THE GLACIAL ORIGINS OF THE PUGET BASIN
The Evolution of the Modern Lowland Landscape

SCIENCE 115: NORTH SEATTLE COMMUNITY COLLEGE
Whidbey Island Field Trip

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The Glacial Origins of the Puget Basin

The Evolution of the Modern Lowland Landscape

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Figure 1 (Above) The Puget Lowland and the Puget Sound Basin. Dashed line shows the general extent of the lowland province. Image from Google Earth.
I Glaciers and the Evolution of the Puget Basin

Introduction: The Ever-Changing Landscape of the Puget Basin

The Puget Sound region is a vast lowland basin nestled between the Cascade and Olympic Mountains, an inland maritime province of over 10,000 square miles. Its center is occupied by the Puget Sound, a marine body of irregular design, featuring over 2,000 miles of coastline. This inland sea surrounds a number of north-south trending islands and peninsulas, and receives the flow of a dozen major river systems draining out of the adjoining mountains. It is a complex hydrologic, climatologic and ecologic system of very unique qualities. Along its shorelines, it is home to some three and a half million people.

Most of those three and a half million people go about their daily affairs completely oblivious to the fact that they are living on one of the most dynamic landscapes on the face of the Earth. The modern landscape of the Puget Basin is only 10 – 12,000 years old, only about 500 generations in human terms. If you were to go back a thousand generations, you would find a landscape entirely different, one that notably didn’t include a Puget Sound. Another two thousand generations back you would find a completely different landscape, and a different one a thousand generations before that. This pattern extends back some two million years, to the dawn of the human species. For all of human time, there have been no permanent landscapes here, only variations on a continuing theme.

For all of human time, the prevailing agent of change here has been the effects of glaciers, particularly the large glaciers which have advanced south out of Canada during various episodes of continental-scale glaciation. There have been dozens of such episodes over the last two million years, the time of the Pleistocene Epoch, known popularly as the recent “ice ages.” Each time that continental ice advanced into the Puget Basin, it erased the features of the previous landscape, and left behind a new version as it retreated. That version would endure over an inter-glacial period of perhaps 50,000 years, before the ice once again advanced over the province.

We live in the modern interglacial period, which commenced with the last retreat of the ice some 11-12,000 years ago. The modern landscape which surrounds us is owed almost entirely to the effects of the last glacial advance, which occupied this region between 18 and 12,000 years ago. This landscape will endure for another 30 – 40,000 years, when the ice will once again advance across the region and re-shape the province.

There are no permanent landscapes here, only variations on this continuing theme.
**PRELUDE:**

*The Early Evolution of the Puget Basin:*

While glaciers have been changing the landscape of the Puget Basin for the last two million years, they have not been responsible for the overall shape of the region. It is a common misconception that glaciers “carved out” the Puget Basin as they advanced south into our province. The Puget Basin existed for millions of years before the glaciers first advanced over this landscape.

Prior to about five million years ago, the entire Olympic Peninsula was a shallow marine province, and the western coastline fell along what are now the western foothills of the Cascade Mountains. With a change in the relationship between the continent and the (oceanic) Juan De Fuca Plate to the west, this setting began to evolve about five million years ago. Since that time, compression along the western edge of the North America has raised a parallel set of folds along the continental margin. The western of these comprise the Insular Mountains of Vancouver Island, the Olympic Mountains, the Wallowa Hills, and the Oregon Coast Range. The eastern of these is the Cascade Range. These ranges have only been rising for about five million years, and are among the youngest on the planet.

Between the rising Olympic and Cascade Mountains, the Puget Basin has formed as a deep trough, or syncline, between these two folds on the continental margin. As those mountain ranges rise, the Puget Basin sinks between them, at a rate of a bit less than half a millimeter each year. This setting was well established some two million years ago, when the glaciers first started advancing on this landscape.

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*Figure 2 (Above) Diagram illustrating the development of the Puget Basin and the flanking mountain ranges. View is looking to the north. Upper diagram shows the continental margin prior to about 5 million years ago. Since that time, east-west compression has raised the mountains as a parallel set of folds, as illustrated in the lower diagram, with the Puget Basin in between.*
Glaciers:
The Agents of Change

Glaciers are bodies of ice which accumulate where, on a regular basis, winter snowfall exceeds the summer melt. As snow accumulates, it changes over time (and under pressure from accumulating snow above) into glacial ice. Glacier ice has a distinctive quality in that it deforms in response to gravity, and thus flows downhill, and away from areas where it forms a thick accumulation.

Glaciers typically develop first in the high mountains, where snowfall is abundant. In their accumulation zones, alpine glaciers are powerful erosive agents. Rocks entrained in the ice carve deep cirques in the mountain slopes as they flow downhill. Where the ice extends down into a valley, the erosive forces of the glacier carve it into a deep U-shaped trough. If conditions are sufficient, that ice can extend out of the mountain valleys and spill out onto the lowlands, where it broadens into a wide piedmont glacier. There, it deposits its load of suspended boulders, sand, silt and clay onto the landscape.

The health of a glacier is determined by an equation of mass balance. If the amount of (frozen) water which accumulates over the winter is greater than the amount which melts away over the summer, the glacier will continue to grow and advance. Under the right climatic conditions, the glaciers spill out of the mountains.
and onto the surrounding plains. Carried further, those glaciers then coalesce into large continental-scale ice-caps which blanket the landscape. These can accumulate to thousands of feet in thickness. This is the process by which the Cordilleran ice-cap has repeatedly formed in western Canada, as glaciers in the Insular, Coast Range and the Rocky Mountains have coalesced into massive continental-scale features.

Glaciers are conveyor-belts of ice, constantly flowing forward and transporting the load of boulders, sand, silt and clay which they quarry from their headwaters. Where this debris is deposited, these are known as “moraine” deposits. They are unique in their composition, lacking in any degree of sorting or stratification. Moraines accumulate along the margins of the ice when the glacier position is stable. “Lateral moraines” often develop along the sides of the ice. If the end of the glacier holds a stable position for some time, it will accumulate a “terminal moraine” in front of it.
The effect of ice advancing into a lowland basin depends on many factors, but a significant variable is the amount of meltwater and suspended sediments which are being produced by the ice. When runoff is relatively low, the ice advances in direct contact with the existing landscape. When runoff is high, a large “outwash plain” of sand, silt and gravel is deposited by rivers in advance of the ice, a thick layer of sediment that the ice then advances over. When this happens as the glacier advances over water, a broad delta (an outwash plain) is deposited in front of the ice. The glacier then advances over this bed of sediment.

When the amount of summer melt exceeds the winter accumulation on a regular basis, the glacier starts to thin in its accumulation zone. If this continues, the decreased flow of ice will eventually cause the terminus of the glacier to start to retreat. In large ice-caps, the time lag between the onset of a negative mass-balance in the accumulation zone and the retreat of ice from the glacial front can be several thousand years. Smaller alpine-scale glaciers are much more sensitive to such changes, reacting on a scale of decades to centuries.

When a continental-scale glacier retreats from a landscape, many factors influence the landscape it leaves behind. One significant variable is how fast the ice is melting. Meltwater accumulates at the base of the glacier, and drains off in channels which parallel the direction of the ice flow. If the glacier is riding on a bed of sediments, faster melting results in a deeper erosion of the sub-glacial landscape. Between these

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**Figure 6.** (Above) Moraines of the Athabasca Glacier, Canada. Terminal moraine appears in front of the glacier, old lateral moraines lie in the foreground. Image: J.B. Ball.
sub-glacial meltwater channels, the intervening ridges are shaped by the continuing flow of the ice above. These characteristic meltwater-cut, glacially-smoothed ridges are known as “drumlins.”

As a glacier finally retreats from the landscape, it collapses across the topography and deposits a layer of morainal debris known as glacial “till”. Glacial till is unique in that, unlike wind or water-deposited sediments, it is laid down as uniform blanket across the existing topography. It is plastered on hilltops, valleys and slopes, clinging even to quite steep hillsides. In this way, its surface mirrors the surface of the underlying substrate. Apart from isolated lateral and terminal moraines, glacial till is the major component directly deposited by the ice itself. Its presence is the quintessential indicator for the existence of past glaciers.
As glaciers retreat from a landscape, a variety of other landforms can develop under suitable conditions. Several of these are common in the Puget Basin. Among the most common features are glacial erratics and kettles. Glacial \textit{erratics} are large boulders, which are essentially moraine features. These boulders can be as big as houses, and can be transported hundreds or thousands of miles on the ice before being deposited as it retreats. Without an understanding of this process, these isolated boulders (often of rock types which are exotic to the area) are profound enigmas to the casual observer.

\textbf{Kettles} are large depressions in the landscape, left by stranded pieces of ice as the glacier retreated. Kettles develop best in settings where outwash streams from the retreating ice blanket the area (and in part, the ice blocks) in an additional layer of sediment. When the stranded pieces of ice finally melt, they leave a distinct depression in the landscape. Sometimes, these are occupied by \textit{“kettle lakes”}. These are distinctive in that they typically have no outlet stream.

\textbf{Figure 9} (Above) Drumlin field in Patagonia. These elongate hills parallel the direction of the ice flow. Image: Mara Rua

\textbf{Figure 10} (Right) Image of a drumlin field in Wisconsin, using terrain-imaging software. Image: Bill Hecht
Figure 11 (Right)
Wedgwood Rock, a glacial erratic in northeast Seattle. You can visit this feature at NE 72nd and 28th NE.

Unless you are familiar with the circumstances by which such huge boulders are deposited, their presence can represent a profound enigma.

Figure 12 (Below)
A kettle lake, Okanogan Highlands. These lakes form when pieces of stranded ice are partially buried in till or outwash sediments from the receding glacier, and then melt to form a hallow.
The Periodic Glaciation of the Puget Basin: Variations on a Continuing Theme

Until not too long ago, most researchers were convinced that the Puget Basin has been the site of something like 6 major glacial advances, based on a scattered record of glacial deposits across the region. More recently, we have come to recognize that there were probably dozens of such episodes, the record of which has largely been lost to the forces of time. From the record of the continental interior, we know that those events stretch back almost two million years into the past.

In addition to the larger continental-scale episodes of glaciation, the Cascade and Olympic Mountains have repeatedly developed glacier systems of their own over this period. Most episodes of continental glaciation start out with the development of glaciers in the mountains, and there have certainly been times when rivers of ice flowed out of the Cascades and Olympics onto the Puget Basin. Sometimes these local advances were not part of a continental-scale episode, other times they contributed to such events. At other times, the local glaciers had actually retreated by the time that continental ice advanced across the region.

In the Puget Basin, the furthest point to which continental-scale ice has advanced appears to be located just north of Tenino, a bit south of Olympia. Across eastern Washington, it doesn’t appear to have extended further south than the latitude of Seattle. In all cases, it does not appear that the large mass of the continen-
tal ice-sheets advances much further than the 48th parallel of latitude, just south of the international border. From this massive ice-cap, large “lobes” of ice flow south down the major north-south valleys which cut the northern half of the state. These include the Puget Basin, the Okanogan Valley, and the upper Columbia River Valley, along with the Purcell Valley in northern Idaho. It would appear that the large lobes of ice which periodically descend these valleys frequently advance into non-glacial settings.

The advance of large glacial lobes into non-glacial settings can have profound effects on local and regional drainage systems. When the Okanogan Lobe advances, it eventually blocks the flow of the Columbia River, forcing it down through what is now the spectacular canyon of the Grande Coulee. When the Purcell Lobe advances far enough, it dams a river which accumulates a lake the size of Lake Erie. That ice dam periodically fails, resulting in truly cataclysmic floods which absolutely scour the surface of Eastern Washington.

When the Puget Lobe advances south into a non-glaciated Puget Basin, it is a far more complex setting. The advancing ice initially dams west-flowing rivers out of the mountains, the Fraser, Nooksack, Skagit and Stilliguamish in order. Great lakes are impounded in these valleys, which eventually overtop the intervening divides to create north-south trending flood-channels between the drainages. The Columbia, Wickersham and Sauk River Valleys all served to carry this vast quantity of water south, to where it could again drain to the west.

**Figure 14** (Above) Illustration showing the Puget Lobe advancing into the Puget Basin, forming a large pro-glacial lake as it dams the north end of the basin. Water drains to the southwest, down the Chehalis River. Base Illustration from Google Earth
Ultimately, the issue is that the Puget Basin is a north-draining feature which empties out into the Strait of Juan De Fuca. A large Puget Lobe, spreading south across the San Juan Islands, has the potential to dam the entire basin between the Cascade and Olympic Mountains. When this happens, the Basin hosts a large pro-glacial lake in front of the advancing ice. As that basin fills, the water either forces a route along the edge of the glacier, or it overtops the divide south of Olympia, and drains to the Pacific down the Chehalis River Valley. If the glacier advances as far south as Olympia, it completely displaces the lake until the ice starts to recede.

The glacial history of the Puget Basin likely includes innumerable variations on these scenarios. Some episodes may have included glaciers flowing out of our mountains, others advanced into an unglaciated landscape. Sometimes the ice effectively dammed the basin, other times the water maintained a channel along its margin. Some episodes advanced as far south as modern-day Olympia, others may have only reached as far as Seattle or Everett. To at least some degree, each episode was a unique event.

For the dozens of glacial episodes which have occupied this basin, we have only a scant record. Most of the landscape is buried in sediments dating from the last glacial advance, and there are not many windows through this cover. Beneath that cover, the evidence for past episodes is only locally preserved. Glaciers are effective agents for erasing such evidence from the landscape.
The Glacial Record
The Writing on the Landscape

We currently have evidence for seven episodes of continental glaciation in the Puget Basin. These include the 2 Ma Orting Glaciation, the 1.6 Ma Stuck Glaciation, the 1 Ma Salmon Springs Glaciation, the XXX Hamm Creek Episode, the 250 Ka Double Bluff Glaciation, the 60-80 Ka Possession Episode, and the recent 18-12 Ka Fraser Glaciation. These periods of glaciation were separated by non-glacial intervals with conditions much like the present. The older “non-glacial” periods likely also include numerous glacial episodes.

The till deposited during the Orting Glaciation is exposed near the town of Orting in the Puyallup Valley. It sits atop streambed deposits of rivers draining off the Cascade Mountains, and lies beneath non-glacial sediments known as the Alderton Formation. It is thought to be about 2 million years old, and is the oldest known glacial deposit in the Puget Basin.

Atop the Alderton Formation is another layer of till (two layers, actually) which represent the Stuck Glaciation of about 1.6 million years ago. Limited evidence suggests that this episode may have dammed the Puget Basin, forming a large lake here. This till layer underlies a non-glacial unit known as the Puyallup Formation. The Puyallup has a distinctive layer of river-laid sand at its base, but most of it consists of debris brought down from Mt. Rainier, in the form of mudflows and river deposits.

Figure 16 (Above) A stratigraphic column for the glacial and non-glacial deposits of the Puget Basin. The Olympia Beds of the Olympia Interglacial Period (between the Possession and the Fraser episodes) are not indicated. Adapted from Easterbrook 1994

Figure 17 (Left) The Double Bluff Till on Whidbey Island. The Double Bluff lies above a layer of outwash gravel and sand. Image from Easterbrook, 1994
The till of the Salmon Springs Glaciation is exposed in the Puyallup Valley east of Sumner. It consists of glacial outwash gravel and till. It overlies a distinctive ash deposit from the Mt. Baker area, a deposit dated at about 1 million years old. Between the 1 Ma Salmon Springs Episode and the 250 Ka Double Bluff episode, the record is quite unknown. There are likely several glacial episodes over this span of time.

Till of the Double Bluff Glaciation is the oldest glacial deposit which can be found in a number of locals around the Basin. The classic exposure is on Double Bluff Beach, on the south end of Whidbey Island. This till overlies a 6 m gravel layer which is interpreted to be a proglacial outwash plain. The till layer itself is about 12 m thick. Above the Double Bluff till lie non-glacial sediments of the Whidbey Formation.

The Whidbey Formation includes silt and peat sections, but is largely a fine sand showing evidence of deposition by a west-flowing river. That river was likely the ancestral Skagit. Thick (90 m) sections...
of these sediments along the west side of Whidbey Island argue against a marine setting in the basin at this time. Pollen samples from the peat beds reflect a climate similar to, or slightly cooler than, exists at the present.

The 60 – 80 Ka Possession Till overlies the Whidbey Formation directly, without intervening outwash deposits. It is best exposed at Possession Point, on the south end of Whidbey Island, but can be found in numerous other places, including in Seattle. On Whidbey Island, it consists of a layer of till, without any intervening outwash deposits, lying on the Whidbey Formation. It is only preserved locally, and in many places is simply represented by an unconformity between the Whidbey Formation and younger sediments.

Above the Possession Till lie the Olympia Beds, accumulated over the last non-glacial interval between 60 and 20 thousand years ago. The Olympia Beds outcrop around the Puget Basin, and consist of fluvial sand and silt deposits, and lacustrine silt and clay beds. Interestingly, none of the outcrops reflects a proximity to a marine setting, suggesting that there was no Puget Sound over this period. Instead, the region was a low-lying river basin at that time. Pollen samples from peat deposits in the Olympia Beds reflect a climate similar to, or slightly cooler than, our current interglacial conditions.

Figure 20 (Above) The Whidbey Formation, the Possession Till, the Esperance Sand and the Vashon (Fraser) Till, on the shores of Penn Cove, Whidbey Island.
II  THE FRASER GLACIATION AND THE EVOLUTION OF THE MODERN LOWLAND LANDSCAPE

THE DEVELOPMENT OF THE PUGET LOBE
An Extension of the Cordilleran Ice-Cap

Most of the modern landscape of the Puget Basin is owed to the effects of the most recent glacial episode, the Fraser Glaciation. Known locally as the Vashon episode, it commenced about 25,000 years ago, and ended about 12,000 years ago.

This episode ended the Olympia interglacial period, which started between 50 and 60,000 years ago. Pollen samples from the Olympia period reveal a climate not dissimilar to that which exists today, a setting dominated by coniferous forests of fir and hemlock. The sediments deposited over this period are known as the “Olympia Beds”, and they are a fairly widespread occurrence along the eastern coast of the Puget Sound. They reflect deposition along rivers, in bogs, and in lakes, a landscape similar to that which exists today. Notably, there are no known marine sediments in the Olympia Beds, which suggests that there was no Puget Sound over this period. Instead, the basin was apparently a vast river valley, with an ancestral Puget River draining north to the Strait of Juan De Fuca.

Figure 21  (Above) The Olympia Beds, exposed along the shoreline at Discovery Park. The Olympia Beds date from ~17,000 to ~50,000 years in age.
The glaciers of the Fraser Glaciation started growing in the Canadian Coastal Range and the Canadian Rockies between 25 and 30,000 years ago. After 25,000 years ago, glaciers started growing in the Insular Mountains of Vancouver Island, and in the North Cascades of Washington. In the Cascades, this is known as the “Evans Creek” episode of alpine glaciation. North of the border, the ice in Canada had coalesced into an icecap by this date, and was advancing to the south.

The Cordilleran Icecap was several thousand feet thick as it advanced south down the Georgia Strait. North of the border, it advanced up the Fraser Valley, eventually blocking the flow of the (very large) Fraser River. The ice impounded a large lake in the Fraser Valley, which accumulated until it overtopped a divide at the head of the Columbia Valley, north of the town of Kendall on the Mt. Baker Highway. This divide was breached in the early glacial episodes, forming the Columbia Valley Spillway. Here, water from the Fraser River spilled south into the Nooksack River drainage.
The icecap spread south of the international border about 20,000 years ago, flowing across the San Juan Islands and the Nooksack lowland. As the ice pushed up against the mountains to the west, it eventually blocked the flow of the Nooksack (and Fraser) River, impounding a large lake in the Nooksack Valley. Again, following a route established during early glacial episodes, this water overtopped a divide to the south, and spilled south down the Wickersham Valley to the Skagit Drainage below. The Wickersham Coulee carried the combined flows of the Fraser and Nooksack Rivers.

By 18,000 years ago the ice had breached the Chuckanut Mountains south of Bellingham, and spilled south into the Skagit Valley. As the ice rode up against the Cascade foothills, it dammed the Skagit River, now also receiving the waters of the Nooksack and Fraser. Once more, a large lake was impounded until it could drain south to the next drainage. Along a route cut in the early glacial episodes, that water flowed south through the Sauk Valley to the Stilliguamish Valley. The Sauk valley was cut through a low divide by floodwaters during the early glacial episodes. The combined floodwaters of the Fraser, Nooksack and Skagit cut the great coulee of the Sauk Valley, which extends south to the headwaters of the Stilliguamish River. This water then flowed west down the Stilliguamish Valley.

By 17,000 years ago, the ice sheet probably extended as far south as what is now northern Whidbey Island. In advance of the glacier, a large outwash plain was being deposited by streams emanating from the ice front. North of this point, this layer of sand and gravel is known as the Quadra Sand, after exposures north of the border. These deposits are best defined where the glacier spread south over water, where they built up as a delta in advance of the ice.
This date marks the maximum extent of the Evans Creek episode of alpine glaciation, where glaciers in the mountains had advanced as far as some of the lower valleys. From this date forward, those glaciers started to retreat rapidly. Alpine glaciers being much more sensitive indicators of climatic change than the larger continental-scale icecaps, this would suggest that the climate was starting to warm by this date.

About 16,000 years ago, as the ice was advancing across the southern end of what is now Whidbey Island, it contacted the northeastern end of the Olympic Peninsula. As this happened, the ice formed a dam across the northern end of the Puget Basin. Behind this dam, the waters of the Puget Basin accumulated rapidly. This included all the runoff from the adjacent mountains, along with water draining directly from the ice front. This lake eventually rose to a point about 200 feet above current sea level, where it completely filled the bottom of the basin. This proglacial lake is known as Glacial Lake Russell, after pioneering geologist Issac Russell.

Large streams emanating from the front of the ice carried huge amounts of gravel, sand, silt and clay, the products of vigorous erosion in the upper reaches of the glacier. These streams now emptied out into the waters of Glacial Lake Russell. The silt and clay-sized particles were carried by currents out into the lake, where they slowly settled to the bottom. These lakebed clay deposits are known as the Lawton Clay, named after exposures at Discovery Park (Fort Lawton) in Seattle. They accumulated on top of the Olympia Beds, and where those were absent, on older glacial and non-glacial sediments. Up to 150 feet (50 m) of these
clay and silt beds were deposited across much of the region. In places, these deposits are comprised of thin alternating beds of clay and silt – representing seasonal changes in the sediment composition.

Back at the glacier terminus, the large quantities of gravel and sand being brought by these streams settled out quickly as they poured into the quiet waters of Glacial Lake Russell. These coarse sediments accumulated in a broad outwash plain, effectively a river delta, in advance of the glacier. This vast sandur (to use the Icelandic term) extended for miles in front of the ice, a broad apron of sand bordering the ice front. This layer of sand and gravel was deposited on top of the Lawton Clay, as the glacier advanced into Glacial Lake Russell.

These proglacial outwash sediments are known as the Esperance Sand, named after a small community near Lake Ballinger, where they were first studied. This layer accumulated to about 150 feet (50 m) in thickness, deposited on top of the Lawton Clay. The lower portions of this unit display the distinctive foreset bedding characteristic of river-delta deposition. The upper portions are cross-beded deposits, reflecting deposition by streams. This pattern developed as the ice front moved south, depositing younger, proximal shallow-water sediments on top of older, more distal deeper-water sediments.

As the Puget Lobe advanced into Glacial Lake Russell, it blanketed much of the region in about 300 feet (100m) of proglacial sediments deposited in front of the ice. As the ice advanced to the south, it advanced over this accumulated sediment package. As the ice advanced into the lake, the water level rose to a point where it eventually overtopped the divide south of Olympia, and drained southwest via the Chehalis River Valley to the Pacific Ocean. This is why the Chehalis Valley is so dramatically over-sized for the incumbent Chehalis River.
By 14,000 years ago the Puget Lobe had advanced to its furthest extent, a point just north of the town of Tenino. By this point, it had completely displaced Glacial Lake Russell. The ice was 6,000 feet thick over Bellingham, and at least 3,000 feet thick over Seattle. To the west, another great lobe of ice extended out the Strait of Juan De Fuca, reaching to the Pacific Coast. Along the margins of the Puget Lobe, great lakes were impounded high up into the mountain valleys, some of which were only recently abandoned by local glaciers. Along the southern end of the glacier, meltwaters coursed through a network of outwash channels directly into the Chehalis drainage.
The Puget Lobe reached its maximum extent about 14,000 years ago, but does not appear to have held that position for very long. As evidenced by the retreat of the alpine glaciers in the Cascades several thousand years earlier, the climate had been warming for some time by this date. While the effects were not felt at the far terminus of the Puget Lobe, the Cordilleran Icecap had probably reached a negative mass-balance by 16,000 years ago. By the time the Puget Lobe stopped its advance, it would appear that large-scale melting was already underway.

The Puget Lobe receded from the Puget Basin at a rapid rate, breaking up as its mass was thinned by rapid melting of the ice. Most of the modern landforms of the Puget Basin have their origins in this rapid melt-off of the Puget Lobe. These events have left the region a mix of upland provinces distinguished by prominent north-south trending hills, and a network of deep north-south-trending channels which border those upland areas. In large part, these features are constructed out of the ~300 foot thickness of proglacial sediments which were originally deposited in front of the glacier. The modern landscape largely reflects erosion into these layers of sediment.
As the ice was rapidly melting, large quantities of meltwater accumulated at the base of the glacier. This water cuts a subglacial streambed underneath the ice, a channel oriented parallel to the movement of the ice above. As these subglacial streams grow larger, the intervening ridges grow more pronounced. Those ridges are continuously shaped by the flow of the ice above, which cuts the ridges steepest on the leading end, and tapers them more gradually on the trailing end. These iceflow-parallel ridges are known as drumlins, and they are ubiquitous features on the upland portions of the Puget Basin. These developed underneath the glacier, as meltwaters cut sub-glacial streams into the sediments below, while the moving ice above smoothed the intervening ridges between them.

The quantity of water produced in this rapid melt-off of the Puget Lobe was impressive. As long as the ice still dammed the basin on its northern end, that water drained south through the Chehalis Valley. The huge quantities of water draining the uplands accumulated to create massive subglacial streams which flowed to the south. These streams excavated large channels in the proglacial sediments, and in places cut down into older glacial and non-glacial material. The Puget Basin is marked by a network of these large north-south trending channels. The central channels of this system are now flooded by marine waters of the Puget Sound. Along the periphery, they are marked by large north-south trending lakes (e.g. Lake Washington, Lake Sammamish), or serve as prominent river valleys (e.g. the Duwamish Valley). These features were all excavated beneath the glacier, by massive subglacial streams carrying off the huge quantities of meltwater draining off the upland areas.

Figure 30 (Above) As the Puget Lobe started to retreat, a new pro-glacial lake (Glacial Lake Bretz) formed in advance of the ice. Base image from Google Earth.
As the glacier finally retreated from this now-eroded landscape, it deposited a layer of glacial till across the entire surface. Ranging from 5 to 15 feet in thickness, it is a uniquely unsorted mix of gravel, sand, silt and clay, deposited in a relatively uniform blanket across the landscape – even adhering to steep slopes. In this way, its surface reflects the eroded landscape beneath it. In this way it can be seen that the origins of the modern landscape lie in the erosional *unconformity* between the proglacial sediments and the glacial till, and that this erosional event happened prior to the final retreat of the ice.

It took the Puget Lobe about a thousand years to retreat from the Puget Basin. As it retreated, a pro-glacial lake once again formed on the southern end of the basin. This feature is known as Glacial Lake Bretz, after another local pioneering geologist. Glacial Lake Bretz was a hydrologically chaotic setting, where the lake level was in a constant state of flux. As the ice retreated from the front of the mountains, lakes which had been impounded there would empty catastrophically into the basin below. In some places those draining lakes built large deltas out into Lake Bretz, such as seen above Issaquah in the Snoqualmie Valley. As ice retreated from the foothills, some rivers cut ice-marginal channels as they drained to the south around the edge of the glacier.

**Figure 31** The order of events responsible for producing drumlins, which are elongate hills formed parallel to the flow of the ice. View is to the north, with the ice moving towards you. (A) Shows sedimentary sequence prior to erosion, at the maximum extent of glaciation. (B) Shows meltwaters from the shrinking glacier eroding ice-parallel drainage channels into the sediments below. (C) Shows moving ice above sculpting the intervening hills into drumlins.

It is important to recognize that even as the glacier is retreating, the ice continues to flow to the south. This flowing ice sculpts the hills into a form that is characteristically steeper on the upstream end, and more gradual on the downstream end. These are the dominant features of the Puget Lowland.

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By 13,000 years ago the ice had retreated to a point where the waters of Glacial Lake Bretz could flow between the glacier and the northeastern Olympic Mountains, draining to the Strait of Juan De Fuca. This channel is known as the Lake Leland Spillway. Not long after that development, the ice dam failed and the lake was emptied. Because the region had been depressed about 300 feet by the weight of the ice above, marine waters flooded the basin at that time.

The ice continued its retreat to the north, exposing modern-day Whidbey Island, just barely below sea level. On the central portion of the island it left a collection of stranded ice blocks. From a position just northeast of the island, the ice then briefly re-advanced on the region, up to the eastern shore of the island. Streams emanating from the ice front blanketed much of the central portion of the island in re-advance outwash, in part burying the stranded ice blocks at Partridge Point. When the glacier again retreated and the ice blocks melted, they formed the prominent kettle features on the central part of the island.

The ice then retreated rapidly to a point north of the Canadian Border. It re-advanced briefly back into Whatcom County about 11,000 years ago, before retreating back into the mountains of Canada. As the ice retreated, the Puget Basin started to “rebound” from being depressed by the weight of the ice. Over the next two thousand years, the land rose about 300 feet, to its present level. As it rose, the retreating marine waters often cut distinct terraces into coastline slopes during relatively stable periods, which preserve evidence for the uplift of the land. By 9,000 years ago, the topography of the region probably looked much as it does today.

People have been here since the retreat of the ice. Ice-age hunters showed up on the Sequim Prairie somewhere around 12,000 years ago, as evidenced by spear points imbedded in mastodon bones. They inhabited a relatively arid post-glacial landscape of tundra and scrub vegetation. As the climate became moister, mature coniferous forests were established between 11000 and 9000 years ago. The oldest of our native cultures likely showed up sometime between 9,000 and 7,000 years ago. Most of our native cultures appear to date from an early horizon of about 4,000 years ago.
Figure 33 (Above)
The modern topography of the Puget Basin. Note the drumlinoid topography of the upland areas. Along with the Puget Sound itself, dark blue regions are sub-glacial drainage channels which carried runoff from the upland areas. Black line shows the extent of the Puget Lobe. Note the deep valley of the Chehalis River, in the bottom left corner. Whidbey Island at top center.
The modern Puget Basin, showing the bathymetry of the Puget Sound. This is a LIDAR image (See figure 64). Note the drumlins which pattern the lowlands, all oriented parallel to the flow of the ice. Image from the PRISM project.
The modern landscape of the Puget Lowland is owed in large part to the effects of the last glaciation. While there are isolated exposures of older sediments, and localized rock outcrops dating from even earlier, most of the landscape here is constructed of material accumulated during the Fraser Glaciation. That material typically consists of a lower layer of glacio-lacustrine clay (the Lawton Clay), a layer of outwash sand and gravel (the Esperance Sand), and a layer of glacial till (Vashon Till) which blankets a subglacial erosional surface which was cut into those (and older) sediments as the icecap melted.

The Puget lowland landscape consists of upland areas where most of this 350-foot thickness of material has been preserved, and large deep troughs which isolate those upland areas, trending along north-south axes. The central troughs have been invaded by marine waters, and make up the Puget Sound and Hoods Canal. More peripheral channels now host lakes like Lake Washington and Lake Sammamish, or serve as river valleys, as in the case of the Duwamish River. Many of these troughs cut down through the deposits of the Fraser Glaciation, and into the Olympia Beds and older sediments. Where they did, they are now typically filled with water. Much of the central channel of Puget Sound is about 100 m (300 feet) deep, excavated into pre-Fraser sediments.

The upland areas of the Puget Basin preserve much of the 300 – 400 foot thickness of proglacial sediments and glacial till left from the Fraser Glaciation. It is a surface dominated by north-south trending drumlins, hills that were excavated and shaped under the flow of the ice. The hills of North Seattle are a good example of this. Trending north-south, they are steepest on their northern ends, while gradually declining to the south. These are ubiquitous features across the lower Puget Sound basin. Wherever you travel across these upland regions, east-west trips involve up-and-down travel, while north-south trips follow more gentle grades. The crests of these features, where the most material is preserved, are typically 200 – 400 feet in elevation.
The surface of these upland areas is almost everywhere covered in a layer of glacial till, typically ranging from 5 – 15 feet in thickness. Glacial erratics, isolated boulders deposited by the ice, are fairly common features on the landscape. In northeast Seattle, Wedgwood Rock (see figure 11) is a good example of a glacial erratic. Another common feature on the landscape is the presence of small kettle lakes. Throughout the region, this is the origin of many of the smaller lakes. Locally, Haller Lake and Bitter Lake are good examples of this. Arguably, Green Lake may be a kettle lake.

As discussed above, these upland areas are isolated by a set of north-south trending channels, the central members of which now hold the waters of Puget Sound. Several of these channels cut the landscape to the east, notably the ones in part now occupied by Lake Washington and Lake Sammamish. Most of Lake Washington is about 100 feet deep, 200 feet at the deepest point, all eroded into pre-Fraser sediments.

The other major features on the landscape here are the post-glacial rivers which have cut channels from east to west, at a high angle to the prevailing landforms. These features are entrenched on the landscape, having removed...
a substantial volume of material as they re-established themselves. Most of this happened over the first couple of thousand years after the ice retreated, as the land “rebounded” from glacial depression. The lower reaches of these valleys have developed as extensive floodplains, and are mantled in younger deposits. South of Seattle, extensive mudflows (lahars) off of Mt. Rainier have filled the river valleys in post-glacial times, altering the courses of the rivers.

Most of the landscape of the Puget Lowland consists of either upland areas with a drumlinoid topography, north-south trending channels which bisect that upland topography (many of which are flooded with marine or fresh waters), and east-west trending river valleys which are entrenched upon that landscape. Locally,
there are places where outwash sediments from the receding ice have filled small basins. To the north, there are isolated locales which evidence a brief re-advance of the retreating ice, in the region between modern-day Arlington and Mt. Vernon.

To the east, as one moves out of the lowlands, the setting becomes more complicated. Here the landscape is modified by a variety of ice-marginal features which developed along the front of the Cascades. These include deltaic and floodwater deposits accumulated as glacially-impounded lakes were emptied as the ice retreated, ice-marginal channels cut by rivers seeking a path around the retreating glacier, and a variety of other features which developed along the edge of the retreating ice.

**THE MODERN PUGET BASIN**

*A unique version on a continuing theme*

The modern landscape of the Puget Lowland is only the most recent in a long lineage of interglacial settings which have evolved here over the last two million years. This particular version represents a fairly radical change from the last (Olympia-age) interglacial period, in that it includes a fairly large body of marine water (the Puget Sound) and comprises a somewhat more diverse topography. This is owed to two key aspects of this most recent glacial advance. These include the deposition of an extensive set of proglacial sediments, and the large-scale erosion of those sediments as the glacier rapidly retreated from the basin. The Lawton Clay and Esperance Sand, in particular, comprise a much thicker proglacial sequence than is seen in previous episodes. The large-scale erosion of these and older sediments, deep enough to create a marine basin in the center of the province, is a reflection of the very rapid rate at which the ice retreated. This abundance of meltwater created a diverse lowland topography by subglacial erosional processes, a more diverse topog-

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*Figure 38* (Above) Foreset beds, Issaquah gravel pit. These beds were deposited as the lake in the Snoqualmie Valley emptied into the waters of Glacial Lake Bretz below. These are classic deltaic deposits.
raphy than is evidenced in older deposits. These unique qualities may reflect the fact that the Puget Lobe continued to advance for several thousand years into a warming climate, one that produced abundant runoff, and one that ultimately precipitated a very rapid melt-off of the ice itself.

In these respects, the modern landscape of the Puget Lowland may be one of the more interesting settings to have evolved here over the last two million years. In that long legacy of transient landscapes, the modern setting would appear to represent a unique geography. This landscape shares a broader geographic setting, a general sense of hydrology, a climate, and a set of evolving ecosystems in common with the dozens of versions which have preceded it over the last two million years.

It is tempting to argue that the most unique aspect of this setting is that it has evolved over (modern) human time, and that it has been occupied by people ever since the ice left. In more recent times, it has evolved into an urban and suburban center of some three and a half million people, a population which is increasingly taking a major toll on the supporting environment. Certainly this setting is most unique because the region is marked by enduring monuments of our modern urban architecture. It is difficult to look upon this modern landscape and to see skyscrapers, freeways and our urban architecture as anything but permanent modifications to this natural setting.

The modern landscape of the Puget Lowland will likely persist for another 30 – 40,000 years, and will almost certainly outlast modern civilization. Eventually, the Cordilleran Icecap will again form in Canada, and a lobe of ice will once again descend the Puget Basin. If it advances with the same abundance of proglacial sediments as were seen in the Fraser Episode, those deposits will likely cover much of what remains of our urban architecture. As the Puget Basin subsides, future glacial episodes will further bury this unique urban layer in more sediment, until it disappears forever from the landscape. In a future time, a very short time in geologic terms, all evidence for our passage will be lost from this unique setting. In the end, there are no permanent landscapes here, only variations along this continuing theme.

*Figure 39 (Above) The modern Puget Basin, looking southwest from Mount Erie, Fidalgo Island*
Figure 40 (Above) Penn Cove, along the east-central portion of Whidbey Island. This is a private beach.

Figure 41 (Right) Mount Baker, from Whidbey Island. Overlooking the town of Coupeville.
INTRODUCTION

For all the varied field trips available for exploring the glacial origins of the Puget Basin, the Whidbey Island trip is perhaps the most instructive. This setting preserves a record of the last three glacial episodes, spectacularly exposed along the shoreline bluffs which border the island. The locale also illustrates the transition from a riverine to lacustrine (proglacial lake) setting, which happened as the Puget Lobe dammed the north end of the Puget Basin. Finally, the central part of the island provides vivid evidence of a brief re-advance of the Puget Lobe as it was retreating from the basin, and offers good examples of outwash plains, kettles, erratics, and other glacial features associated with this event.

These features are displayed in a unique natural setting which provides scenic vistas on the Puget Sound region, including spectacular views of the Olympic and Cascade Mountains. The island is a charming setting of small towns nestled in a pastoral landscape of small farms and woodlands, reflecting a distinctive way of life which has persisted here for generations. About 60,000 people live here, about half of which reside in rural settings.

For these reasons and others, the Whidbey Island field trip has always been a favorite among those curious about our glacial past. It enjoys a close proximity to Seattle, yet features an island setting and a rural culture which offer a refreshing change from the metropolitan environs. The central part of the island lies in the rain shadow of the Olympic Mountains, and often enjoys pleasant weather when the rest of the region is gray and soggy. Importantly, State Route 20 traverses the entire island, from the high span of Deception Pass to the ferry terminal at Clinton, providing a line of convenient access. By including the I-5 corridor, this trip provides an opportunity to compare and contrast glacial features along both the mainland and island stretches. Finally, the trip involves a short ferry ride, which is a quintessential part of the Puget Sound experience. For all these reasons, it is one of the most popular field trips in the Puget Sound region.
Geography:
The Lay of the Island

Whidbey Island lies at the north end of the Puget Sound, about 30 miles (50 km) north of Seattle. It is a long, narrow feature, typically less than 10 miles (18 km) wide by about 62 miles (100 km) long. This makes it the fifth largest island in the contiguous United States. The north end of the island is separated from Fidalgo Island by Deception Pass, a narrow channel between the Rosario Strait and the Skagit Bay.

The northern half of the island faces west to the Strait of Juan De Fuca, while the southern end lies within the Puget Sound Basin. The central part of the island faces west on the strategic Admiralty Inlet, the northern entry to the Puget Sound. The east side of the island faces on Skagit Bay, the Saratoga Passage, and the Possession Sound, which intervene between the island and the mainland. It is the largest island in Washington.

From a geomorphic perspective, the island comprises three distinct provinces. The southern end of the island is characterized by the north-south oriented drumlinoid topography which is the norm across the Puget Lowlands. The central portion of the island, in marked contrast, is a region of flat prairie-lands. This is owed to a brief re-advance of the icecap, which buried this region in a re-advance outwash plain. The northern end of the island still retains elements of the older drumlin-marked landscape, but has been softened and modified by the re-advance of ice across that portion of the island.

The two major towns on the island are Oak Harbor and Coupeville. Coupeville is the county seat for Island County, and was incorporated in 1910. It has a population of about 1725 people, and is located on scenic Penn Cove. It boasts a strong arts community. Oak Harbor is the largest town, at about 20,000 people, and was encorporated in 1915. It was named for the Garry Oak trees which are found in the area. Many of its residents work at the Whidbey Island Naval Air Station, located northwest of the town. Owing to this strong military presence, it is a decidedly conservative and historically Republican population.

Figure 42 (Above) The Deception Pass Bridge, linking Whidbey Island to Fidalgo Island, and the mainland.
The northern and southern ends of the island are marked by gentle hills covered with farm, pasture and woodlands. The central portion of the island is marked by distinctive prairies, an anomalous stretch of flatland amidst the otherwise hilly terrane. While most of the beaches are in private ownership, the island has a good number of waterfront parks open to the public. These include Deception Pass State Park, a 4100 acre (17 km square) reserve which is the second most popular state park in Washington. Also included are Joseph Whidbey, Fort Ebey, Ebey’s Landing and Fort Casey State Parks. At the southern end of the island, Double Bluff Beach is in private ownership, but is open to the public. These parks all provide waterfront access.

State Route 20 crosses the historic Deception Pass Bridge, and extends to the Keystone - Port Angeles Ferry about halfway down the island. The road passes through Oakville and Coupville. State Route 525 continues south from the Keystone area, traversing the island to the town of Clinton and the Clinton - Mukilteo ferry back to the mainland.
HISTORY:
*A Few Notes on the Course and Character of Island Life*

On the arrival of European peoples, Whidbey Island was inhabited by members of the lower Skagit, Swinomish, Suquamish, Snohomish and other Native American groups. Most of these groups date from an early horizon of about 4,000 years ago. These were largely maritime cultures, gaining their sustenance from the surrounding waters. Great epidemics of the 1770’s and 1830’s, brought by the arrival of Europeans, killed off most of the indigenous population before the first permanent settlers arrived.

The island was noted by Spanish explorer Manuel Quimper in 1790, but was first thoroughly examined by Captain George Vancouver in 1872, sailing for Great Britain. He dispatched Joseph Whidbey to circumnavigate the island in May of that year, and gave the island its name. For his second lieutenant Peter Puget, he gave the name of Puget Sound. Vancouver named many of the geographic points on Whidey Island and around Puget Sound, intentionally applying a distinctly British nomenclature to the region.

The first permanent settler on the island was Colonel Isaac Ebey, who settled at what is now Ebey’s Landing in 1850. At that time, there remained a substantial native population. He had a small farm, but was employed as the postmaster in Port Townsend, on the other side of Admiralty Inlet. On a daily basis, he rowed across the inlet to his job. In 1857 he was killed by members of the Hiada Tribe, in retribution for the killing
of a Hiada chief at Port Gamble. He was 39 years old. Over the 1850’s a large number of settlers moved to the island, largely of Irish descent. They were joined by a large influx of Dutch settlers in the 1890’s, who moved here from the midwest.

Whidbey Island stands at the entrance to the Puget Sound. The Admiralty Head lighthouse is among the oldest in the region, established in 1861 and rebuilt in 1903. The strategic setting prompted the government to install coastal gun batteries at Fort Casey, Fort Worden (Port Townsend) and Fort Flagler (Morrowstone Island) in the late 1890’s. Fort Ebey was similarly sited during World War II. All large ships entering the Puget Sound must pass through this inlet. The narrow channel and turbulent currents of Deception Pass were considered a suitable defense in themselves.

The two seminal events in the history of the island were the opening of the Deception Pass Bridge in 1935 and the siting of the Whidbey Island Naval Air Station in 1942. The bridge was built under the Works Progress Administration, a depression-era recovery program. It united the island with Fidalgo Island to the north, extending a mainland highway onto the island setting. The opening of the Whidbey Island Naval Air Station in 1942 transformed island life to an equal degree. The station is by far the largest single employer on the island, and is the economic engine behind the town of Oak Harbor. Beyond the military presence, a substantial number of people on the island work at the Boeing facility at Paine Field in Everett, a major regional employer.

The local island economy is largely based on tourism, agriculture and seafoods. Penn Cove seafoods (oysters and mussels) are regionally distributed as gourmet fare. The island also hosts wineries, berry farms, cheesemaking and other industries. Increasingly, island farmers are producing organic products, in compliment to the pristine natural setting of the island.

![Figure 44](Left)
Whidbey Island and Mt. Rainier, from the Wilkes Expedition of 1854. This would appear to be a scene at Penn Cove.

![Figure 45](Right)
Shops of the Greenbank Farms, a leading national producer of loganberries and a local winery of historic standing. The parcel was bought by Chateau St. Michele, but then was put on the market for real-estate development. The community rallied to save the property, which was purchased and is held as a private non-profit public trust.
ITINERARY:
*A Schedule of Events*

From all the possible variations on a Whidbey Island trip, it is always difficult to choose a “best” selection of field stops. This is a setting where one could easily spend several days exploring the diverse topography, and examining the geologic record revealed along its shorelines. Trying to summarize this remarkable setting in just six or seven field stops invariably involves making some major compromises on an understanding of the broader picture here.

The trip outlined here starts out on the north end at Fidalgo Island. Here, the road to the top of Mt. Erie provides a spectacular overview of the Puget Sound region, and of the San Juan Islands to the northwest. This is a good point to consider the overall pattern of glacial advance, and how such advances interact with the existing landscape. From Mt. Erie, the route then follows SR 20 south to Deception Pass. This is something of a “tourist” stop, but a traditional must-do viewpoint.

From Deception Pass the route follows SR 20 south to the shores of Penn Cove, where consideration can be given to the succession of strandlines cut in the slope above the cove. These reflect the progressive drop in relative sea-level as the land re-bounded from glacial depression. Just to the west, the next stop is at Point Partridge (Fort Ebey State Park) for a view of glacial sediments and a good example of a kettle feature. This is a popular lunch-site, as the State Park has public restrooms.

The next stop is in Coupeville, for a view of the famous “Coupeville Erratic” on the outskirts of town. After contemplating this monolith, we will head east to the flatlands of the Smith Prairie. This is a vast re-advance outwash plain, which stands in marked contrast to the hilly terrane to the south. It is a good place to consider the course of events which have produced this setting. From here, we will take SR 20 and SR 525 to the south end of the island.

The final field stop is at Double Bluff Beach, a privately-owned parcel which is open to the public. There are restrooms here. The bluffs along this beach feature a record of the last three glacial episodes, and are a premier locale for examining the regional glacial record. This stop requires low tide conditions in order to walk the beach (about 1 mile) to the lowest sediments. At high tide, a more limited record is still in evidence. It is imperative that one does not get stranded down-beach as the tide comes in. The bluffs do not afford a route off the beach.

From Double Bluff, a return to SR 525 takes one to the town of Clinton, and the Clinton - Mukilteo Ferry. Taking Interstate 5 and SR 20 to Fidalgo Island, this makes for a convenient loop trip.
Figure 46 (Left)
View of Mt. Baker, over Camano Island, from Whidbey Island.

Figure 47 (Right) Image detailing the field trip route. From north to south, stops include:

(1) Mount Erie
(2) Deception Pass
(3) Penn Cove
(4) Fort Ebey State Park
(5) The Coupeville Erratic
(6) Smith Prairie
(7) Double Bluff Beach

The general route of the trip follows Interstate 5 to Burlington, State Route 20 to Deception Pass, Oak Harbor and Coupeville. SR 20 and SR 525 to Clinton, and the Clinton-Mukilteo ferry back to the mainland. Side trips include Mount Erie, Fort Ebey State Park, and Double Bluff Beach.

Base image from Google Earth
Figure 48 (Above) Looking south from Mount Erie, Campbell Lake in the foreground. The island on the right is Whidbey Island, with the mainland on the left. Between them is the Skagit Bay, part of an inland passage heading on Deception Pass. The three islands in the center are (front to rear) Skagit, Hope, and Goat Islands. Skagit and Hope Islands are state parks.

**STOP 1: MOUNT ERIE**

Take interstate 5 north from Seattle ~60 miles to the intersection with SR 20 (Exit for Anacortes and the North Cascades Highway). Head west on SR 20, heading south for the Deception Pass Bridge and Whidbey Island from the intersection on Fidalgo Island. Take the Campbell Lake Road north off of SR 20 to the Mount Erie Road. Take the latter to the parking area on the top of the mountain.

The summit of Mount Erie, at 1273 feet (388 m) affords a spectacular vantage on the Puget lowlands, the San Juan Islands, and the surrounding mountain ranges. It occupies a strategic setting at the northern end of the Puget Sound, and provides a commanding view of the region.

From this point north, the San Juan Islands are composed of bedrock, repeatedly smoothed and sculpted by the southward advance of the ice. Lake Campbell (below) occupies a depression carved by the ice as it flowed over the landscape. The islands are not comprised of particularly durable rock, and have been diminished in size with each successive glacial advance. Their ultimate exposure depends on the relative sea level, which fluctuates with the status of continental icecaps and other factors.
Not far south of this location, the south-advancing ice contacted the northern end of the Olympic Peninsula, damming the northern end of the basin and accumulating Glacial Lake Russell. At the height of glaciation, some 6,000 feet (2 km) of ice mantled this province. That ice extended from the foothills of the Cascades to the slopes of the Olympics.

From this point south, the islands of the Puget Sound are comprised entirely of glacial and non-glacial sediments. Their surfaces display a drumlinoid topography of north-south trending hills and valleys. They are upland regions preserved between a set of north-south trending channels. These channels served as subglacial drainage routes, draining meltwaters to the south underneath the decaying glacier. As one looks south to Camano, Whidbey and the other islands in Puget Sound, the north-south alignment of the intervening channels is evident. From this point south, the topography of the Puget Basin reflects the effects of voluminous subglacial drainage, during a rapid melting and retreat of the Puget Lobe some 13,000 years ago. The main channels cut in the process were deep enough that when the ice retreated, sea waters flooded them. Only since that time has there been a Puget Sound. Previous versions of this landscape featured the basin as a lowland floodplain province, drained by a north-flowing river.

As a result of these different glaciologic settings, there is a sharp contrast between the islands of the San Juan Archipelago to the north and those of the Puget Sound to the south. The San Juan islands are rocky uplifts which rise as much as 2,000 feet (650 m) above sea level. Mount Erie is a good example of this. By contrast the islands to the south never exceed about 400 feet in elevation - the combined thickness of the Olympia Beds, the Lawton Clay, the Esperance Sand and the Vashon Till. They are comprised almost entirely of material accumulated during the last glacial episode, and were sculpted by water and ice as the Puget Glacier rapidly melted and retreated.

**Figure 49** (Right)

*View to the northwest from Mount Erie, looking over the west end of Lake Erie. Allan Island in the foreground, Lopez Island in the background. These are islands of the San Juan Archipelago.*
Stop 2: Deception Pass

Return to SR 20 via the Campbell Lake Road, and head south for two miles to the Deception Pass Bridge. There is usually parking on the right on the north end of the bridge.

This stop is offered purely for its scenic and cultural significance. The rocky nature of the San Juan Islands extends to just the northernmost shores of Whidbey Island. With this rocky foundation, it has been possible to span this narrow channel with a high bridge. The opening of this bridge in 1935 was a major event in the history of the island, opening it up to mainland traffic. Prior to that date, the only access to the island was by ferry.

Deception Pass was named by Captain George Vancouver in 1792, while exploring the Strait of Juan De Fuca and Puget Sound. Vancouver originally assumed that this passage was a dead-end, and declined to explore it. Instead, he dispatched Joseph Whidbey in a boat to explore the shoreline. Whidbey circumnavigated the island, emerging through the pass. Recognizing that he had been deceived by its appearance, Vancouver named the channel “Deception Pass”.

Figure 50 (Above) The Deception Pass Bridge, linking Fidalgo and Whidbey Islands. Completed in 1935, it was an impressive achievement in engineering which changed the course of island life forever. Here, Whidbey Island lies concealed in the fog. Image: River2 @ Flicker.com
The narrow passage is marked by treacherous currents during the changing of the tides, and lives have been lost here in the process. The channel enjoys an international reputation among boaters, who avoid it. Kayakers can often be seen in at the entrance to the channel, waiting for currents to subside to make the passage.

For those not subject to acrophobia, a walk across the bridge is a scenic stroll. The water is about 180 feet below the narrow span. The span is actually two bridges, the 976’ Deception Pass Bridge and the 511’ Canoe Pass Bridge, connected on a small island. The total length is over a quarter mile. The span was completed on July 31, 1935, at a cost of under a half-million dollars. It now costs more to paint the structure than it originally cost to build.
STOP 3: PENN COVE

Continue south on SR 20, through the town of Oak Harbor. Where the highway follows the north side of Penn Cove, a turnout at the base of Zylstra Way provides a waterfront stop.

This locale provides an example of phenomena which occurred just after the ice had retreated from the area. When ice occupied this area, it was something like 6,000 feet thick. This tremendous volume of ice actually depressed the land underneath it, a process called glacial subsidence. Here, the land was depressed about 300 feet (100 km) by the ice.

When the ice retreated from the landscape, the land started to rise, in a phenomena known as post-glacial isostatic rebound. Over something like a thousand years, the land rose back to its original standing - an uplift of about 300 feet. As the land was uplifting, however, it did so in a dynamic setting of changing sea-levels. At the height of glaciation, enough water was stored in the continental ice-sheets that world-wide sea levels were about 420 feet (140 m) lower than they are at present. When the icecaps melted, the sea level rose by that amount. Accordingly, uplift of the land was happening during a period of rising sea levels. This resulted in setting of changing coastlines over the early post-glacial years.

At various times and places, however, these two variables resulted in coastlines of at least temporary stability. This is one such location, as evidenced in the slope northwest of the cove. Here are preserved three “fossil” shorelines, cut by waves as the shoreline remained constant for some time. These are preserved in a

**Figure 53** (Above) Penn Cove, along the east-central portion of Whidbey Island. Bald Eagles and Great Blue Herons can often be seen feeding here. Coupeville lies on the far side of the cove.
succession of distinct terraces, the highest stand being 140 feet above current sea level.

These terraces bear field evidence for their origin as paleo-shorelines, including shoreline gravels, shell fragments and other beach features. They were probably preserved here because of the protective setting offered by Penn Cove. On more open shorelines, wave action would tend to erode into the older terraces. Similar terraces can be seen on the south end of the island, above the town of Clinton. This is also an east-facing slope.

The setting of Penn Cove is northwest idyllic. Great Blue Herons and Bald Eagles fish along the waterfront here. Out in the bay, you can often see square float boxes - part of the rigging for growing mussels and oysters. Penn Cove shellfish are sold regionally, and are considered gourmet fare. Much of the coastline is in private ownership, but the west end of the cove is preserved in state park lands.

Penn Cove was named by Vancouver, after the nephews of his friend William Penn.
STOP 4: FORT EBEY STATE PARK

Continue west on SR 20 for .25 miles to the turn-off for Fort Ebey State Park (Libby Road). Follow the signs to the parking area above the beach.

The environs of Fort Ebey State Park provide a vantage on two important glacial features, along with a spectacular view of the northern Olympic Peninsula and the Strait of Juan De Fuca. The most important geologic illustration here is the contact between the Esperance Sand and the Vashon Till, as evidenced along the beachside bluffs. Additionally, the site features a kettle lake (Lake Pondilla), a good illustration of the effects of a brief re-advance of the ice here, and the mechanics of kettle formation.

The beachside bluffs here are primarily composed of the Esperance Sand, the outwash plain deposited in advance of the Puget Lobe by streams emanating from the glacier terminus. The Esperance here is largely sand and gravel, with a somewhat higher proportion of gravel layers than is typically seen to the south. Above the Esperance is a distinctive layer of glacial till, the Vashon (Fraser) Till. This layer can be distinguished by the wide range of clast (gravel, boulders, sand, silt) sizes, and the unsorted character of their amalgamation. In contrast to the Esperance, the till does not display any sense of layering - layering which results from deposition by water or wind.

The most important aspect on display here is the contact relationship between the Esperance Sand and the Vashon Till. While the Esperance was deposited in flat layers, the contact between the two is an irregu-
lat line which cuts across those layers. This irregular line is known as an unconformity, and it represents a period of erosion which took place after the Esperance was deposited, but before the Vashon Till was deposited on top of it. This means that the erosion took place after the ice advanced over the Esperance Sand, but before it deposited the Vashon till as the last of it retreated. Accordingly, this illustrates that this period of erosion took place while the ice still occupied the area - that this erosion took place *underneath* the ice.

Because the Vashon till fairly uniformly blankets the landscape, this erosional surface in the Esperance Sand is the source of the major landforms of the Puget Basin. These relationships allow us to determine how, where and when this landscape was formed. Were are left to conclude that this landscape was formed by subglacial erosion, erosion which appears to have taken place during a very rapid period of glacial melting as the Puget Lobe retreated from the basin.

The bluff along the beach here was originally constructed as a north-south trending drumlin, the western half of which has been lost to wave erosion. The layer of Vashon till on top dips to the east. On that side the till is overlain by more outwash deposits, deposits associated with a brief re-advance of the ice.

This remnant of a drumlin is the only evidence for that original post-glacial landscape on the central portion of the island. East of here, the central portion of the island is completely mantled in a layer of re-advance outwash, deposits which have buried that older landscape.

*Figure 57* (Right) Outwash sand and gravel of the Esperance Sand, unconformably overlain by the Vashon Till. Fort Ebey State Park. This unconformity is the source of most of the topography of the lowland Puget Basin.
Figure 58 (Above) View from the northwest of the beach at Fort Ebey State Park, with Lake Pondilla behind. The linear crest along the beach is a north-south trending drumlin, part of the original landscape as the glacier retreated. Everything else in this view is covered in re-advance outwash, as the ice briefly advanced on the island again. The large hollows (kettles) in this area were formed as stranded icebergs were partially covered in re-advance sediments, and later melted away. Base image from Google Earth.

As discussed further at an ensuing stop, this re-advance outwash was deposited when the ice briefly re-advanced on the island during its retreat from the Puget Basin. As the ice was initially retreating, it stranded a pack of icebergs along the western edge of the island. Those icebergs were partially buried in re-advance outwash when the ice re-advanced to the eastern edge of the island. When the ice retreated and those icebergs melted, they left the western side of the central portion of the island pock-marked with kettle basins. This part of the island is known locally as “kettle country”, for these features.

The westernmost of these kettle basins lies behind (just east) of the remnant drumlin we examined on the beach. Here, the floor of the basin lies directly on the Vashon Till, which is relatively impervious to water. By these circumstances, a small lake (Lake Pondilla) has accumulated in this basin. This is a classic example of a kettle lake. Distinctively, such lakes usually have no outlet stream.

Lake Pondilla is a short hike from the parking area. A trail heads down to the water from the Park offices just above the parking area. It is a scenic setting, and well-worth the short hike of perhaps ten minutes. The lake accumulates entirely from infiltration, having neither an inlet nor an outlet stream. The trail which circumnavigates the lake is not particularly recommended. If offers some alternative vistas, but is a rough feature in places. It has largely been pounded out by fisherpeople.
Figure 59 (Above)
Diagram illustrating the formation of kettles. “A” shows icebergs stranded on the original landscape left at the retreat of the Puget Lobe. “B” shows re-advance outwash blanketing the region. “C” shows the kettle surface left behind when the icebergs melted.

Figure 60 (Right)
Lake Pondilla, a kettle lake. Out of the numerous kettles which mark this portion of the island, only one contains a kettle lake. This may be owed to the layer of glacial till which floors this hollow.
STOP 5: THE COUPEVILLE ERRATIC

Return to SR 20 and head south and east to the town of Coupeville. Turn south on Main Street. After a few blocks (past the school) look for this large boulder behind a restaurant, in front of the Big Rock Apartments.

The Coupeville Erratic is the largest and best-known boulder on the island. It is a glacial erratic, deposited by the ice as it retreated from the landscape. This feature is almost completely covered in various ivy and vine species, but its scale is readily apparent. Were it not covered in vegetation, it would likely be patterned in high-school graffitti.

This boulder is a greenstone, a type of rock which occurs not far north of here, on the flanks of Fidalgo Island. Most likely, this was transported only a short distance, after having been broken off from an outcrop to the north. It was deposited by the ice as it retreated from the region, about 13,000 years ago. Prior to the arrival of European settlers, native peoples used this feature as an important landmark. Unless one understands the glacial origins of this landscape, large isolated boulders like this one can represent a profound enigma.
Stop 6: Smith Prairie

Return to SR 20 and head east to Smith Prairie. One can park in innumerable places, but a favorite is at the northeast end of the Outlying Landing Strip.

Smith Prairie is one of several large prairie-features on the central part of Whidbey Island. The other notable example is Ebey’s Prairie, to the west. These large flat prairie-lands stand in marked contrast to the drumlinoid topography of the rest of the island, which is marked by north-south trending hills. These were the earliest farmlands to be cultivated on the island, because the region is not blanketed in a layer of till.

Instead, the Vashon Till and its drumlin-marked landscape lies buried here, buried in outwash sediments brought by a brief re-advance of the Puget Glacier. At the time that this happened, the central portion of the island was submerged in shallow water, having not yet rebounded from glacial subsidence. As the glacier re-advanced against the east side of Penn Cove, it blanketed the submarine landscape in layers of sediment brought by glacial streams. The landscape here formed as proglacial outwash deltas accumulated over the central portion of the island. As discussed earlier, these sediments partially buried a set of icebergs stranded on the western tip of the island, forming the “kettle country” landscape there.

The sediments which blanket the landscape here are largely sand and gravel. In places where they have been excavated, their cross-section shows bedding patterns consistent with shallow-water deltaic deposition. The flat surface of the modern landscape is comprised of what are called “topset” beds. Below them are distinctive “foreset” beds which dip to the west. That the glacier did not re-advance over the central part of the island is evidenced by the lack of an upper till layer. Here, the re-advance outwash is the uppermost surface deposited. It makes for excellent well-drained farmland, and provides a very convenient surface for siting an auxiliary air strip for NAS Whidbey.

Figure 62 (Above) The central portion of Whidbey Island, highlighting the area which was covered by re-advance outwash when the ice briefly re-advanced on the island. In this area, the original drumlinoid topography was buried in deltaic sediments deposited by streams emanating from the ice. Base image from Google Earth.
Figure 63 (Above) Smith Prairie, looking to the southeast. The hill in the distance represents the edge of the re-advance outwash, and the emergence of the original topography of north-south trending drumlins.

Figure 64 (Left) Sequence of events producing the modern topography of the central portion of the island:

“A” Shows the scene as the glacier has initially retreated from the area, leaving behind a landscape patterned in north-south trending hills and valleys. On the west side of the island, a group of icebergs has become stranded. At this time, the island was largely under water, having not yet “rebounded” from the effects of glacial subsidence.

“B” Shows the glacier re-advancing on the island, and depositing a thick sequence of sediments across the central portion of the island. These were deposited as river-delta deposits, brought be streams emanating from the front of the glacier. The icebergs on the west side of the island are covered in these sediments.

“C” Shows the modern topography of the central portion of the island. Star denotes field stop location. The area formerly occupied by icebergs is now terrane marked by kettles. The large flat areas of Ebey’s and Smith Prairie are evident. It can be seen that Smith Prairie is the top of a large river-delta. Note how the area to the north has partially retained the older topography, although it has been modified by the re-advance of the ice over it.

These are LIDAR images, produced by computer analysis of laser rangefinding data taken on flights over the area. The computer selects only true ground reflections (as opposed to those from vegetation), and can model the landscape based on that data. This technique has fostered a true revolution in the way that we see the landscape, and has been particularly valuable in reconstructing the glacial past of this region. These images are from the Puget Sound LIDAR Consortium.
Stop 7: **Double Bluff**

Continue south on SR 20 to the intersection with SR 525. SR 20 goes west to the Keystone Ferry. SR 525 heads south towards Clinton. Just outside of the town of Freeland, take the Double Bluff Road down to Double Bluff beach. Note that the beach itself is private property, open to the public. Walk down the beach to the prominent bluffs.

The bluffs at Double Bluff are perhaps the best exposure of glacial history available in the Puget Sound region. Here are preserved a record of the last three glaciations - the Fraser, the Possession and the Double Bluff episodes. In addition to the proglacial deposits of Esperance Sand, as seen on the northern end of the island, here one can also view the Lawton Clay. These are lacustrine (lakebed) deposits of Glacial Lake Russell, deposited in advance of the Esperance Sand. These deposits appear on the south end of the island because this location lies just south of the point where the Puget Lobe dammed the north end of Puget Sound, creating Glacial Lake Russell. These factors make it the leading field site for exploring the glacial history of this region.

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**Figure 65** (Above) View of Double Bluff, from the southwest. The bluffs are the truncated southern end of a series of drumlins, as can be seen here. Image from Google Earth

**Figure 66** (Right) A stratigraphic column for the sedimentary layers exposed at Double Bluff. Adapted from Easterbrook, 1994
As one approaches the bluffs, the first view is of the sands of the Whidbey Formation. These are non-glacial river deposits, which can be considered in short order. At the near end of the bluffs however, is a peculiar structure which demands some attention. Here, the normally flat layers of river-laid sand are deformed, bending up toward to top. This peculiar structure is a “sand-spout”, also known as a “sand blow”, and it is associated with a violent shaking event - an earthquake. When this happens, certain layers underground can acquire liquid characteristics - a process known as “liquifaction”. Here, a layer of sand became “liquified” and erupted through the surface as a geyser of sand. The ejected debris subsequently became entrained in the next layer of sediment. The scale of the event is roughly proportional to the size of the feature. This was a very big earthquake. It is located roughly half-way through the Whidbey Formation, so it probably dates from something like 100,000 years ago.

A bit further up the beach are good exposures of the Whidbey Formation, a section of non-glacial sand, gravel and peat which accumulated between the Double Bluff and Possession Glaciations, between 250 and 65 thousand years ago. The important observation is that these are river-laid deposits, in
Figure 69 (Above) The Whidbey Formation, consisting largely of sand. These are likely the deposits of the ancestral Skagit or Stilliguamish River. The Lawton Clay outcrops above.

Figure 70 (Right, below) Map showing relationship of the modern Skagit River to Whidbey Island. In times past, the Skagit and Stilliguamish Rivers probably joined in the lowlands before flowing west over what is now Whidbey Island. Base image from Google Earth

places showing the distinctive pattern of cross-bedding which reflects the flow of water.

The Whidbey Formation consists of sand and sandy gravel, with occasional lenses of peat - the remains of organic material. This is a suite of deposits characteristic of a river floodplain, a setting not at all unlike that of the modern Skagit River to the northeast. Because the bedding patterns indicate a flow of water to the west, it is a reasonable interpretation that these represent the deposits of the ancestral Skagit or Stilliguamish River, something like 80,000 years ago. Pollen samples taken from the peat beds reveal a climate similar to that which exists today, becoming cooler as it approaches
the Possession Glaciation some 60,000 years ago. Because this locale is now in the middle of the Puget Sound, and at that time evidences a west-flowing river system, it is a reasonable deduction that Puget Sound, as a marine body of water, did not exist during Whidbey time. Instead, the ancestral Skagit or Stilliguamish River probably met with an ancestral Puget River not far to the west, and flowed north to the Strait of Juan De Fuca.

From the east end of the bluff, it is possible to see the blocky layer of Lawton Clay above the Whidbey Formation. A better perspective is to be found around the corner. As you round that corner, a prominent boulder lies on the beach. The boulder is a sandstone, a non-descript rock until you climb to the top, and notice the imprint of a palm frond in it. This identifies it as part of the Bellingham Bay Member of the Chuckanut Formation, exposed along the shores of Bellingham Bay to the north. It accumulated between 53 and 48 million years ago, at a time when the climate was much warmer than today.

As you round the corner (possible only at low tide), a more complete perspective comes into view. The Whidbey Formation lies at beach level, and the distinctly blocky layers of the Lawton Clay can be seen above it. Just beyond the corner, a thin layer of sand and gravel intervenes between the two. This is the ~60,000 year old Possession Till, deposited during the previous glaciation. As you continue down the beach,
Figure 72 (Above)

The stratigraphy of Double Bluff, at a locale just beyond the prominent point on the beach. Visible are the Whidbey Formation, the Possession Till, the Lawton Clay, the Esperance Sand and the Vashon till.

The apparent differences between these layers is subtle, but can be discerned with some patience. The Whidbey sands are distinctly brown, compared with the gray color of the Lawton Clay. Between the Whidbey and the Lawton is a distinctly rocky layer, which is the Possession Till. The Lawton has a more “blocky” structure than the Whidbey, or than the Esperance Sand above. The Esperance is light gray-brown, and has distinctive layers. The overlying Vashon Till is a resistant layer, and typically forms a short cliff at the top of the slope. From a distance, you can still see boulders in that layer.

Figure 73 (Right) Stratigraphic column for the Double Bluff area. Adapted from Easterbrook, 1994.
it is evident that the contact between the Whidbey and Possession Till is a relatively flat one - suggesting that this area was of subdued topography at the time. This is consistent with our interpretation that the Whidbey was deposited on a flat river floodplain. The generally conformable nature of the contact suggests that the Whidbey continued to be deposited right up until the time that the ice advanced over the region. This is consistent with our interpretation that it was being deposited by the ancestral Skagit River.

**Figure 75** The stratigraphy at Double Bluff. Note that the layers dip slightly to the right (east), meaning that you are going deeper as you head up the beach to the west. Feature to the left is a landslide in the Lawton Clay.

**Figure 76** (Right) The Double Bluff Till, exposed near the end of the bluffs. It is a bit of a hike to reach this point, but well-worth it if the tide schedule allows. Exposed here is the glacial till of the Double Bluff episode, and a layer of advance outwash sediments below. Image from Easterbrook, 1994
The further that you go up the beach, the better defined is the layer of Possession Till. At its base, a thin layer of gravel apparently represents advance outwash materials. If possible, get well back from the bluffs to gather a complete perspective. The difference between the composite layers is often subtle, but can often be recognized with the untrained eye. The layers dip slightly to the east, so traveling up - beach gets one deeper and deeper into the stack of sediments here. If you go well down the beach, eventually (~1 mile) you get to a point where you can see a distinctive layer of glacial till beneath the Whidbey Formation. This is the Double Bluff Till, dating from ~250,000 years ago. At the far end of the bluff, the till becomes about thirty feet thick, and sits on a layer of outwash gravel about ten feet thick.

This stack of sediments reveals much about the local glacial and non-glacial record over the last quarter-million years:

There is no exposed record for the interglacial period preceding the Double Bluff Glaciation. The outwash deposits beneath the Double Bluff Till are largely gravel, in contrast with the sand and gravel seen in the Esperance Sand. This suggests that the ice had not yet dammed the northern end of the basin, creating a pro-glacial lake in the region. It might be that these outwash gravels were washed clean by the waters of the ancestral Skagit River.

As the Double Bluff Glacier retreated from the region, the ancestral Skagit or Stillaguamish River appears to have taken (resumed?) a course across this area. Deposition of riverbed and floodplain deposits extended from 250,000 to perhaps 75,000 years ago, over the Whidbey Interglacial Period. As discussed earlier, there is no evidence for a marine body of water in the Puget Basin over this period.

The ~60,000 Possession Till was deposited over the Whidbey Formation as the Possession Glacier retreated from the Puget Sound. This event likely capped a 15 - 20,000 year episode of glacial advance and occupation. Some evidence suggests that the Possession Glacier did not extend far past modern-day Seattle. The lack of outwash sediments beneath the till suggests that, as the ice was advancing across the floodplain of the ancestral Skagit River, any advance outwash was being carried off by the river waters. These relations also suggest that the ice had not yet advanced to a point where it dammed the northern end of the Puget Basin.

Here, there are no deposits between the ~60,000 year-old Possession Till and the ~16,000 year-old Lawton Clay. Elsewhere in the Puget Basin, the Olympia Beds accumulated over this period. Moreover, there are no deposits of the ancestral Skagit River preserved above the Possession Till. Over the Olympia Interglacial Period, it would appear that the Skagit did not flow through this area. It may well be that this locale was uplifted to some degree in late Whidbey or early Olympia time. The logical mechanism for this would be a south-side-up sense

Figure 77 (Right) The contact between the Possession Till and the Esperance Sand on Penn Cove, to the north. Note the absence of the Lawton Clay at this latitude. Note also the absence of the Olympia Beds here.
of displacement on the Southern Whidbey Island Fault, which lies just 2 km north of the bluffs. Activity on this fault likely caused the sand-spout seen further down the beach.

The presence of the Lawton Clay at this locale, while it is absent along the bluffs of Penn Cove to the north, indicates that the Puget Lobe dammed the northern end of the Puget Basin as it advanced between modern-day Penn Cove and Double Bluff. The 30-foot (10 m) accumulation of the Lawton Clay here suggests that this happened not far south of the latitude of Penn Cove.

Finally, as is characteristic across the Puget Lowlands, it can be seen that the Vashon Till of the Fraser episode caps an irregular surface which has been eroded out of the Esperance Sand. *This erosional surface, a stratigraphic unconformity, reflects the time, place and manner in which the modern landscape of the Puget Lowlands was formed.*

*Having paid witness to this spectacular record of the last three cycles of glaciation, spanning 250,000 years, return down the beach to the parking area in somber silence. In these bluffs, you have seen a record of landscapes which have not existed for tens to hundreds of thousands of years. They are a record of the changing landscape of the Puget Lowlands, changing as the glaciers periodically re-arrange the lowland morphology as they advance and retreat from the region. Walk with the knowledge that our brief occupation of this basin will in due time be just another layer of sediment in the continuing cycle of glacial and non-glacial settings which will evolve here far into the future. Leave this beach with an understanding that there are no permanent landscapes here, only variations along this continuing theme.*
Return to SR 525 and travel south to the town of Clinton. From there, take the ferry to Mukilteo.

**Special Warnings for the Whidbey Island Trip**

*Tsunami Danger*
This field trip includes travel on island beaches which are vulnerable to tsunami events. While these events are rare in human terms, the novelty is lost when you are faced with the imminent prospect of dying.

The major tsunami hazard on this trip lies at Double Bluff Beach, which is subject to tsunamogenic activity on the Seattle Fault to the south. If you should feel an earthquake on the Seattle Fault, it is imperative that you move to higher ground with all possible urgency. This is a problematic circumstance if you are far up the beach at the base of the cliffs. You should strive for a position at least 30 - 50 feet above sea level, to be reached over the next ten minutes.

If an earthquake happens when we are on the central portion of the island, be prepared to drive south like a bat into hell so that we can get photographs of the unfolding cataclysm.

*Earthquake and Landslide Danger*
This field trip includes travel through, and adjacent to, active tectonic zones. In addition to the danger of tsunami (see left), the major local feature of concern is the South Whidbey Island Fault. This fault, which displays a south-side-up sense of displacement, cuts along a north-west trend just north of the Double Bluff area. This is an active fault zone, the history of which is currently under investigation.

In the event of large-scale displacement, large sections of the cliffs along Double Bluff might become dislodged, crashing to the beach below. If the cliffs start collapsing, you should run, with all possible haste, toward the water. If the tide is in, swimming would be an option worthy of serious consideration.

In the event that you feel an earthquake on the beach, you will have to assess the situation. If the active fault is the South Whidbey Fault, you should run toward the water (see, above). If it is the Seattle Fault, you should run away from the water (see, above).

**Figure 78** (Left) Walking the beach at Double Bluff. Image by Stone55 @ flicker.com

**Figure 79** (Below) The Clinton-Mukilteo Ferry is run by the Washington State Ferries, the largest ferry fleet in the nation.
A Few Final Words
From Your Instructor:

The Pacific Northwest is home to some of the most remarkable geology to be found anywhere on the planet. No region can claim to a greater variety of rock types, or features them in more spectacular settings. More significantly, no region affords such a remarkable venue on the truly colossal forces which drive the dynamics of our planet, or such graphic illustrations on the variety of geologic processes which they support. There is simply no better place on the planet to see how the Earth works. There is certainly no better place on Earth to learn and experience geology.

Most students who are taking this course are not planning to major in the sciences, and have other plans for their immediate future. My intention is not to dissuade anyone from following their passions. My only point is that, if you are planning on living in this area (and what rational person wouldn’t?), you should know that you are living in the midst of some of the most incredible geology in the world. You should know that the modern landscape that surrounds you is the product of a truly amazing course of geologic history, one that stretches back hundreds of millions of years. You should recognize that you occupy a unique point in time and space in that course of history, and in the ongoing geologic processes which will continue to shape this region into the future.

This course takes a dip in the “shallow end” of that story, concentrating on the events of the last two million years, and largely those of the last 250,000 years. These remarkable events, the events which have produced the modern lowland topography, are spectacularly illustrated in the landscape which surrounds you on a daily basis. After taking this course, it is my hope that you will look upon that landscape differently, now knowing the remarkable course of events which has produced it. It is my hope that it will inspire your curiosity about the world around you, and that you will continue to pursue that curiosity.

(Right) The summit ridge of Eldorado Peak, in the North Cascades. Your instructor has spent a lifetime climbing these mountains. Image courtesy of Eric Andersen
A Few Selected References:

Non-technical summaries on this subject are essentially non-existent. The following are largely from professional journals, but many are readable with only a modest background in the field.


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Admiralty Head Lighthouse