SECTION A.I. SITE CHARACTERIZATION
40 CFR 146.82(a)(2), (3), (5), and (6)

MONTEZUMA NORCAL CARBON SEQUESTRATION HUB

Facility Information

Facility name:	Montezuma NorCal Carbon Sequestration Hub IW-A1
Facility contact:	Jim Levine, Managing Partner 2000 Powell Street, Suite 920 Emeryville, CA 94608 Phone: (510) 409-1765 Email: jim.levine@upstream.us.com
Well location:	Collinsville, Solano County, California Lat: 38° 5' 7.334" N Long: -121° 51' 30.914" W NAVD 88 Sec 28 T 3 N R 1 E

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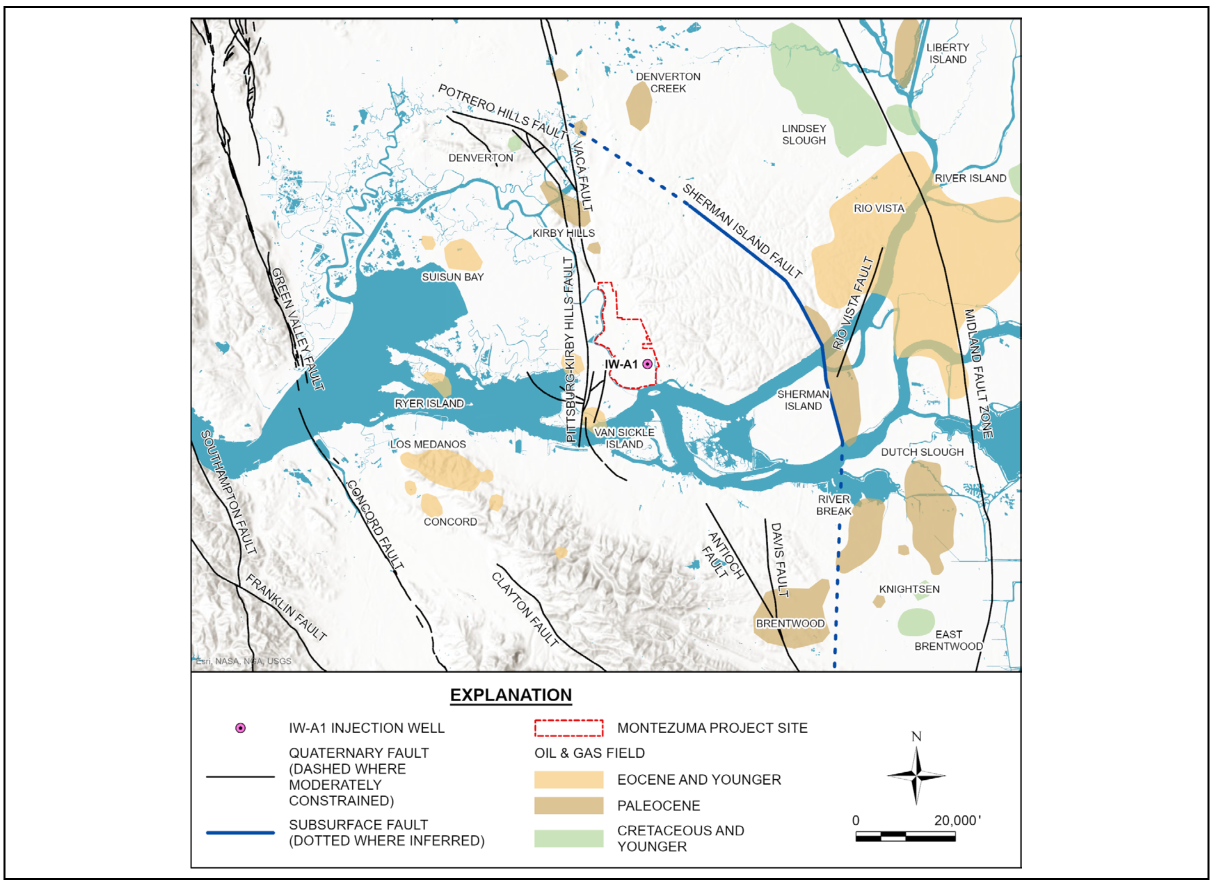
A.I.1 REGIONAL GEOLOGY, HYDROGEOLOGY, AND LOCAL STRUCTURAL GEOLOGY [40 CFR 146.82(A)(3)(VI)]

The proposed injection site is in southwestern Montezuma hills, an area of modestly elevated topography north of the Sacramento River between the reclaimed Delta islands to the east and southeast, and Grizzly Island and Suisun Bay to the west (Figure A.I-1). The Montezuma hills are at the southwestern end of the Sacramento Valley, a subaerial, intermontane basin between the Coast Ranges to the west and Sierra Nevada to the east. The modern Sacramento Valley evolved from an ancestral Mesozoic-Tertiary marine forearc basin that formed above a long-lived, east-dipping subduction zone beneath western California (Ingersoll and Dickinson, 1981). Over the past approximately 28 million years, plate convergence and subduction have been progressively replaced by transcurrent motion and strike-slip faulting in western California, leading to shoaling of the marine basin, uplift of the Coast Ranges to the west, and a transition to continental fluvial deposition in the Sacramento Valley (Graham et al., 1983, and references therein).

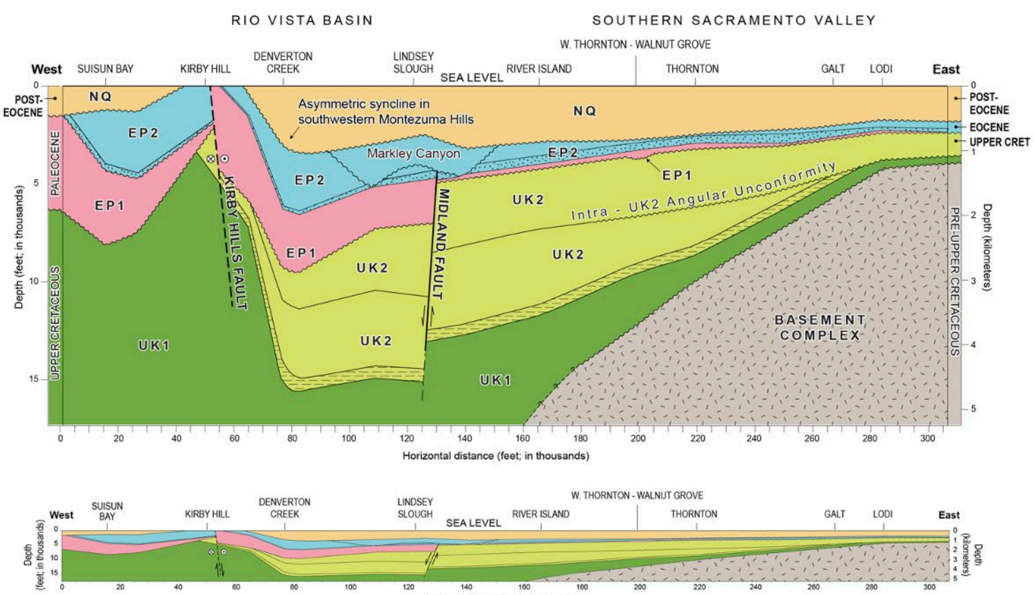
FIGURE A.I-1. MAP OF MAJOR SURFACE AND SUBSURFACE FAULTS IN THE MONTEZUMA HILLS STUDY AREA



The Montezuma hills approximately coincide with the central part of Rio Vista basin, a north-south-trending extensional sub-basin within the larger forearc basin that formed in early Tertiary time (MacKevett 1992; Krug et al. 1992) (Figure A.I-2). Although the early Tertiary Rio Vista basin is now buried north of the Sacramento River by younger Tertiary and Quaternary terrestrial deposits, an oblique cross-sectional view of the bounding structures and thickened Paleogene marine section in the basin is exposed south of the river in the northeast-dipping backlimb of Mount Diablo anticline. From inspection of this natural, map-scale cross section, the Midland and Kirby Hills fault zones form the eastern and western margins, respectively, of the Rio Vista basin (Figures A.I-1 and A.I-2). Both structures were originally normal faults, and they can be traced in the subsurface of Rio Vista basin southward across the river into the exposed stratigraphic section on the northern flank of Mt. Diablo. The structure correlative to the Kirby Hills fault south of the river is the Kirker fault, which is exposed in the Los Medanos hills between the cities of Pittsburg and Concord. These faults are both active faults and the Kirby Hills fault has evidence of Holocene deformation.

FIGURE A.I-2. EAST-WEST STRATIGRAPHIC CROSS SECTION THROUGH THE MONTEZUMA HILLS

(Modified from Pasquini and Milligan, 1967; and DOGGR, 1982a)



The Sherman Island fault is a secondary antithetic normal fault to the Midland fault and terminates westward against the Kirby Hills fault zone (Krug et al., 1992). Other examples include the Antioch and Davis faults, which are mapped in Tertiary outcrops in south of the river. The Sherman Island fault is mapped west of and subparallel to the Midland fault and interpreted to dip moderately to steeply east (DOGGR, 1982b).

The Paleogene growth section in the Rio Vista basin can be subdivided into at least two distinct packages (Figure A.I-2):

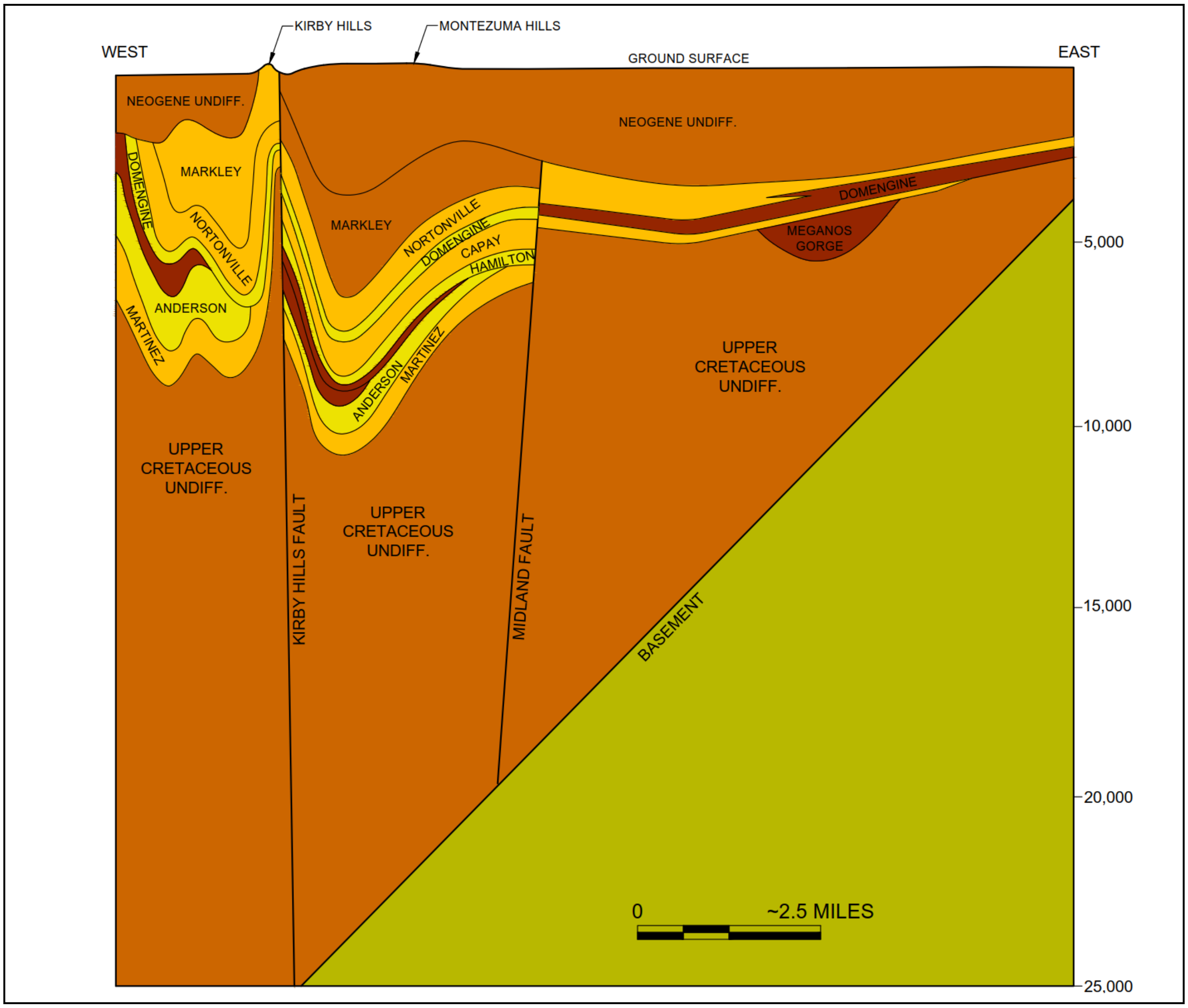
1. Package EP1: Paleocene and Eocene strata comprising a lower sequence associated with the cutting and filling of the older Martinez submarine canyon, and an upper sequence associated with the cutting and filling of the younger Meganos submarine canyon (Figures A.I-1 and A.I-2). The thalweg of the Martinez canyon trends west across the northern Rio Vista basin, and the south- to southwest-trending thalweg of the Meganos canyon is exposed on the northeast limb of Mount Diablo (Cherven 1983).
2. Package EP2: The basal unit of EP2 is the transgressive early-middle Eocene (50 Ma) Domengine Formation, a regional stratigraphic marker and a distinctive quartz-rich sandstone that historically has been a prime target for gas exploration and production. In western Rio Vista basin, the Domengine Formation cuts downsection westward across east-tilted EP1 strata, omitting about 250 m of EP1 section below the basal EP2 unconformity (see Figure 5 in Cherven 1983). In outcrop on the northeast limb of Mount Diablo anticline south of the river, the Domengine Formation is mapped as progressively cutting downsection from east-southeast to west-northwest through the entire EP1 section and well into the Upper Cretaceous section (Crane 1995).

Paleogene growth strata in the hanging walls of the main and subsidiary normal faults of the Rio Vista basin are exposed on the northern flank of Mt. Diablo (Sullivan et al., 2021a; 2021b), and support interpretation of open-hole logs and other subsurface data from gas exploration in Rio Vista basin (Pasquini and Milligan 1967; DOGGR, 1982; Krug et al. 1992, and references cited therein) for early Tertiary extension and subsidence in the hanging wall of the ancestral western California subduction zone (Unruh 2021).

Active subsidence of the Rio Vista basin ended in Eocene-Oligocene time. Normal displacement on the bounding Kirby Hills and Midland faults dies out upsection in or below the Oligocene Markley Formation (Figure A.I-2). The forearc basin gradually shoaled in middle to late Tertiary time with the transition from convergent motion to transcurrent motion along the western California plate boundary, and marine conditions were replaced by subaerial fluvial environments. The Paleogene marine strata in Rio Vista basin currently are buried by about 1 km of Neogene and Quaternary deposits (Unit NQ in Figure A.I-2).

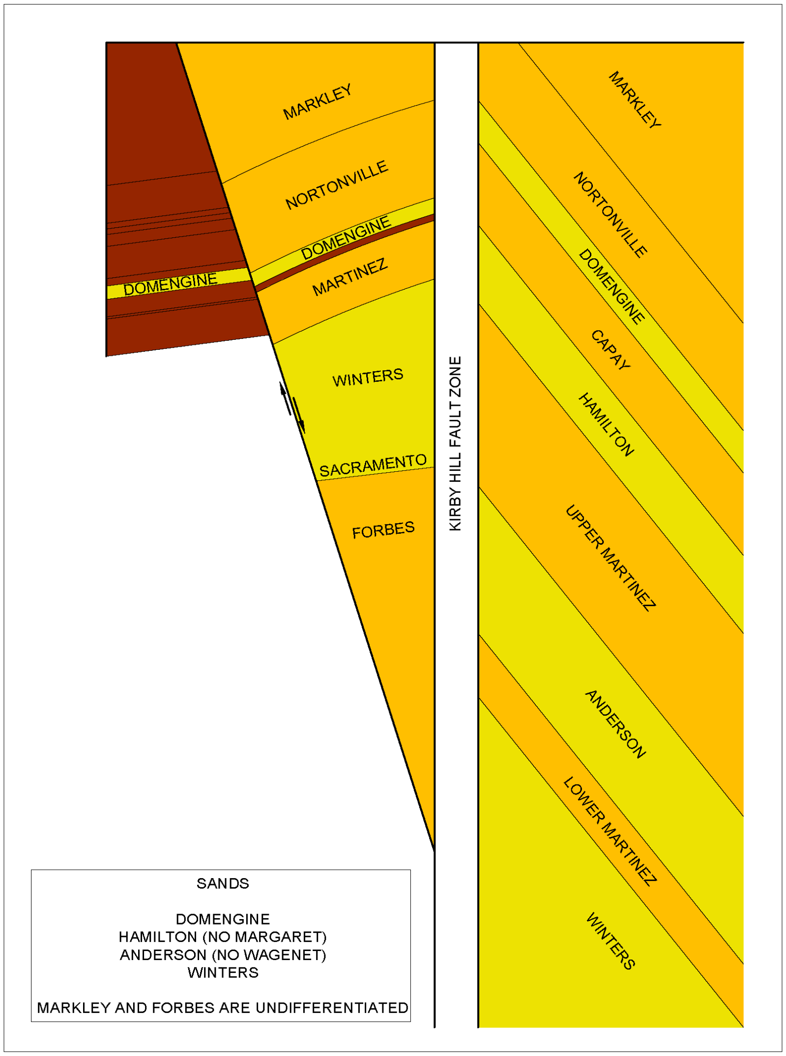
Plio-Pleistocene uplift, tilting and shortening along the eastern margin of the northern Coast Ranges elevated the Montezuma hills above the surrounding estuarine areas of the Sacramento-San Joaquin Delta, and locally folded and faulted the buried strata of the Rio Vista basin. Folding of the base of the NQ unit (Figure A.I-2) and structure contours on key Paleogene markers in the Rio Vista basin indicate that at the top of the primary injection zone, the Anderson sand, the proposed borehole location, is close to or east of the axis of an asymmetric south-southeast-plunging syncline that is subparallel to and about 5-7 km east of the Kirby Hills fault (Figure A.I-3). The syncline axis passes east of the Denverton Creek gas field, as shown in Figure A.I-2, and trends south toward the southern tip of the Montezuma hills. The top of granitic or Franciscan basement is estimated to be greater than 6 km.

FIGURE A.I-3. CROSS-SECTION OF KIRBY HILLS FIELD



Although subsurface data in this part of the Montezuma hills is sparse, extrapolation of structural trends from the homoclinally northeast-dipping section on the northern flank of Mount Diablo, open-hole logs from the central Montezuma hills to the northeast, and east-west trending 2-D seismic reflection lines suggest that a wellbore drilled to about 14,000 ft would encounter the formations shown in Figure A.I-4.

FIGURE A.I-4. CROSS-SECTION OF KIRBY HILLS FAULT TRAP



The Montezuma Hills is approximately coincident with the early Tertiary Rio Vista basin, which is bounded on the east and west by the Midland fault and Kirby Hills fault, respectively. Early Tertiary marine strata of the Rio Vista basin are labeled EP1 (pink) and EP2 (blue); the stippled layer at the base of EP2 is the Eocene Domengine sandstone. The early Tertiary Rio Vista basin strata are overlain by several thousand feet of younger Tertiary continental fluvial deposits (Neogene and Quaternary; NQ) in the Montezuma Hills. Plio-Pleistocene deformation related to plate boundary tectonism in western California has reactivated the Midland fault as a reverse structure, producing a low-amplitude anticline in the overlying NQ strata. Transpressional strike-slip deformation localized along the Kirby Hills fault has produced uplift and eastward tilting along the western margin of Rio Vista basin, creating an asymmetric syncline with a steeper western limb in the southwestern Montezuma Hills. This syncline plunges southward toward the Sacramento River where it appears to level out. The syncline is probably truncated by the Antioch fault which is mapped south of the Sacramento River.

As shown in Figure A.I-1, the area bounded by the Sherman Island Fault to the East and North, the Kirby Hills fault zone to the west, and the Antioch fault to the south bound the syncline. These faults juxtapose the injection zone sands against shales and are seals for gas fields along the faults.

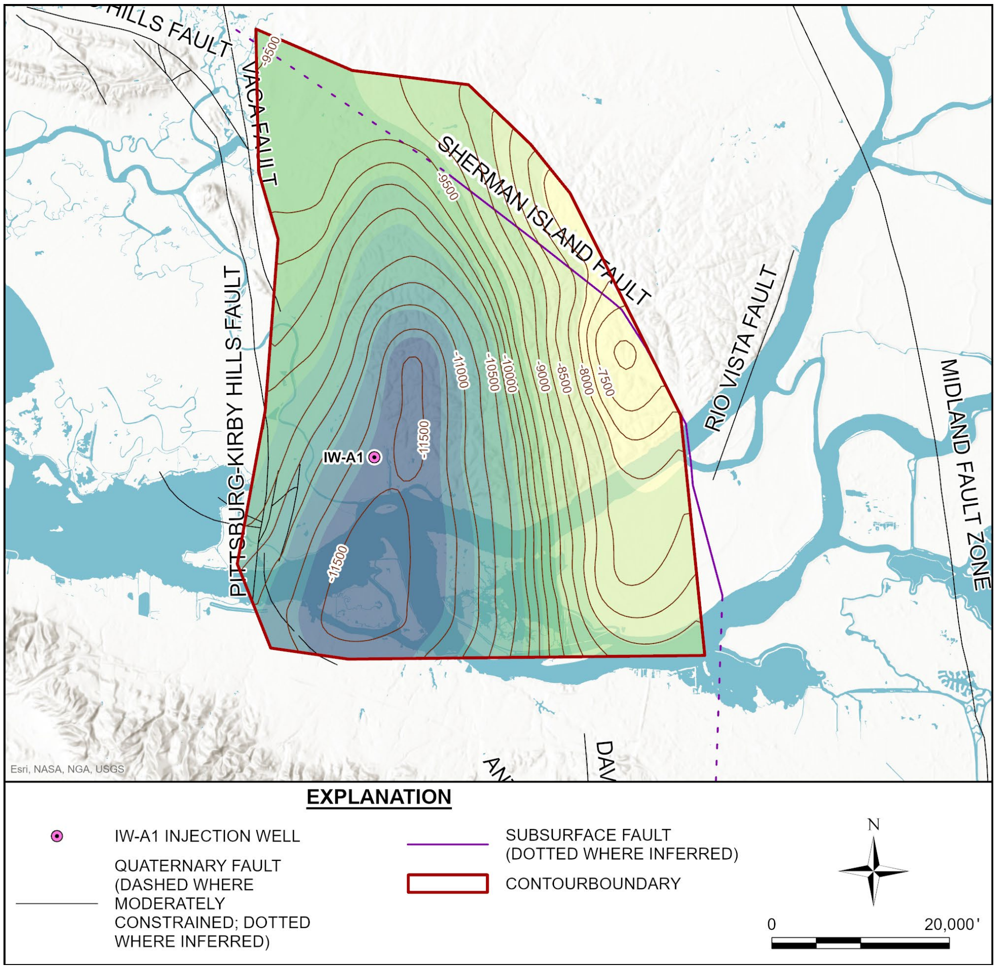
The study of the geology of the area has shown that three possible confinement zones should be analyzed, and these confining units overlie the Domengine, Hamilton and Anderson sandstone units. The Anderson sandstone is the planned reservoir for IW-A1 (Figure A.I-3), but the other units are potential future injection intervals for future development of the potential CO_2 hub and injection reservoir storage complex. The confinement zones for this project include the Nortonville Shale (above the Domengine), the Capay Shale (between the Domengine and the Hamilton sandstones), and the Meganos/Martinez shales (between the Hamilton and the Anderson sandstones and below the Anderson). A more detailed description of injection intervals and confining zones is provided in subsequent paragraphs within this template for the application.

Figure A.I-5 shows structural contours on the Anderson injection zone in an area bounded by the Sherman Island Fault to the east and north, the Kirby Hills fault zone to the west, and the Antioch fault to the south. Note that parts of the Antioch fault interpretation and the intersection of the Sherman Island fault with the Kirby Hills fault zone have not been imaged and will be updated with a 3D seismic survey prior to drilling the stratigraphic test well. There are no identifiable faults inside the area outlined by these faults, and thus we believe this sub-basin of the Rio Vista basin forms an area of pressure communication within a distinct reservoir.

A.I.1.1 NEARBY GAS FIELD

The characterization of the possible injection and confinement zones has been defined by a study of published literature, gas field studies, seismic data and well log data. Figure A.I-1 provides an illustration of the regional geologic faults and structures that create a series of gas fields in the vicinity of the MC project site. There are numerous natural gas fields surrounding the Rio Vista basin including the Rio Vista field which lies on the Midland fault and is one of the largest gas fields in the country, having produced the equivalent of over 100 MMtonnes of natural gas, primarily from Paleocene sands that are the target reservoir intervals for the Montezuma injection well. The withdrawal of gas has left reservoir pressures near the Midland fault at the Rio Vista field at generally less than 10% of virgin pressures, although unproduced sands are at virgin pressure indicating no pressure communication across the confining shales. The Midland fault acts as part of the trapping mechanism on the west side of the Rio Vista field from which most of the gas (>3.5 TCF) has been produced. While the drive mechanism on the west side is gas drive, on the east side the mechanism is water drive and no pressure depletion is observed.

FIGURE A.I-5. STRUCTURAL CONTOURS FOR TOP OF ANDERSON SANDSTONE



Figures A.I-3 and A.I-4 show a couple of cross-sections of the Kirby Hills field. Note that the Kirby Hills fault (with over 600 ft of throw), juxtaposes Paleocene reservoir sands against older shales. The Kirby Hill gas field is the closest gas field north of the proposed location. The center of this field is roughly 6 miles north of the proposed well. The Kirby Hill gas field was discovered in 1966 and produced natural gas from the Domengine and Anderson zones. It is now being used as a gas storage field. In 2007, additional injection wells were drilled, most into the Anderson zone at approximately 5500 ft. During gas withdrawal reservoir pressures drop to less than 500 psi and during injection they rise to over 2000 psi. At Kirby Hills, measured permeability in the Anderson (~5500 ft subsea) was between 30 and over 600 mD although we expect compaction effects with depth to reduce the permeability at 11,300 ft at the Anderson level in the injection well.

Other fields in the area (Van Sickle Island (the closest gas field (1.5 miles) to the proposed injection well location), Sherman Island, and Brentwood) have similar reservoirs and trapping characteristics. Thus, the faults bounding the deep syncline act as no flow boundaries for fluid injection.

These gas fields and specifically, the key gas wells near the vicinity of the MC project site Figure A.I-1 are discussed in the following paragraphs.

West of MC Site: The Van Sickle Island gas field is located 1 mile to the west of the proposed injection well site. This field has 20 wells in it, 16 of which are in section 29, only 1-2 mile west of the proposed well. A typical gas well in this field is between 7,500 ft and 8,000 ft deep and produced gas from the Domengine at that depth interval.

South of MC Site: There is one well drilled south of the proposed IW-A1 location and also in section 28. This was the Brazos Oil and Gas "Concord Gun Club'. It was drilled in 1951 and drilled to a depth of 7,003 ft. Unfortunately, the well bottomed in the Markley Formation, and thus did not reach any of the zones of interest. However, this well does give data on the shallower zones and the base of the USDW ($\geq$10,000 ppm TDS) was found to be 1,235 ft. In addition to that well, about one mile to the southwest is the Chevron "Feykert" #1 well. It was initially drilled to a depth of 11,040 ft and then redrilled to TD into the Domengine.

North of MC Site: The Kirby Hill gas field is the closest gas field north of the proposed IW-A1 location. The center of this field is roughly 6 miles north of the proposed injection well. The Kirby Hill gas field was discovered in 1966 and produced natural gas from the Domengine and Anderson zones. It is currently being used as a gas storage field. In 2007, additional injection wells were drilled, most into the Anderson zone (called Wagenet unit in that field). There are also several dry holes between the Kirby Hill and Van Sickle Island fields along the Kirby Hills fault zone. Most important of these is the Hershey Oil "McDougal" well, which was drilled in a similar section as expected for the Montezuma Carbon well, and cut the Kirby Hill fault near total depth, ending up in Upper Cretaceous Forbes formation rocks (MacKevett, 1992). Farther north and within or near the center of the syncline are a group of deep wells. These were drilled at depths of 10,000 ft to over 12,000 ft. Krug, et.al. (1992) show in their paper that these wells were drilled on the western side of the syncline. These wells give good control on the thickness of the Anderson zone across the syncline.

East of MC Site: There are some significant dry holes drilled by oil and gas companies that explored for natural gas east of the proposed location. These wells lie between the proposed IW-A1 location and the gas fields that are farther to the east: the Sherman Island and Rio Vista gas fields. These wells are the McCulloch Oil "GP" and "Anderson" wells. The Anderson 5 well is important because it drilled over 14,000' and bottomed in the Upper Cretaceous, thus seeing all the potential relevant geologic units of potential interest for the MC project. The "GP" well went to 11,000 ft and penetrated all zones of interest. This deep control is important, even though the wells are miles away from our proposed drill site. These data points help determine the regional dip of beds on the eastern side of the syncline. The Sherman Island field is important to the project because it produced natural gas in a fault trap from two of our potential injection zones: the Hamilton Sand and the Anderson Sand. The Rio Vista gas field lies just east of the Sherman Island gas field. This is the largest natural gas field in the State of California, with ultimate recoverable reserves of close to 4 trillion cubic feet of gas. Most of this gas came from two of the proposed injection zones for our project: the Domengine and the Hamilton sands. Well data from this field shows that the Anderson sand thins and eventually is absent in this area due to erosion.

A.I.2 MAPS AND CROSS SECTIONS OF THE AOR [40 CFR 146.82(A)(2), 146.82(A)(3)(I)]

As described in the Area of Review and Corrective Action Plan, preliminary modeling indicates that the Area of Review (AoR) is bounded by faults. Figures A.I-1 and A.I-5 provide maps of this region and fully encompass the AoR. These maps are supplemented by the cross sections on Figures A.I-2, A.I-3, and A.I-4. Each of the cross sections encompasses the AoR, providing different orientations and scales for inspection. See the Area of Review and Corrective Action Plan for additional maps and cross sections of the AoR.

A.I.3 FAULTS AND FRACTURES [40 CFR 146.82(A)(3)(II)]

A detailed description including maps and cross-sections of the MC site and the associated geologic faults and associated regional structures is provided in the preceding sections of this template document for this application.

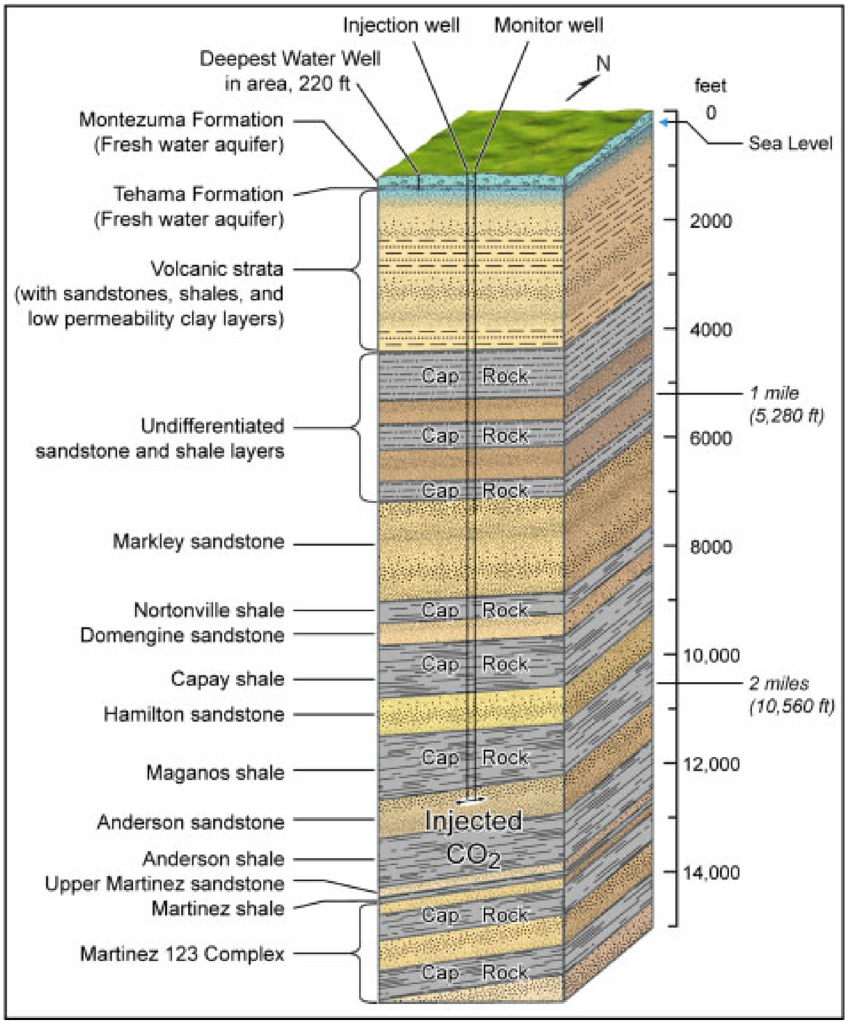
A.I.4 INJECTION AND CONFINING ZONE DETAILS [40 CFR 146.82(A)(3)(III)]

Figure A.I-6 shows the predicted formations along with their approximate depths/thicknesses near the proposed injection well (IW-A1) location. A summary the relevant formation names, lithology, depths, and properties are provided below in the following paragraphs.

Holocene-Pleistocene-Pliocene [0-2,000 ft]: For the most part, undifferentiated non-marine. Medium to dark gray-green sands, poorly consolidated, volcanic fragments, inclusive of the Tehama Formation. Interbedded soft, silty, massive gray-green and brown clays. Though there is typically a thin zone of very recent materials at and near the surface, a large portion of the lower section from this interval of rock has been named the

Tehama Formation. The lowermost USDW zone in the MC project area is considered to occur within this unit at an approximate depth of 2,000 ft.

FIGURE A.I-6. GENERAL STRATIGRAPHIC COLUMN FOR MC PROJECT AREA



https://www.westcarb.org/norcal_co2reduction_project.html

Upper Eocene [2,000-7,850 ft]: Includes the Sidney Flat Shale, a massive brown shale, and the Markley Sand, a fine to medium grained sand of gray-brown color interbedded with carbonaceous brown shales. This interval is anticipated to include about 80% shale.

Nortonville Shale [Confining unit] - middle Eocene [7,850-8,150 ft]: Medium to dark gray-brown brittle shale, locally calcareous, with many fossils (forams and diatoms). This confinement zone is present throughout the study area. This unit is shown as being hundreds of feet thick in all of the gas fields around the area, including Van Sickle and Suisun Bay fields to the west, Sherman Island and Rio Vista to the east, and Kirby Hill to the north.

Domengine Sandstone [Potential future injection zone] - middle Eocene [8,150 -8,550 ft]: This sand unit is one of the most productive zones in the area, and it is active at the nearby Van Sickle gas field, as well as to the north at Kirby Hill field and to the east at Rio Vista field. A basal unconformity that eroded away all of Lower Eocene, Paleocene and much of the Upper Cretaceous on the high side of the Kirby Hill fault lies at the base of this unit. This formation consists of very fine-medium grained, greenish-gray or white quartz sand, friable, moderately sorted, silty, glauconitic, shell fragments. Fining upwards sequences with two distinct sand units are separated by a more shaley section. Thus, this 400 ft interval is expected to have approximately 270 ft of net permeable zones. Average sand porosity: 20%, range: 16-32%, average sand permeability 40mD, range: 10-100+mD. Thickness of >20 mD sands: 320 +-64 ft. Average total dissolved solids (TDS): 11,000 ppm, range: 10,200-13,000 ppm.

Capay Shale [Confining unit] – lower Eocene [8,550-9,200 ft]: This shale unit is present in most of the project area. However, it is absent in an area along the west side of the Kirby Hill fault zone. This unit is composed of light-medium pure gray shale, soft-firm, gummy, moderately cohesive, with very-fine, sub-rounded clear quartz, moderate sorting, with abundant glauconite at the base. The sandstone beds in the Capay Shale farther east at the Rio Vista gas field are not expected here at the MC Project site.

Hamilton Sandstone [Potential future injection zone] - lower Eocene [9,200-9,900 ft]: This unit is actually found at the bottom of the Capay Formation, below the Capay Shale. It is described as a light gray, very fine-fine grained, micaceous, carbonaceous sand, friable, clear quartz. This 700 ft thick interval is estimated to have a net thickness of between 200 to 280 feet at the MC project site. The Hamilton Sand itself has a distinctive shape on the electric logs, with a predominantly shaley and silty sand character near the top gradually becoming more sandy and becoming much more permeable and sandy at the bottom several hundred feet of the zone. Similar to the Capay Shale, this unit is present across most of the project area, however is absent in an area along the west side of the Kirby Hill fault. Average sand porosity: 18%, range: 14-26%, average sand permeability 30mD, range: 10-50md. Thickness of >15 mD sands: 240 +-48 ft. Average total dissolved solids (TDS): 12,000, range: 10,500-13,000 ppm.

Meganos/Upper Martinez Shale [Confining unit] - lower Eocene [9,900-11,300 ft]: Electric logs of the wells closest to the proposed drill site show that there is a thick continuous shale section below the Hamilton Sand that includes the Meganos Shale and the Upper Martinez Shale. The lower Eocene Meganos shale and the upper Paleocene Upper Martinez shales combine to form a thick confinement zone that is present in the entire project area east of the Kirby Hill fault. Meganos: Light-medium, gray to black shale, soft, clayey. Upper Martinez: Medium-dark brown, firm, hard siltstone, occasionally massive with light-medium gray claystone. The total thickness of the Meganos Shale and Upper Martinez Shale formations is expected to be 1,400 ft at the MC project site.

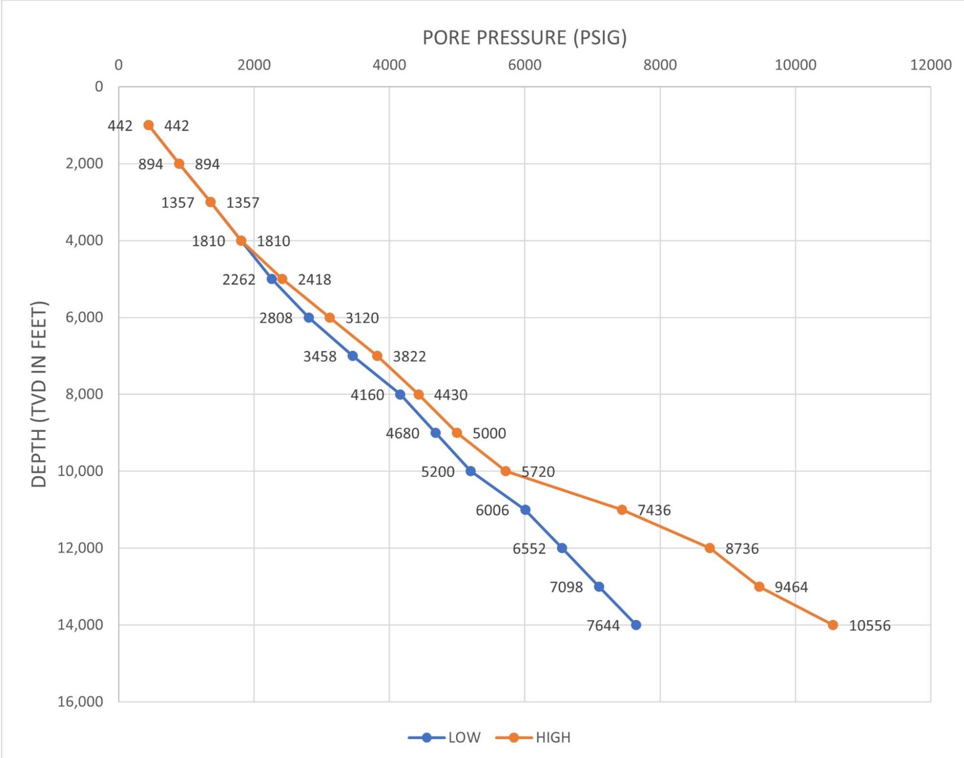
Anderson Sandstone [Targeted injection zone] - middle Paleocene [11,300-12600 ft]: This sandstone unit can be very thick based on well control and seismic data mapped by MacKevett (1992). However, the unit does thin rapidly to the east towards the Rio Vista gas field, where it ends up being missing due to erosion. But, in the heart of the regional syncline, there is a large area in which the sand is at least several hundred feet thick around the outer portion and up to roughly 2,000 feet thick in the center of the regional syncline. In general, the Anderson sandstone is described as a light gray, fine-medium grained, micaceous quartz sand. Logs suggest two main sand packages with a more shaley interval in between. This is the thickest potential injection zone beneath the MC project site, with an expected total thickness of approximately 1,300 ft (MacKevett, 1992). Based on the available regional data, the anticipated net pay zone for the Anderson Sandstone unit is anticipated to range between 300 ft to 780 ft thick. Average sand porosity: 20%, range: 16-28%, average sand permeability 200mD, range: 20-400mD. Thickness of >50 mD sands: 910 +--182 ft. Average total dissolved solids (TDS): 17,000, range: 13,000-25,000 ppm.

Lower Martinez Shale [Confining zone] - lower Paleocene [12,600-13,900 ft]: This shale layer is the lower confinement zone beneath the Anderson sandstone. The description of this unit in the published literature is similar to that for the Upper Martinez Shale: medium-dark brown, firm, hard, siltstone, occasionally massive with light-medium gray claystone. There is a base Martinez sand unit named the McCormick sand which is described as a very fine-medium grained, white, quarzitic sand, friable, sorted. However, the thickness of the Lower Martinez Shale should provide suitable confinement for the targeted Anderson injection zone. If IW-A1 or a test well is drilled to only reach and test the Anderson sandstone and then limited to no more than an additional 400 feet depth below that unit, the borehole should be able to verify adequate confinement beneath the targeted injection interval.

Overall, the injection and confining zones are continuous across the MC project site and throughout the AoR. The base of the Domengine, base of Hamilton, and Base of Meganos are all erosional unconformities. Additionally, the zone between the base of the Hamilton and the Base of the Anderson thickens considerably toward the axis of the syncline, and also the units below the Domengine thin toward the Kirby Hills fault.

Estimates of pore pressure and ranges for each of the formations of interest were obtained from mud weights used from Rio Vista to Suisun Bay and are illustrated in Figure A.I-7.

FIGURE A.I-7. PORE PRESSURE ESTIMATES VERSUS DEPTH



These formation properties as well as geologic structure were defined by a study of published literature (see references), public gas field data, seismic data, well log data, core data, drillers logs and mud logs.

Figure A.I-1 shows a map of the key wells and gas fields used to obtain data for site characterization near the injection well.

1. The Hershey Oil "McDougal" well, roughly 1 mile from, and drilled in, a similar section to that expected in the Montezuma Carbon well, was cut the Kirby Hill fault near total depth, ending up in Upper Cretaceous Forbes shales (MacKevett, 1992).
2. Farther north and within or near the center of the syncline are a group of deep wells. These were drilled at depths of 10,000 ft to over 12,000 ft. Krug, et. Al. (1992) show in their paper that these wells were drilled on the western side of the syncline. These wells give good control on the thickness of the Anderson zone across the syncline as do some published seismic lines which indicate that there is no observable faulting near the injection well (Myer, 2010).
3. There are also some key dry holes to the east of the proposed location, the McCulloch Oil "GP" and "Anderson" wells. The Anderson 5 well is important because it drilled over 14,000 ft and bottomed in the

Upper Cretaceous, thus seeing all the potential zones anticipated in the injection well. Mud weights below 10,000 ft in these wells were typically between 10 and 11 lbs/ft at TD suggesting that the Anderson zone at the proposed location will be nearly normally pressured.

A.I.4.1 INJECTION AND CONFINING ZONE GEOLOGIC STRUCTURE

The three potential injection intervals for the full-scale GS Hub include the Domengine Sandstone, the Hamilton Sandstone, and the Anderson Sandstone. The Anderson Sandstone is the proposed target interval for IW-A1 and this Class VI permit application. Each of these three potential injection zones are vertically contained by thick shale units, both above and below them. The following paragraphs provide additional detailed information about these injection intervals and confining units (See Figures A.I-3, I-4, I-5, and I-6).

Domengine Sandstone. This mid-Eocene aged sandstone was deposited in relatively shallow water. The sandstone is in outcrop a few miles to the northwest at the Potrero Hills gas field. But that field is on the other side of the Kirby Hill fault. There is a significant offset along the fault that separates this zone from the nearby gas fields that produce gas from the Domengine zone (i.e., Kirby Hill and Van Sickle Island gas fields). Though Van Sickle Island field has been mapped as being located east of the Kirby Hill fault, there are other faults in the field that separate the Domengine that will be found in the test well from the field. Additionally, the Capay shale below the Domengine and the Nortonville shale above the Domengine both appear to be very fine grained deep-water shales that form excellent confinement layers.

Hamilton Sandstone. This zone is actually the basal unit of the Capay Formation. Almost all of the Capay Formation is the overlying dense deep-water shale, but at its base lies this relatively thick sandstone layer. Published data on the geology of this area shows the geology in an east to west direction between the Van Sickle Island gas field and the Suisun Bay gas field (which lies some 6 miles or so west of the Van Sickle field). This work shows that the geologic stratigraphic section of lower Eocene and Paleocene times is gone on the western side of the Kirby Hill fault. Below an unconformity at the base of the Domengine, the rocks are the Forbes formation of Upper Cretaceous age. Thus, the lateral confinement for the Hamilton sand, as shown in MacKevett (1992), is gone on the high side of the major fault.

Anderson Sandstone. The Anderson Sandstone is also gone on the high side of the Kirby Hill fault. However, it is very thick on the lower eastern side of the fault and will likely be over 1,000 feet thick at the proposed IW-A1 location. As is the Hamilton, the Anderson is also overlain and underlain by thick competent shale beds (the Meganos and Upper Martinez shale above, the Lower Martinez shale below). While the Anderson does not produce gas in the Van Sickle Island field, it has produced natural gas at both the Kirby Hill and Sherman Island gas fields, which are both adjacent to our project site. The Anderson sand is currently used at Kirby Hill gas field for natural gas storage. From our understanding and interpretation of the regional geology, the location of the proposed IW-A1 appears to be at the axis of the regional syncline, and the Anderson sandstone unit is encountered where it would be thousands of feet structurally lower than the gas zones in the closest gas fields.

In summary, all the injection and confining zones are continuous in the AoR. The base of the Domengine, base of Hamilton, and Base of Meganos are all erosional unconformities. The Zone between the base of the Hamilton and the Base of the Anderson thickens considerably toward the axis of the syncline. Units below the Domengine thin toward the Kirby Hills fault.

A.I.5 GEOMECHANICAL AND PETROPHYSICAL INFORMATION [40 CFR 146.82(A)(3)(IV)]

The geologic suitability of the MC project area was previously evaluated by Shell and LBNL as part of a US DOE-supported pilot CO_2 injection project to handle the CO_2 from Shell's refinery in Martinez. The pilot project included drilling and formation property testing followed by injection and monitoring of a small amount of CO_2. Based upon those previous efforts, Shell concluded that the site geology was very attractive, with the ability to safely store large volumes of CO_2. Although much of this project and testing results are confidential/proprietary in nature, many of the same UCB/LBNL professionals are part of the MC project team.

In addition to the information and experience gained from these previous investigations, the UCB/LBNL team conducted a thorough research of the available technical literature for this region, and specifically obtained and reviewed published data related to the nearby natural gas fields. The fields in proximity to the MC project site, between the Kirby Hill and Sherman Island faults, include the Kirby Hill, Sherman Island and Van Sickle Island gas fields. Other gas fields nearby include the Rio Vista field to the east, the Honker and Suisun Bay gas fields to the west, and the North Kirby Hill and Denverton Creek gas fields to the north.

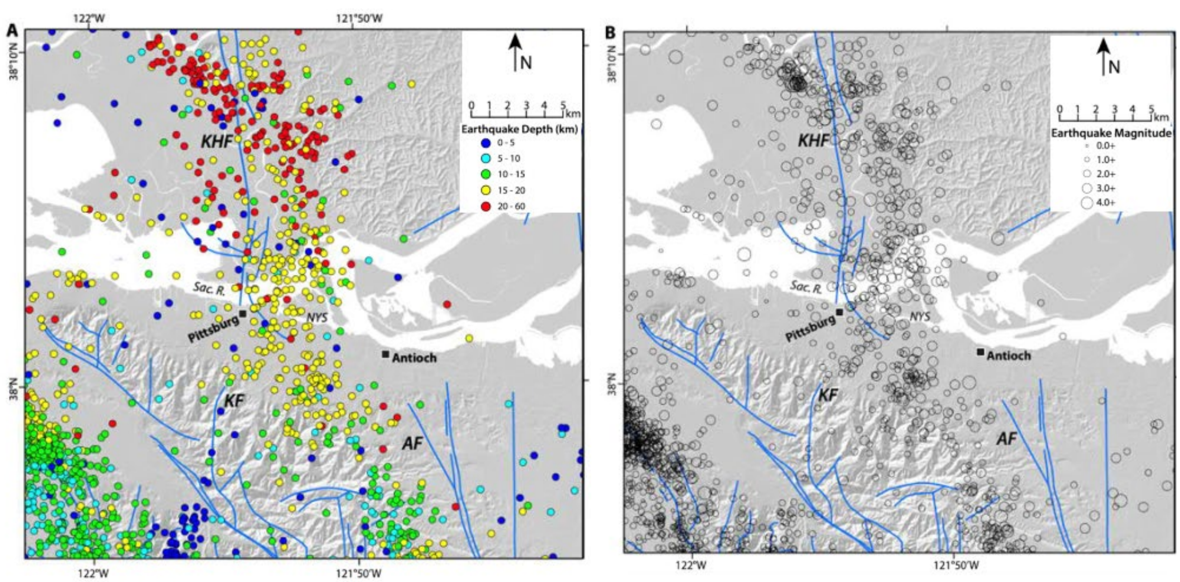
The Area of Review and Corrective Action Plan presents regional information on the geomechanical and petrophysical properties of the study area. This regional information was used to develop the preliminary modeling and the AoR estimate. The Pre-operational Testing Program describes the plan for obtaining site-specific data on geomechanics and petrophysics of the area. This will include open hole logging as well as soil coring and analysis.

A.I.6 SEISMIC HISTORY [40 CFR 146.82(A)(3)(V)] AND POTENTIAL FOR INDUCED SEISMICITY

A.I.6.1 EARTHQUAKE HISTORY OF MONTEZUMA REGION AND FAULTING

The Kirby Hills fault is an active fault that has a history of extremely deep earthquakes in the Montezuma area. FigureA.I-8 is a map showing event locations near the Kirby Hills fault for the period from 1969 and to 2019 (Wong and Unruh, 2019). As shown in the maps, nearly all earthquakes have M<3.0 with hypocenters at depths below 15 km, at least 7 km below the estimated top of basement. The focal mechanisms indicate predominantly right-lateral strike-slip motion. Some, but probably not all the seismicity within the seismic zone are associated with the Kirby Hills fault, although the majority of earthquakes are > 20 km, much deeper than most earthquakes within the San Andreas fault system. This raises the question whether this deep seismicity is actually related to the shallow Pitttsburg-Kirby fault zone. Other investigators have suggested that the Midland fault, which dips west, may be involved.

FIGURE A.I-8 – SEISMICITY HISTORY OF KIRBY HILLS FAULT AREA (1969 - 2014)



(A) Earthquake depth in kilometers (B) Earthquake magnitude

KHF - Kirby Hills Fault; KF Kirker Fault; AF Antioch Fault; Sac. R. - Sacramento River; NYS New York Slough

USGS and CGS, 2020; Horton et al., 2017

The only large earthquake observed in the area was an (M~6) near Antioch in 1889. It is unknown where the hypocenter was located or even if it was on the Kirby Hills fault.

The Kirby Hills fault strikes roughly N/S and based on the deep hypocenters is assumed to dip about 75 degrees E. In the sedimentary section, the fault zone expands into numerous faults believed to be a flower structure (MacKevett,1992). At the surface the fault zone is about 0.5 km wide and there is evidence of Holocene deformation. The nearest faults cutting the reservoir interval are just east of the Kirby Hills fault and act as traps for several depleted gas fields west of the Montezuma area (Honker Bay, Van Sickle, and Kirby Hills (now a gas storage field)). The main Kirby Hills fault also acts as a trap with Paleocene sands on the west side of the fault opposite upper Cretaceous Forbes and Dobbins shale units Figure A.I-4.

A.I.6.2 INDUCED SEISMICITY

Induced earthquakes from pressure diffusion

Elevated pore pressures that travel from injection wells to a critically stressed fault via pressure diffusion can initiate slip by reducing the effective pressure, weakening the fault (Walsh and Zoback, 2015). Over the past 15 years in Oklahoma, high volume water disposal wells have induced large (M>5.0) earthquakes in basement rocks, often miles away from large volume injection wells. Wastewater is injected in the Arbuckle aquifer (which sits on top of basement) resulting in pressure perturbations that diffuse out into the aquifer and then down vertical faults into the basement. Prior to 2009, Oklahoma operators injected water at much lower rates and pressures and there were few induced earthquakes of a detectable magnitude. Beginning around 2009, large scale fracking and horizontal wells generated much larger volumes of wastewater and induced earthquakes increased in frequency. After the Pawnee M=5.8 earthquake the State of Oklahoma directed injection well operators to stop injection if an earthquake of M=4 or greater occurred within 6 miles of an injection well, and to reduce injection volumes if that earthquake occurred between 6 and 10 miles of the injection well. Earthquake magnitudes and frequencies dropped precipitously after the directive began in 2016-2017.

Small Induced earthquakes (M<2, White and Foxall, 2016) related to CO_2 injection have been created by a similar mechanism. The seismic networks monitoring the demonstration CCS project near Decatur, Illinois, recorded about 10,000 events in the magnitude range -2 to 1 from 2011 to 2014 when injection volumes were ~1 MMtonnes/year. Like the Arbuckle injection zone in Oklahoma, the Mt. Simon injection zone in Illinois sits on top of faulted basement and the induced seismicity mechanism is believed to be similar. When the injection zone was moved up away from the basement, induced earthquakes were reduced. A similar pattern of injection zone proximity to basement and frequency of induced earthquakes was observed in Oklahoma.

Induced earthquakes from a poro-elastic mechanism

Earthquakes have also been induced from pressure *reduction* due to oil and gas production (Segall, 1989, Sukale 2009). Given that negative fluid pressure changes should *increase* stress and make faults stronger, another mechanism for induced earthquakes called poro-elastic stress transfer was proposed in these papers. In poro-elastic stress transfer, the increased pressure caused by the injection zone radiates a poro-elastic response in the formation in all directions and travels farther and more rapidly than fluid pressure, which stays within the reservoir if there are confining layers above and below. Poro-elastic stress travels with velocities that are a small fraction (<1%) of elastic wave velocities, so the poro-elastic waves reach the hypocenter within minutes to hours depending on the distance between the pressure perturbation and the hypocenter. Unlike pressure diffusion, impermeable layers do not completely impede stress transfer.

An example of what are believed to be poro-elastic stress induced earthquakes due to wastewater injection is shown in Zhai, et al. (2021). The Delaware Basin of West Texas has experienced a dramatic increase in earthquake activity that has produced several M>5.0 earthquakes within the last three years. The Delaware Basin has also seen an increase in water disposal volumes in recent years. However, unlike Oklahoma, the injection zone is far above the basement, and there are permeability barriers between the injection zone and the earthquake hypocenter depths. Consequently, pressure diffusion is unlikely to be the mechanism for inducing deep seismicity.

Potential for Induced Earthquakes in AoR

The Montezuma area geology is quite different from the Oklahoma or Illinois geology. At Montezuma, the injection zones are located over *two miles* above top of basement, and over *six miles* above the hypocenters. There are also thick (up to 400m), regionally continuous, low permeability shales between the injection zones and the basement (MacKevett, 1992). These shales do not allow pressure to move outside of the production interval. Produced zones are depleted while unproduced sands above or below are normally pressured (Hadsell, 2023).

Besides the gas fields along the Kirby Hills fault zone, the supergiant (3.8 TCF) Rio Vista field produced from over 15 named formations down to 11,000 ft along the Midland fault zone. Most of the wells in these gas field are depleted with formation pressures up to 95% less than hydrostatic. West of the Midland fault is the Sherman Island fault which has not been active since the Oligocene. The Sherman Island fault has a throw of approximately 300 ft and is a reservoir trap at the Sherman Island field.

The numerous wells drilled between the Sherman Island field and the Kirby Hills gas fields in the AoR encountered normal pressures, confirming that these faults have sufficient throw to act as traps. Consequently, our AoR is bounded on the West by the Kirby Hills fault zone and on the east and north by the Sherman Island fault.

The huge mass of gas extracted from the Rio Vista field undoubtedly modified the state of crustal stress for tens of km around the field. Yet there does not appear to be any trend in induced earthquakes over the past 50-75 years. The mass of CO_2 proposed at Montezuma is orders of magnitude smaller than that withdrawn from nearby gas fields, therefore we see no mechanism by which deep earthquakes can be generated from CO_2 injection in the AoR.

Preliminary Assessment of CCS Induced Seismicity Potential

White and Foxall (2016) performed a review of CCUS-induced seismicity and described two notable cases. There are, of course, numerous cases of induced seismicity due to high volume water injection (Oklahoma, Texas, Canada, Ohio, etc). The primary mechanism for most of this seismicity is likely to be pressure diffusion where pressure propagated from the injection well through the aquifer into faults extending up to the top of crystalline basement. In these cases, the aquifer was in pressure communication with the basement faults.

The Montezuma site is quite different from the examples above.

1. The Montezuma injection interval is 2-3 miles above top of crystalline basement, and 8-12 miles above seismicity in the area.
2. The confining units are impermeable thick, continuous shales with an additional 2-3 miles of largely shale confining zones separating the reservoir from the basement.
3. All the major faults in the area (Kirby Hills, Midland, and Sherman Island) are known from gas production adjacent to the fault to be impermeable.
4. None of the huge volumes of gas withdrawn in the area (over 4 TCF) has affected pressures away from the fields nor was any induced seismicity or change in active seismicity due to gas production been observed indicating that poroelastic effects are insufficient for creating seismicity either in the reservoir or the basement.

Consequently, the risk of CO_2 injection causing large (M>4.5) events is negligible and if any seismicity is detected it is most likely to be unfelt small events near the reservoir interval and the injection well.

Small faults and fractures below the resolving power of 3D seismic data (25-50 ft of throw) cannot be ruled out in the AoR and could slip due to pressure changes in the reservoir, or changes in rock properties due to the plume. However, these earthquakes are highly unlikely to cause any damage.

Potential for Damage to injection wells or compromise of seals from natural or induced seismicity

The report of Pratt, et al. (1978), concludes that there are virtually no examples of underground damage from the vibrations produced by earthquakes of any magnitude. Even the 1964 Alaska quake had no damage to underground structures including oil and gas wells in Cook Inlet. The report also states that underground examples of well damage are invariably correlated with fault displacement. In the Montezuma AoR, any fault slip in the plume region (if there are any faults at all), will be far less than the thicknesses of the bounding shales and the seals will not be compromised. Even a small fault intersecting the well is highly unlikely, particularly because the well will be sited using 3D seismic data. Should one be encountered during drilling, the well will be sidetracked to avoid the fault.

A.I.7 HYDROLOGIC AND HYDROGEOLOGIC INFORMATION [40 CFR 146.82(A)(3)(VI), 146.82(A)(5)]

The Montezuma Hills are low-lying, reaching a maximum elevation of less than 90 meters (300 feet) above sea level. The hills drain predominantly to the Sacramento River to the southeast. The only perennial streams in the hills occupy some of these drainages. Minor seasonal streams drain the margins of the hills to the north and west. The water table depth in the Montezuma Hills may increase to as much as 30 m (100 ft) beneath the highest ridges (elevation 90 m) in the central portion of the hills, however, there are perennially wet drainages in this central area at an elevation of approximately 60 m (200 ft).

The maximum horizontal gradient occurs from the center to the edge of the Montezuma Hills, a minimum distance of 6.5 km (4 mi). Assuming the water table elevation to be 60 m (200 ft) at the center and sea level at the edge, this yields a gradient of about 0.01. Gradients outside this area can be expected to be much less due to the flat topography and pervasiveness of perennial water channels.

The average hydraulic conductivity in the Sacramento Valley aquifer is 0.9 m d^{-1} (3 ft d^{-1}) (Williamson et al., 1989). Combining this with the maximum gradient of 0.01 and an estimated effective porosity of 25% yields an estimated maximum linear groundwater velocity of 15 m yr^{-1} (50 ft yr^{-1}). While the hydraulic conductivities may be higher or lower, they are probably similar to the Sacramento Valley average. Water pressures are hydrostatic from the water table down to the Cretaceous Delta Shale.

The main USDW in the area is the thick gravel-rich Tehama Formation, which is an approximately 610 m (2000 ft) thick aquifer that extends to about 915 m (3000 ft) below the surface. The Tehama Formation is a sedimentary rock unit that is primarily composed of sandstone, siltstone, shale, and conglomerate. It is part of the larger Cenozoic sedimentary sequence within the Sacramento Basin. The deposition of the Tehama Formation began during the late Cretaceous period, approximately 80 to 70 million years ago, and continued into the early Tertiary period. It represents a time when the Sacramento Basin was submerged beneath a shallow marine environment.

The Tehama Formation consists of layers of marine and non-marine sediments that were deposited in various environments, including coastal plains, estuaries, and shallow marine environments. The deposition of sediments was influenced by factors such as sea-level changes, tectonic activity, and sediment supply from nearby mountain ranges. The sandstone and conglomerate layers within the Tehama Formation indicate the presence of ancient river systems that transported and deposited coarse sediments. These sediments likely originated from the uplifted Sierra Nevada Mountains and other nearby sources. The siltstone and shale layers, on the other hand, represent finer-grained deposits that settled in calm marine or estuarine environments.

This shallow freshwater aquifer is separated from the underlying Tertiary and Upper Cretaceous deep saline formations by a thick, low permeability aquitard of clay-rich volcanoclastic sandstones. All CO_2 injection targets lie well below this aquitard and therefore there is good low permeable separation between the USDWs and the deep saline formations in the area.

A.I.8 GEOCHEMISTRY [40 CFR 146.82(A)(6)]

The amount of geochemical data available at present on the Montezuma Carbon Project is somewhat limited. Much of the lack of data is due to the rules of the State of California and how much of the data gained during the well drilling into the deep formations can be kept confidential and not released to the public. However, the Testing & and Monitoring efforts proposed to be undertaken for this project will work to fill those data limitation, and much more will be known.

Nonetheless, some geochemical data pertaining to potentially suitable carbon sequestration injection zones/reservoir is published for each natural gas field in the MC project area. The fields in proximity to the MC project site, between the Kirby Hill and Sherman Island faults, include the Kirby Hill, Sherman Island and Van Sickle Island gas fields. Other gas fields nearby include the Rio Vista field to the east, the Honker and Suisun Bay gas fields to the west, and the North Kirby Hill and Denverton Creek gas fields to the north.
The MC Project has three deep sandstone units that have the potential and may be suitable for the future injection and storage of CO2: the Domengine Sandstone, the Hamilton Sandstone, and the Anderson Sandstone. For the purpose and focus of this Class VI application for IW-A1, the Anderson Sandstone is the targeted injection interval, in part because it is the deepest and thickest of these units underlying the project site.
The table below shows each of these potential injection zones and their confining zones:

TABLE A.I-1. POTENTIAL INJECTION INTERVALS AND ASSOCIATED CONFINING UNITS

UPPER CONFINING ZONE	INJECTION ZONE	LOWER CONFINING ZONE
Nortonville Shale	Domengine Sandstone	Capay Shale
Capay Shale	Hamilton Sandstone	Meganos &U. Martinez Shales
Upper Martinez Shale	Anderson Sandstone	Lower Martinez Shale

Domengine Sandstone: Of these three potential injection zones, only the Domengine zone has a geochemistry paper written about it. That paper is by Todd and Moore (1968), and it is entitled "Petrology of Domengine Formation (Eocene) at Potrero Hills and Rio Vista, California" and was published in the Journal of Sedimentary Petrology. They describe the formation as a feldspathic subgraywacke unit that includes clayey sandstone, sandy siltstone, and silty shale. It accumulated under primarily transgressive marine conditions. This study was done from both outcrop samples in the Potrero Hills and from core samples in the Rio Vista gas field, located some 15 miles apart. Both of these areas are either in or near the MC project AoR. It was found that most of the Domengine is comprised of quartz, with 60%-70% being common quartz. The most common clay mineral was kaolinite. The most common rock fragments were metamorphics, which included quartz-muscovite schist, argillite, and aphanitic and plagioclase lath-bearing varieties. The average grain had subangular roundness and was between 0.09 and 0.19 mm in size.

The Domengine zone is the most productive natural gas producing unit in the Sacramento Basin. It is productive in almost all of the gas fields within or near the project site: Kirby Hill and Van Sickle Island and Suisun Bay, Honker and Rio Vista in close proximity to the project area. This unit is not as productive as the Sherman Island gas field, which instead produces gas from the two other potential injection zones: both the Hamilton and the Anderson sandstone units. The giant Rio Vista gas field (cumulative production 4 TCF of gas) lies east of the MC project site and has the Domengine as its major producing zone.

The State of California's Division of Oil, Gas and Geothermal Resources, or DOGGR (now the Division of Geologic Energy Management or CalGEM) has basic data (i.e., data sheets) on the zones that produce within these gas fields. The closest production to the study area is the Van Sickle Island gas field. The average pay thickness there in the Domengine zone is 150 feet. The average depth to the top of the zone is 6,800 feet. The initial reservoir pressure was 3,000 psi and the initial temperature was 153 ^{o}F. The porosity is listed at 18% and the initial gas saturation was 60%. The salinity of the water was 1,272 ppm. The heat value of the gas was 1,030 Btu and the weight of the gas was 0.602. The initial gas content was 940 MSCF/ac.ft.

Hamilton Sandstone: The Hamilton Sand is a sandstone of lower Eocene age and is actually a basal member of the Capay Formation. Most of that formation is composed of the Capay Shale, but the sandstone is an omnipresent member. The sandstone is gas productive near the MC project site at the Sherman Island gas field. It is also a major production interval at the Rio Vista gas field. Several papers have been written on the Sherman Island gas field (Krug, 1992; Ditzler 1972). The Hamilton Sandstone and the overlying Capay Shale record a transgressive event. The Hamilton contains shallow-marine burrows and fossils in outcrops south of the MC project site on the slopes of Mount Diablo. It grades upward into the marine Capay Shale which indicates a transgressive marine deposit.

The Lower Eocene Hamilton Sand is the shallower of the two natural gas producing zones at the Sherman Island gas field. The sand is situated below the Capay Shale at an average drill depth of 5,800-5,900 feet in the producing area. The Hamilton has an average thickness of 400-500 feet of quartzose sandstone with thin interbedded shale bodies. The overlying Capay Shale has an average of 900 feet of thickness in the field area (Ditzler, 1972). As to the sand, Ditzler mentions that the uppermost 100 feet of the formation consists of a silt zone that has low permeability. This silt zone grades downward into the main sand body which generally consists of fine to medium grained quartzose sandstone. Gas shows are present in the upper silt member in Sherman Island wells that are completed from the Hamilton, but this zone appears to be too low in permeability to sustain a commercial gas flow. All Hamilton producing wells are completed with perforations in the more permeable sand sections which immediately underlies this uppermost silty section.

In the gas fields where the sandstone is productive, the State of California has published the data on the reservoir (State of California, Division of Oil and Gas, Volume 3: Oil and Gas Fields). The Hamilton Sand at Sherman Island produced 1,016 Btu gas from an average depth of 5,750 feet. The data sheet lists the initial reservoir pressure as being 2,591 psi and the reservoir temperature as being 149 ^{o}F. The average net thickness of the pay zone was 75 feet. The water salinity is listed at 1,810 ppm. The porosity is listed as being between 25 and 29%, and the initial gas saturation as being between 55% and 60%. The specific gravity of the gas is listed as 0.593 and the initial gas content as 1,000-1,300 MSCF/ac.ft.

Anderson Sandstone: The Anderson sandstone is the major productive zone at the Sherman Island gas field. As Ditzler (1972) says in his paper: “The Paleocene Anderson Sand is located beneath this shale body (the overlying Meganos Shale) and consists of approximately 200 feet of clean, medium grained, well sorted quartz sandstone. This sand is progressively truncated by the unconformity (above it) from north to south across the productive area (of the field). The Anderson is represented by 200 feet of clean sand section in the Signal Upham No. 1 well located on the north end of the field and progressively thins to the south until only 10 feet of the Anderson Sand remain in the Occidental Reynolds Unit 1-A well on the southern end of the field. The erosion of and the eventual total truncation of the Anderson is responsible, in part, for the hydrocarbon entrapment in this zone on the southern end of the field.”

The Anderson Sand is listed on the gas field data sheets for Sherman Island gas field as being found at a depth of 6,100 feet. The initial reservoir pressure was 3,122 psi and the temperature was 152 ^{o}F. The salinity of water in the zone at this field was greater than 10,000 ppm. The Btu value of the gas is listed at 1,028, and the gas saturation as 65 to 70 percent. Porosity is listed at 29 to 32 percent. The specific gravity of the gas is 0.593 and the initial gas content is shown as between 1,700 and 2,000 MSCF/ac.ft.

The Anderson Sand is listed as the Wagenet Sand on the field data sheets for the Kirby Hill gas field. This field has several pools in the Anderson since the field is heavily faulted where it is near the Kirby Hill fault. The pool relevant to our study had a water salinity of 14,723 ppm at a depth of 5,400 feet. The gas Btu was 990 and specific gravity 0.595. The porosity of the reservoir is listed as 20% and the initial gas saturation at 65% to 70%.

Nortonville Shale: This unit provides a layer of several hundred feet of dense shale that overlies the Domengine Sandstone. The type log of the Rio Vista gas field (Johnson, 1992), describes the shale as: "medium to dark gray-brown brittle shale, locally calcareous and containing forams and diatoms."

Capay Shale. The Capay Shale underlies the Domengine Sandstone and overlies the Hamilton Sandstone. The eastward coarsening of the Hamilton and eastward onlap of the Capay indicate that transgression occurred from west to east during the major rise in sea level that began about 54 million years ago (Krug 1992). The shale can be up to or over 900 feet in thickness (Ditzler, 1972). As Johnson (1992) stated: "micropaleontologic data indicate that the lower portion of the Capay was deposited in an outer-neritic environment whereas the upper portion was deposited in an inner-neritic to brackish-water environment. Thus, the Capay records a partial shoaling of the basin during Eocene time.

The type log of the Rio Vista gas field (Johnson, 1999) describes the shale as: "light to medium gray shale, soft to firm, gummy, moderately cohesive, with very fine to fine, subrounded clear quartz, moderate sorting, abundant glauconite at the base."

Meganos Shale / Upper Martinez Shale: A combination of the Meganos Shale of Eocene age and the Upper Martinez Shale of Paleocene age combine to form a confinement layer of shale between the Hamilton Sand above it and the Anderson Sand below it. The thickness of the Upper Martinez can be hundred feet thick in the area of the proposed drilling of this project, but a basal Eocene unconformity at the base of the Eocene cut down the thickness of the underlying Martinez Shale from a west to east direction. Thus, the Anderson Sand can be over 1,000 feet thick at the western edge of the study area and totally gone at the eastern edge of the study area, due to an unconformity that cuts down into it.

The Anderson sand is underlain by the Martinez Shale, just at is overlain by that shale except where it has been eroded off.

The type log for the Rio Vista gas field (Johnson, 1999) describes these shales as follows:

- **Meganos Shale**: light to medium gray to black shale, soft, clayey.
- **Upper Martinez Shale**: Medium to dark brown, firm, hard siltstone, occasionally massive with light-medium gray claystone.
- **Lower Martinez Shale**: Medium to dark brown, firm, hard siltstone, occasionally massive with light-medium gray claystone.

A.I.9 SITE SUITABILITY [40 CFR 146.83]

The proposed injection site was previously studied for geologic suitability by Shell and LBNL as part of a DOE-supported pilot CO_2 injection project to handle the CO_2 from Shell's refinery in Martinez roughly 10 years ago. The pilot project included drilling and formation property testing followed by injection and monitoring of a small amount of CO_2. Based upon those previous efforts, Shell concluded that the site geology was very attractive, with the ability to safely store large volumes of CO_2. The reservoir zones are thick, porous, continuous sands and the relevant confining units are thick, laterally continuous shale units known to be flow and pressure barriers in nearby gas fields. However, at that time the economics for a carbon capture project of this potential scale were not justified. Those economics and governmental support have changed in recent years.

In the development of this proposal, we have built off the previous Shell/LBNL study, focusing it on our specific acreage in the Montezuma hills. We have performed additional studies of reservoir properties, incorporating not only well logs and seismic, but drilling and production data from nearby wells and gas fields and newer geologic studies of the area. Using this information to create a geologic and physical property model, the plume and pressure front was simulated.

The simulations showed:

1. A single vertical well can inject one MMtonnes/year for over 40 years into the 1,300 ft thick Anderson sand reservoir located at 11,300 ft.
2. The plume extent is approximately 1.3 km in radius after 100 years and pressure increases of less than 1.7 MPa are created on the sealing faults to the east and west of the injection well.

3. There is enough acreage at the site to put in at least three Anderson vertical injection wells on the current acreage.
4. Other sand units (Domengine, Hamilton and potentially others), could potentially store comparable amounts of CO_2, and we believe that overall site has a most likely storage estimate of over 250 MMtonnes of CO_2 at injectivity rates of over 5 MMtonnes per year.
5. Even if pessimistic forecasts of reservoir parameters are used, the site has storage potential of over 80 MMtones at rates of over 2 MMtonnes per year.

Risks of Leaks and Induced Seismicity

It is our current opinion that there is a negligible risk of leakage into shallow units due to injection. The confining units are impermeable thick, continuous shales that extend in intervals for thousands of feet above the injection interval. All the major faults in the area (Kirby Hills, Midland, and Sherman Island) are known from gas production adjacent to the fault to be impermeable traps, so fluids cannot migrate up the large faults to the surface. Moreover, there is no evidence of faulting near the injection well, and the shales above and below the reservoir are continuous far past the modeled plume extent.

White and Foxall (2016) performed a review of CCUS-induced seismicity and described two notable cases. There are, of course, numerous cases of induced seismicity due to high volume water injection (Oklahoma, Texas, Canada, Ohio, etc). The primary mechanism for most of this seismicity is likely to be pressure diffusion, whereby injection pressure propagates from the injection well through the aquifer and then down into faults extending up to the top of crystalline basement. In these cases, the aquifer is in pressure communication with the basement faults.

The Montezuma site is quite different from the examples above.

1. The Montezuma injection interval is 2-3 miles above top of crystalline basement, and 8-12 miles above seismicity in the area as described by Unruh and Wong (2021).
2. The confining units directly below the reservoir are impermeable, thick, continuous shales with an additional 2-3 miles of largely shale confining zones separating the reservoir from the basement.
3. All the major faults in the area (Kirby Hills, Midland, and Sherman Island) are known from gas production and storage activities adjacent to these faults to be impermeable.
4. None of the huge volumes of gas withdrawn in the area (over 4 TCF) has affected formation pressures away from the fields nor was any induced seismicity or change in active seismicity due to gas production observed indicating that poro-elastic effects are insufficient for creating seismicity either in the reservoir or the basement.

Consequently, the risk of CO_2 injection causing large (M>4.5) events is negligible and if any seismicity is detected it is most likely to be unfelt small events near the reservoir interval and the injection well.

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