Map Unit Properties Table: Palo Alto Battlefield National Historical Park

Colored rows indicate units mapped within Palo Alto Battlefield National Historical Park.

Age	Map Unit (Symbol)		Geologic Description	Geologic Issues	Geologic Features and Processes	Geologic History and Unit Location
Modern	Artificial Units	Made Land (Hml)	Unit consists of anthropogenic land at boat basins and dikes.	**Sea level rise and hurricanes**—Anthropogenic units were created primarily via dredging to facilitate boat navigation and access along the coast. Tidal currents and wave action rework spoil deposits. Units are vulnerable to damage or inundation from sea level rise and hurricanes. **Erosion**—Dredged spoil is commonly piled along the margin of the cut channel. This creates local artificial relief which then exposes the spoil to erosion processes. The local relief also acts as a tidal dam in places. The spoil is naturally reworked and redistributed by rainfall sheetwash, gullying and subsequent alluvial fan development, tidal currents, and waves. This redistribution increases the areas of wind-tidal flats and lagoon bottom that are covered by spoil. **Disturbed lands**—Dredging channels interrupts groundwater flow. **Oil and gas exploration and development**—Spoil deposits occur along small channels dredged into shallow water and wind-tidal flats (**Hw**, **Hwa**) to provide access to oil and gas well drill sites.	**Geologic influences on ecosystems**—the artificial units represent the modern developments occurring along the Texas gulf coast in recent decades.	**Hml** is limited in area to the boat basins at Port Mansfield and Port Isabel, extending almost 10 km (6 mi) of the western side of the southernmost stretch of South Padre Island. A dike extends across Bahia Grande. Spoil units **Hsr**, **Hsae**, and **Hsaq** were originally derived from excavation and maintenance of the Intracoastal Waterway, extending along the entire length of Laguna Madre and interconnected ship channels (Port Mansfield, Arroyo Colorado Cutoff, Brownsville Ship, and Port Isabel Ship channels).
		Reworked Spoil, Subaerial (Hsr)	Spoil is reworked from old dredge deposits. Dredging of the Intracoastal Waterway, ship channels, small channels, and access channels yields churned deposits of sand, muck, and organics.			
		Spoil, Subaerial (Hsae)	Spoil from dredging that is not covered with water.			
		Spoil, Subaqueous (Hsaq)	Spoil that occurs below water on the bay bottom.			

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QUATERNARY (Holocene)	Bay-Estuary-Lagoon System	Berm, Vegetated (Hblv)	Berms form as bay or lagoon-margin sand or shell debris accretes along the shores. This unit is relatively stable with abundant vegetation.	**Sea level rise and hurricanes**—Wind-tidal flats can flood rapidly. **Hg** areas are expanding with relative sea-level rise in north Laguna Madre. **Hg** is spreading into **Hbls** with rising seas. Water table fluctuations strongly impact areas of **Htz**. When water is high, salt-tolerant grass species stabilize the area. When water is low, eolian processes of deflation dominate. **Erosion**—berms that are no longer actively accreting are subject to erosion and incorporation into adjacent wind-tidal flats or subaqueous lagoon-margin sand. **Disturbed lands**—Construction of islands and shoals has reduced the fetch of winds blowing across Laguna Madre and thus the wave energy that can build up natural berms. As anthropogenic construction and sea-level rise increase water depth, salinity, and/or turbidity, flora and fauna compositions of **Hg** may change rapidly.	**Fluvial Features and Processes**—**Hsp** is a surface water unit. Some surface water features formed in association with sand and loess sheet deflation and are flanked on their leeward side by clay-sand dunes (**PEda** and **PEdi**).Others developed from relict drainage systems (pirated or diverted by the Arroyo Colorado), or from the damming effect of levees deposited along distributary channels. **Geologic influences on ecosystems**—**Hsp** can support fairly dense vegetation growth. In the tidal flats areas around Bahia Grande, **Hsp** is barren flats with areas of spare to dense vegetation including marshes. Small areas of saltwater marsh can occur behind and along the bay and lagoon-margin berms of **Hble** and **Hblv**. **Hg** composes lagoon-margin and lagoon-center environments of less than 1 m (4 ft) depth. Five species of marine grass thrive in **Hg**: *Halodule* (*Diplanthera*) *wrightii* (shoalgrass), *Cymodocea manatorum* (manatee-grass), *Ruppia maritima* (widgeongrass), *Thalassia testudinum* (turtlegrass), and *Halophila engelmannii* (clovergrass). Grass distribution is changing with salinity fluctuations, turbidity, and water depth. Algae (including leafy calcareous *Acetabularia)* thrive in **Hg**, which also provides food and protection for a variety of invertebrates and fish to spawn. **Hg** is locally replacing areas of **Hbls**. **Hg** provides habitat for modern mollusks, such as the pelecypods (clams) *Cumingia*, *Tellina*, *Tagelus*, and *Mysella* and the gastropods (snails) *Bittium*, *Caecum*, and *Mitrella.* Burrowing organisms such as clams (*Laevicardium, Chione*, *Anadara*, *Mulinia, Tellina, Tagelus Ensis*, and *Anomalocardia* [in hypersaline areas]) bioturbate **Hblm**. South Bay contains the only significant occurrence of the oyster *Crassostrea* south of Corpus Christi Bay; these particular oysters may be a new physiological race adapted to higher-than-normal salinities (in excess of 40%). **Hblm** requires areas of low wave and current energy to accumulate and supports sparse marine grass. Many wet areas of **Htz** have become vegetated and are currently stabilized with salt-tolerant grasses such as *sacahuista.* When drought conditions return, eolian processes resume active deflation of the flats. Four environments compose the spectrum of wind-tidal flats: 1) firm sand and mud flats which extend from frequently flooded low elevations to higher elevations; 2) sand and mud flats that are alternately emergent-submergent, contributing to the development of extensive algal mats; 3) firm gypsiferous mud and sand with algal-bound mud; and 4) soft mud and sand with extensive algal mats that are frequently wet because of locally depressed relief. **Eolian features and processes**—a berm at Bahia Grande has accreted in part through eolian processes, active when wind-tidal flats are dry thereby providing a source of sediment to the winds. **Htz**, when not inundated by wind tides, is the site of wind deflation, winnowing of airborne sediment, windward accretion of small eolian clay dunes, and large landward-trending blowout depressions intermittently inundated by wind tides. Wind-driven tides (or drops in barometric pressure) inundate **Hw** and **Hwa**. Winds from the east and southeast drive water off the flats. Prolonged subaerial exposure of wind-tidal flats causes severe desiccation that fragments the surface sediment into sand- and silt-sized particles, which are blown to the northwest where these particles accumulate to form clay-sand dunes.	Mud-filled coastal lakes and ponds occur northwest of El Jardin and in the area of Bahia Grande. **Hg** covers almost 65% of the subaqueous area in the bay-estuary-lagoon system. **Hg** extends the length of Laguna Madre. **Hbls** is derived principally from eroded Modern-Holocene deposits along the mainland shore. **Hw** and **Hwa** occur along lagoon margins adjacent to the mainland and South Padre Island. They vary in width from 0.2 to 11 km (0.1 to 7 mi) along the mainland and from 0.4 to 6 km (0.2 to 4 mi) on South Padre Island for a length of 63 km (39 mi). **Htz** is related to **Hw** and **Hwa** of the Texas coastal region. It marks the area of transition between the wind-tidal flats (remnants of deflated sand sheets, clay dunes, and blowout depressions) and the South Texas eolian system. Wind-tidal flats containing extensive algal mats (blue-green algae) are present throughout the central part of the flats (middle flats) associated with South Padre Island and on the mainland flats between Fourmile Slough and Stover Cove among other areas.
		Berm, Occasionally Emergent (Hble)	Typically bare sand or mud and shell debris from bay or lagoon marginal areas. Locally **Hble** is covered by sparse marine grass. Berms are narrow, elongate features only 1 m (2 to 3 ft) above mean sea level.			
		Grass Flat (Hg)	Grass flats are saline to hypersaline subaqueous areas of muddy sand with abundant shell debris.			
		Bay and Lagoon Sand (Hbls)	Sparse marine grass grows in the muddy bay and lagoon sand in water depths between 0.3 and 1 m (1 and 3 ft). Tides driven by wind cause these areas to be subaerially exposed occasionally. Southeasterly and northerly winds move **Hbls** landward into shallow subaqueous bars and berms. Accretion only occurs during high-energy wave events. Longshore transport continues to redistribute the winnowed sediment of **Hbls**.			
		Bay and Lagood Mud (Hblm)	**Hblm** consists of mottled bay and lagoon mud mixed with abundant shell debris. This unit occurs in water depths of less than 1 m (3 ft) as wide, parallel bands, and narrow sinuous channels.			
		Wind-tidal Flat, Rarely Flooded (Hw)	**Hw** is firm sand and mud that forms part of a wind-tidal flat. Much like **Hwa**, **Hw** is broad, flat, barren, and virtually featureless. Different from the other two units, **Hw** is rarely inundated. It is less than 1 m (3 ft) above mean sea level. Wind-tidal flats form from sediments derived from the shoreface, beach, and dune areas transported to the flats by hurricane storm surge and prevailing southeast winds.			
		Wind-tidal Flat, Algal Mats, Emergent-submergent (Hwa)	**Hwa** consists of sand and mud with extensive algal mats that are frequently inundated with wind-driven tides. Surfaces of the flats are always near the water table; the upper few inches of the wind-tidal flat deposits are oxidized light brown (above the water table), whereas the sediment beneath the water table is light green. Secondary gypsum deposits are common for these units.			
		Transitional Zone (Htz)	**Htz** marks the transition from wind-tidal flat to eolian sand sheet with wind deflation, concentrated clay-sand dunes, and blowing sand.			

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QUATERNARY (Holocene)	Barrier-Standplain and Offshore System (continues on next sheet)	Shelf Mud (Hs)	**Hs** consists of mud and sand, shell, and mottles (patchy/blotch texture caused by bioturbation). These components make up the area just seaward of the fore-beach (see **Hsb**). Deposits are thin and patchily distributed throughout the map area. **Hs** is part of the offshore system (shoreface and inner continental shelf). The transition between the inner continental shelf and shoreface occurs at a depth of 13 m (42 ft) where there is a decrease in slope.	**Sea level rise and hurricanes**—Many years of sand deposition blowing from the beach may be necessary to restore the former dune position after a storm. The fore-island sand ridge protects the barrier island from the full impact of storm surge. As relative sea level rises, barrier island systems will continue to migrate landward. The configuration and stratified layers of fore-island dunes (**Hfi**) may record long-term climatic changes. **Erosion**—beaches (**Hb**) are eroding on South Padre Island. This is due to: (1) a sand deficit, (2) storm conditions on a thin sand body, (3) strong longshore drift northward, (4) dominant winds and storms move sand into Laguna Madre and out of the buffer zone, and (5) Rio Grande deltaic mud continues to compact causing a relative rise in sea level. Current rates of erosion are about 6 m (21 ft) per year based on a fixed well location that was 100 m (330 ft) from the beach in 1956, but was in the swash zone by 1972. The beach is repeatedly eroded by storm-surge floods in areas where the dunes (**Hfi**) are absent. **Hfi** may be eroded many meters during storms or hurricanes. **Disturbed lands**—In areas where there are fore-island dunes (**Hb** and **Hfi**), no sharp line exists between the beach and other barrier island depositional environments. Activities such as 19th and early 20th century ranching on Padre Island reduced vegetation cover, which in turn led to the destruction of fore-island dunes (**Hfi**) and promoted an increase in large back-island dune fields. **Hsf** currently occupies areas of the island previously occupied by **Hfi**. Jetty systems largely prevent the accumulation of **Hi** in active inlets. Two jettied inlets—Port Mansfield Channel to the north and Brazos Santiago Pass to the south—cut through South Padre Island. The jetties associated with these artificial inlets reroute sand that would otherwise be transported into south Laguna Madre through the inlets.	**Fluvial features and processes**—Channels of unit **Htc** share features similar to traditional fluvial systems including meanders and scour features. **Geologic influences on ecosystems**—In areas where vegetation is disturbed, either through drought or anthropogenic causes, fore-island dunes (**Hfi**) experience erosion. In areas of sufficient precipitation to promote vegetation, areas of **Hsf** have developed into small fore-island dunes (**Hfi**). Without the tidal exchange facilitated by **Htc**, salinity and circulation patterns would be substantially different. The flora and fauna (mainly marine grasses and oysters) would also change resulting in a substantial reduction in biologic productivity. Restricted circulation leads to the development of hypersaline basins. **Eolian features and processes**—fore-island dunes are a major component of **Hb**. The vegetation line coincides with the gulfward side of the fore-island dune ridge. Eolian crossbeds within **Hfi** records a complex history of dune deflation and deposition. **Hsf** includes low coppice and wind-shadow sand dunes, and broad sandflats. Between storm events, eolian processes erode and redistribute sands of **Hwf** and **Hwd**. This nourishes back-island dune fields, wind-tidal flats (**Hw**, **Hwa**), and vegetated transverse dunes. **Hb** contains lag, or wind-deflation deposits composing shell pavements left behind when the wind removes finer particles. **Paleontological resources**—**Hs** contains abundant shelly remains. **Hsb** is burrowed. **Hb** contains large clams *Eontia*, *Mercenaria*, and *Echinochama*. There may be a relationship between high, well-developed, fore-island dunes and abundant shell content on adjacent beaches. **Hb** contains abundant shell pavements. Oysters are the primary fauna in lagoonal basins.	Accumulation of modern sediment (**Hs**) is rather slow offshore from South Padre Island. **Hsb** accumulated atop Pleistocene and Holocene Rio Grande fluvial-deltaic deposits. The Gulf shoreline of South Padre Island is rapidly eroding; a continuous fore-island dune ridge (**Hfi**) will likely never develop again. There are 12–16 active areas of **Hsf** on South Padre Island. The broadest areas of the island, up to 7.2 km (4.5 mi) are associated with **Hsf**. At least 12 distinct washover channels are recognized locally.
		Shoreface (Hsb)	**Hsb** consists of sand and muddy sand deposited in the shoreface zone. **Hsb** forms in a high energy environment along the shore. Breaking waves occur along the upper shoreface, less than 5 m (15 ft) deep. Storm waves mold **Hsb** into a series of breaker bars en echelon or parallel to the shoreline. Prevailing southeast winds and northeast winds accompanying polar fronts create a zone in the upper shoreface (sea level down to 4 to 5 m [12 to 15 ft]) where waves touch bottom and break. This forms several lines of breakers in water above the upper shoreface.			
		Beach (Hb)	**Hb** contains sorted sand and shell fragments. Bedding of beach deposits generally dips towards the Gulf of Mexico at angles of 5°—accentuated by dense, dark heavy minerals concentrated by swash and backwash. **Hb** occurs between low tide and the first inland line of vegetation. **Hb** consists of a forebeach (the seaward-sloping smooth part of the beach where the waves wash up) and a back-beach (separated from the forebeach by a berm). The backbeach slopes gently seaward or may slope the opposite way forming a backbeach trough or runnel.			
		Fore-island (Hfi)	**Hfi** is a discontinuous sandy dune ridge. The sand is well sorted and arranged in steeply dipping eolian crossbeds. The highest island elevations occur within this unit ranging from 2 to 9 m (5 to 30 ft). **Hfi** forms as sands are blown from the backbeach toward Laguna Madre. This represents a delicate balance between onshore winds that deflate backbeach sands and vegetative cover that stabilizes the dunes.			

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QUATERNARY (Holocene)	Barrier-Standplain and Offshore System (continued from previous sheet)	Sand Flats (Hsf)	**Hsf** is sand flats, coppice sand-dune fields, and/or wind-shadow dunes. **Hsf** covers broad flat areas about 1 m (4 ft) above mean sea level with a mixture of fine-grained sand and shell. The broadest areas of the island, up to 7.2 km (4.5 mi), are associated with **Hsf**. **Hsf** is associated with several active or potentially active washover areas—places where sand is transported during hurricanes from the shoreface onto the backside of the island, where the sand may form dunes.	**Sea level rise and hurricanes**—Many years of sand deposition blowing from the beach may be necessary to restore the former dune position after a storm. The fore-island sand ridge protects the barrier island from the full impact of storm surge. As relative sea level rises, barrier island systems will continue to migrate landward. The configuration and stratified layers of fore-island dunes (**Hfi**) may record long-term climatic changes. **Erosion**—beaches (**Hb**) are eroding on South Padre Island. This is due to: (1) a sand deficit, (2) storm conditions on a thin sand body, (3) strong longshore drift northward, (4) dominant winds and storms move sand into Laguna Madre and out of the buffer zone, and (5) Rio Grande deltaic mud continues to compact causing a relative rise in sea level. Current rates of erosion are about 6 m (21 ft) per year based on a fixed well location that was 100 m (330 ft) from the beach in 1956, but was in the swash zone by 1972. The beach is repeatedly eroded by storm-surge floods in areas where the dunes (**Hfi**) are absent. **Hfi** may be eroded many meters during storms or hurricanes. **Disturbed lands**—In areas where there are fore-island dunes (**Hb** and **Hfi**), no sharp line exists between the beach and other barrier island depositional environments. Activities such as 19th and early 20th century ranching on Padre Island reduced vegetation cover, which in turn led to the destruction of fore-island dunes (**Hfi**) and promoted an increase in large back-island dune fields. **Hsf** currently occupies areas of the island previously occupied by **Hfi**. Jetty systems largely prevent the accumulation of **Hi** in active inlets. Two jettied inlets—Port Mansfield Channel to the north and Brazos Santiago Pass to the south—cut through South Padre Island. The jetties associated with these artificial inlets reroute sand that would otherwise be transported into south Laguna Madre through the inlets.	**Fluvial features and processes**—Channels of unit **Htc** share features similar to traditional fluvial systems including meanders and scour features. **Geologic influences on ecosystems**—In areas where vegetation is disturbed, either through drought or anthropogenic causes, fore-island dunes (**Hfi**) experience erosion. In areas of sufficient precipitation to promote vegetation, areas of **Hsf** have developed into small fore-island dunes (**Hfi**). Without the tidal exchange facilitated by **Htc**, salinity and circulation patterns would be substantially different. The flora and fauna (mainly marine grasses and oysters) would also change resulting in a substantial reduction in biologic productivity. Restricted circulation leads to the development of hypersaline basins. **Eolian features and processes**—fore-island dunes are a major component of **Hb**. The vegetation line coincides with the gulfward side of the fore-island dune ridge. Eolian crossbeds within **Hfi** records a complex history of dune deflation and deposition. **Hsf** includes low coppice and wind-shadow sand dunes, and broad sandflats. Between storm events, eolian processes erode and redistribute sands of **Hwf** and **Hwd**. This nourishes back-island dune fields, wind-tidal flats (**Hw**, **Hwa**), and vegetated transverse dunes. **Hb** contains lag, or wind-deflation deposits composing shell pavements left behind when the wind removes finer particles. **Paleontological resources**—**Hs** contains abundant shelly remains. **Hsb** is burrowed. **Hb** contains large clams *Eontia*, *Mercenaria*, and *Echinochama*. There may be a relationship between high, well-developed, fore-island dunes and abundant shell content on adjacent beaches. **Hb** contains abundant shell pavements. Oysters are the primary fauna in lagoonal basins.	Accumulation of modern sediment (**Hs**) is rather slow offshore from South Padre Island. **Hsb** accumulated atop Pleistocene and Holocene Rio Grande fluvial-deltaic deposits. The Gulf shoreline of South Padre Island is rapidly eroding; a continuous fore-island dune ridge (**Hfi**) will likely never develop again. There are 12–16 active areas of **Hsf** on South Padre Island. The broadest areas of the island, up to 7.2 km (4.5 mi) are associated with **Hsf**. At least 12 distinct washover channels are recognized locally.
		Washover Distributary Channel (Hwc)	**Hwc** consists of washover channels where sandy slurries are washed from one side of the island towards the other during periods of high tides and storms. **Hwc** contains shells and sand. The sand and shells of **Hwc** moves as dunes and sand waves during a storm surge. The washover channel moves water from the gulf to the back-island lagoon. Then, as the storm moves inland, ebb flows move water the opposite direction from the lagoon toward the gulf through channels. Within a few weeks, the channels are sealed on the gulf side by sand transported via longshore drift. When the channel is sealed, clay and fine-grained material settles to the floor of the former channel.			
		Washover Fan (Hwf)	Deposits of **Hwf** may be vegetated or barren (see **Hwd**). Vegetated fans resemble eolian deposits and may rise to heights greater than 2 m (6 ft). **Hwf** and **Hwd** occur where channels (**Hwc**) open onto the wind-tidal flats.			
		Washover Distal Fan (Hwd)	Barren fans (**Hwd**) contain sandy shell, shelly sand, and sand lobes in subaerial deposits. **Hwd** is part of an active environment. **Hwf** and **Hwd** occur where channels (**Hwc**) open onto the wind-tidal flats.			
		Tidal Channel (Htc)	**Htc** consists of active, sand-lined channels with pockets of muddy sand and shells. Units of **Htc** facilitate tidal exchange between bay, estuary, lagoon, and gulf environments. The channels are commonly located within a complex network of wind-tidal flats (**Hw**, **Hwa**) and lakes. **Htc** channels may function as drainage channels when rain floods inland basins.			
		Inlet-related Shoal (Hi)	**Hi** includes the sand that accumulates within natural or dredged inlets and is transported by longshore currents within the shoreface (**Hsb**).			

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QUATERNARY (Holocene)	Fluvial-Deltaic System (continued on next sheet)	Levee and Local Crevasse Splay Deposits (Hls)	**Hls** consists of silty, muddy, and locally sandy deposits covered with sparse grass. Levees form elevated berms flanking stream channels. Crevasse splays are fan-shaped lobes of sediment that spread out onto the floodplain beyond a break or breach in a levee.	**Fluvial system**—The low elevation of the park area, including areas of **Hds**, and **Hf,** are particularly susceptible to drought, storm, and flood cycles. Precipitation patterns will change as climate continues to change. The fluvial system has been altered to control flooding and store water for agriculture. **Sea level rise and hurricanes**—As sea level continues to rise, the barrier system is migrating landward burying features such as former river deltas beneath the transgressive shelf. **Disturbed lands**—Many areas of **Hf** are now cultivated, but were once elongate, grass-covered areas underlain by mud and clay. **Oil and gas exploration and development**—An oil pipeline and access road at the park crosses portions of **Hds** and **Hf**.	**Fluvial features and processes**—The meander loops or scrolls, abandoned channels, and accretionary point bars of **Hms** document the fluvial processes that constructed these distinctive depositional units. In an area with little relief, meander belts and levees (**Hms** and **Hls**) stand in stark contrast to the surrounding lowlands. **Hls** occurs along the Rio Grande and is only active during periods of major flooding during major storms and hurricanes. **Hls** forms when floodwaters breach levees and discharge into adjacent floodplains, floodbasins, or interfluve depressions. Most of **Hms** is inactive with a few small, active point bars along the present Rio Grande channel. The anastomosing pattern of sandy point bars, silty levees and splays, and mud-filled oxbow lakes of **Hms** formed by fluvial processes of fluvial meandering and channel abandonment. **Hds** is transitional landwards with **Hms** and includes sandy point bars, silty/sandy levees and splays, and abandoned mud-filled channels with finer grained compositions than **Hms**. **Hfe** and **Hf** are contains within an entrenched valley. **Hf** consists of the following fluvial features: floodbasins, abandoned channels, and interfluve (interdistributary—areas between channels) areas with small abandoned channels. Portions of **Hf** may flood following intense rainfall. **Hmf** is part of a small, headward-eroding stream system. **Geologic influences on May 1846 battles**—**Hds** underlies some of the high ground within the park including Arista Hill used by Mexican forces during the battle. **Hf** underlies the majority of the battlefield at Palo Alto. The high clay content of **Hf** can cause low-lying areas of this unit to hold water. This likely impeded troop movements in 1846. **Geologic influences on ecosystems**—Saline soils occur within **Hds**, including the Jackass Prairies where the salinity limits agricultural activity. Saline silty clay loams of the Laredo and Sejita series support salt-tolerant grasses, alkali invasives, and thorny shrubs. **Hfe** and **Hf** are characterized by predominantly nonsaline clay soils of the Harlingen and Benito series—these are heavily cultivated locally. During dry years, freshwater influx is reduced and freshwater marsh assemblages (**Hmf**) are replaced by assemblages adaptable to brackish water conditions. **Eolian features and processes**—**Hf** includes some clay-sand dunes.	**Hls** occurs mostly along the present Rio Grande channel (the international border). Meander belts (**Hms**) record the passage of former channels of the Rio Grande River across the landscape throughout its evolution. **Hds** records the presence of a subsiding and inactive San Benito Rio Grande delta plain where nearly 195 km^2 (75 mi^2) of relict distributary channels crisscross the landscape in sinuous patterns. Delta lobes of **Hds** are now buried beneath the transgressive shelf as the barrier system continues to migrate landward. **Hf** and **Hfe** once covered 360 km^2 (140 mi^2) of the mapped area and much of this area is now cultivated. **Hmf** and **Hmb** may not include smaller freshwater marsh features including perennial ponds, lakes, and abandoned channels that are too small to be mapped at the 1:125,000 scale of the source map. **Hds** occurs within park boundaries adjacent to the resacas (see **PEa**). **Hf** occurs within park boundaries in the northwestern corner and the center of the C-shaped pattern of **PEa** along the eastern side.
		Meander Belt (Hms)	**Hms** contains belts of sand and silt, some of which are grass- and shrub-covered. Individual belts average about 3 to 5 km (2 to 3 mi) wide and up to 48 km (30 mi) long. Each belt may reach 2 to 3 m (5 to 10 ft) high and 20 m (65 ft) thick. Most have a sharp base eroded into older floodplain muds. Relict point bars contain coarse, basal gravels and coarse-grained sand that fines upward.			
		Distributary Sands and Silts (Hds)	**Hds** contains sands and silts in relict meandering to sinuous bodies. **Hds** occurs where meander belts (**Hms**) become smaller and split apart (bifurcate) gulfward across a gradational transition.			
		Flood Basin (Hfe)	**Hfe** is gradational with **Hf** and consists of overbank mud and silt.			
		Flood Basin Grading to Interdistributary Mud (Hf)	**Hf** consists of overbank mud and silt in a variety of depositional environments including fluvial, lacustrine, and eolian.			
		Fresh-water Marsh (Hmf)	**Hmf** consists of marshy areas of mud and sand inundated by fresh water.			

Colored rows indicate units mapped within Palo Alto Battlefield National Historical Park.

Age	Map Unit (Symbol)		Geologic Description	Geologic Issues	Geologic Features and Processes	Geologic History and Unit Location
QUATERNARY (Pleistocene)	Fluvial-Deltaic System (continued from previous sheet)	Abandoned Channel (PEa)	**PEa** (resaca) consists of mud-filled channels and stream courses.	**Fluvial system**—The low elevation of the park area, including **PEa,** are particularly susceptible to drought, storm, and flood cycles. Precipitation patterns will change as climate continues to change. The fluvial system has been altered to control flooding and store water for agriculture. **Erosion**—**PEss** results from the mass removal of sands from dunes. **Disturbed lands**—Water control and storage infrastructure, as well as agricultural activity, altered areas of **PEa** and **PEss**. **Oil and gas exploration and development**—An oil pipeline and access road at the park crosses portions of **PEa**. Access is limited to where the road and pipeline cross a resaca	**Rio Grande resacas and other fluvial features and processes**—**PEa** records the process by which rivers change their courses in response to changes in the flow characteristics of the stream system (meandering and channel cutoff). Remnants of the Rio Grande levees or delta plain concentrate accretion of clay-sand dunes (**PEda** and **PEdi**). Units of **PEdi** occur around erosional remnants of meander belts (**Hms**). **Geologic influences on May 1846 battles** —Areas within the park of **PEa** (resacas) played significant roles during the 1846 battle. Marshy lowlands impeded repeated attacks on the U.S. western flank by Mexican forces trying to cross the resaca. **Eolian features and processes**—Wind-blown sediment fills depressions (**PEcl**). **PEda** occurs as active dunes formed of clay and sand. These hawk-shaped dunes are the products of windward accretion of salty clay and silt particles against a nucleus of levee remnants left exposed on wind-tidal flats. **PEss** are inactive elongate dune fields or trains that resulted from wind-caused deflation of relict fluvial (associated with rivers) and deltaic sediments. **Paleontological resources**—Channels of **PEa** may contain additional fossil animal remains and/or traces. **Geologic influences on ecosystems**—Some areas of **PEa** support fresh-water marshes. Sediments within **PEa** support gypsum-tolerant vegetation. Low permeability clays flooring depressions (**PEcl**) support local marshes in areas where precipitation allows. These areas support aquatic plants (hydrophytes) during periods of higher rainfall.	The complex pattern of filled channels (**PEa**) records the shifting, meandering nature of the Rio Grande fluvial system through time. Resacas (**PEa)** cover 340 km^2 (130 mi^2) of the mapped area. Coastal lakes or ponds (**PEcl)** are relicts of Pleistocene fluvial systems throughout the area. They total approximately 8 km^2 (3 mi^2) of the mapped area. Active clay-sand dunes cover approximately 16 to 21 km^2 (6 to 8 mi^2) of the mapped area. Sand sheets (**PEss**) cover nearly 105 km^2 (40 mi^2) of the mapped area. Gavilans (**PEda**) takes its name from Mesa del Gavilan (a dune complex shaped like the head of a hawk). **PEa** occurs in sinuous low-lying resacas predominantly in a C-shaped curve across the northern, western, and southern areas of the park.
		Coastal Lake or Pond (PEcl)	**PEcl** is a mud-filled depression.			
		Gavilans (clay-sand dunes) (PEda)	Gavilans occur in dune fields that occur on or border extensive wind-tidal flats (**Hw**, **Hwa**). These dunes are linear to crescent in shape.			
		Clay-sand Dune Complexes (PEdi)	Units of **PEdi** are primarily grass- or brush-covered dunes. Vegetation renders them inactive (see **PEda**).			
		Sand Sheets (PEss)	**PEss** is primarily grass-covered, base-leveled dune areas composed of sand. **PEss** areas have sharp boundaries.			