to the total saline formation capacity, the storage capacity associated with potential CO_2 EOR is still equal to over 27 years of current utility and industrial sector emissions. An independent study of the CO_2 EOR potential in California performed by ARI (2004) concluded that the technically recoverable reserve is over 5.6 billion barrels, which would enable storage of 1 Gt of CO_2 with conventional CO_2-EOR flooding technology.

The capacity of California gas fields, screened by depth, was also estimated using the expression in Equation 1. The result yielded 128 gas fields with a combined storage capacity of 1.8 Gt. Oldenburg et al. (2001) have shown that CO_2 can be used to enhance production from depleting gas fields (EGR), though an estimate of the CO_2 EGR potential for California has yet to be done.

4. Faulting

The presence of active faults was not one of the criteria for excluding a basin from the storage capacity assessment. The coexistence of oil fields and active faults in some basins, such as the Ventura basin, is evidence that buoyant fluids can remain trapped in the vicinity of active faults. However, it is also known that faults can provide pathways for fluid movement. Price et al. (2005) have suggested that sequestration should be excluded from a zone of about 2 km on either side of an active fault, on the premise that the fault zone is a potential leak path.

Figure 5 is a map of Quaternary and later faults in California overlain on the sedimentary basins. While almost all basins have some faults, the Sacramento-San Joaquin basins are noteworthy for the absence of Quaternary and later faults (except in the extreme southern end). The shaded areas along the basin's west margin represent the approximate location of deep thrust faults not intersecting near-surface sediments.

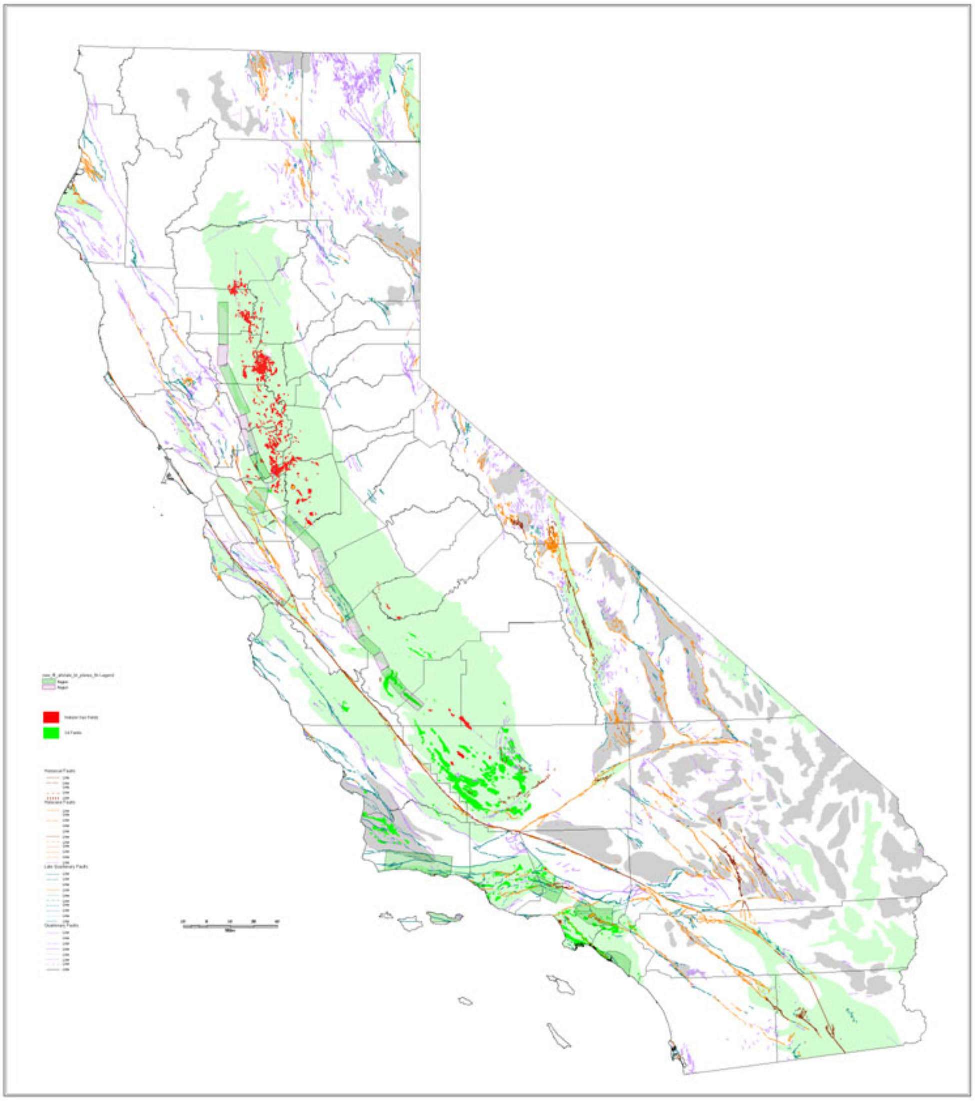

Figure 5. Active faults in California (modified after Wagner, 2000)

5. Summary

A regional-scale assessment of the sedimentary basins in California has revealed a huge potential geologic sequestration capacity. Even though 76 of the 104 identified sedimentary basins were excluded from the assessment, the saline formations in the remaining basins have a storage capacity of 146 to 840 Gt of CO_2, depending on assumptions about filling capacity and salinity. Over half the capacity is located in the Sacramento-San Joaquin basins. These basins also have large numbers of oil and gas fields and significant potential for CO_2 EOR. The desirability of these basins as sequestration targets is further enhanced by the low occurrence of active faulting. Though the level of detail in the geologic characterization was adequate for a regional assessment, additional, more detailed characterization is needed for site-specific project planning. Characterization of particular formations representing likely early sequestration targets is planned.

Acknowledgments

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