The Geology of Sonoma Mountain

by Norwick, 2007

The Franciscan Complex

In geology we start at the bottom when we start at the beginning. So if we could see the rocks a mile or so below Sonoma Mountain, we would see rocks of the Franciscan Complex, the same rocks we can see along the Sonoma Coast. The Franciscan Complex is named for San Francisco, which is the "type locality", the best example. It underlies the California coast from a little north of the Oregon border, to south of San Luis Obispo. It was formed over a long period from perhaps 200 million years ago to about 60 million years ago. During this period, California was a coast, but a very different coast from the present. It was something like Oregon or Japan; with strings of giant volcanoes just inland from the sea, and steep mountains, much larger than our little mountains like Sonoma Mountain. Sometimes this region was a string of islands along a coast like Japan or New Zealand, and sometimes it was a mainland like Oregon or Chile, or Kamchatka. Off shore there was a great deep-sea trench filling rapidly with sediment, and sometimes, basalt with curious pillow shaped pieces.

At that time, the Earth's crust below the Pacific Ocean was pushing from the west toward the east, against the continental crust of North America. The rocks in the ocean crust were denser that the continental rocks, and so the ocean rocks slid under the continental crust in a subduction zone. This zone was very violent. The rocks were broken and crushed and mixed up, and this went on for more than a hundred million years. That is why the Franciscan Complex is so hard to understand.

A Change of Direction and Volcanism

Between 60 and 30 million years ago, the ocean crust stopped pushing as hard and rapidly against the continental crust, and things quieted down around here. The great volcanoes stopped erupting, and the high mountains eroded, over millions of years, down to low hills. The soil which came from this erosion was deposited in the sea next to the coast as sediments which were cemented together over the years to make sandstones which are found in the Cotati Valley west of here, but which do not occur just here where Sonoma Mountain is today. Or if it did, it has been eroded.

Then, about 30 million years ago, a great fault began to form along the west coast of Mexico. This was the beginning of the San Andreas fault, which now runs along the northern California coast. This crack extended north slowly. At the same time, a new form of volcanism began along the California coast. The volcanoes were smaller than the giant stratavolcanoes of Oregon or Japan, and there was much less basalt than in the past. Most of the eruptions were more violent on the average, but less violent than the most violent eruptions of the previous, giant volcanoes. The volcanoes produced a little basalt, but mostly fine white volcanic dust which we call "ash". Thirteen million years ago, this volcanic activity, called the Tolay Volcanic field, had reached Sonoma County, at the north side of San Pablo Bay. Mount Burdell, north of Novato, is the deeply eroded volcanic root of one of these volcanoes.

By about 8 million years ago, the growing San Andreas fault had reached our region. This giant fault is a place where the crust of the ocean and the crust of the continent are both moving horizontally past each other. North America is moving southeast and the rocks under the Pacific Ocean are moving northwest. It is not a single crack, but a whole set of cracks most of which run northwest-southeast. Most of the motion is taken up on the San Andreas, which lies along the present coast of California. It is believed that about 400 hundred miles of movement have taken place in the last 20 million years, at about two inches per year. But it does not happen smoothly. Different parts of the fault move at different times. The last time the portion of the fault in Marin and Sonoma County moved was 1906, when it moved 21 feet, and destroyed San Francisco, and even worse per capita: Santa Rosa. The fault in our region has its major movements about every two or three hundred years, so none of us alive today is likely to see the next "big one".

One of the medium sized secondary faults of the San Andreas fault system, opened up here at about this time. We call it the Rogers Creek fault. It is probably the north end of the Hayward fault, which runs down the east side of San Francisco Bay. I have found a body of glass made by friction along the Rogers Creek Fault, on Taylor Mountain, just north of Sonoma Mountain. This glass was dated by Argon / Argon age determination to be 7.6 million years old. It may represent the early movements along the Rogers Creek Fault. The Rogers Creek fault had its last major movement about 1800, and is considered very likely to move again very soon. In 1969, two small earthquakes on the Rogers Creek fault on the east side of Santa Rosa, destroyed the downtown because Santa Rosa is built on very deep and flexible soil which makes earthquakes even more dangerous. This jello like soil was the reason that the 1906 earthquake along the San Andreas caused more death and destruction per square mile and per capita in Santa Rosa than in San Francisco.

There were two different types of volcanoes in the Tolay Volcanic field. One kind produced mostly basaltic cinders, light, puffy, chunks of lava, about the size of your thumb. These cinders piled up around the vent (the hole from which the lava blew up) and made little cinder cones, a few hundred feet high, and covering a few dozen acres. You can see similar features on the south east side of Clear Lake today. They produce cinders for a few years, then there is often a small basalt flow, and then they plug up with their own cooled lava, and they become extinct. However, a few thousand years later, another cinder cone is likely to appear nearby. The cylindrical hole which fills with liquid rock below the cinder cone become a solid “neck” of rock. The cinder cones erode away in a million years or less, and leave these “plugs” behind. Mount Burdell, (the mountain on the west side of the freeway, north of Novato) has a plug at the top. There are two knolls on the ridge south of the road as you drive to the preserve, which are the plugs of two of perhaps hundreds of cinder cones, which have disappeared from the surface of our area due to erosion.

The other type of volcanoes in our area, were much bigger, stratavolcanoes, much like Mount Konocti, on the west side of Clear Lake, although as stratavolcanoes go, ours are rather on the small side, compared to Shasta or Lassen, which are more typical of stratavolcanoes in size. These volcanoes are called “strata” because they tend to have layers of lava flows, interbedded with layers of white ash, and other layers of sedimentary materials, and layers of volcanic debris flows.

The volcanoes in our neighborhood tended to put out two different types of material, black basalt and white rhyolite. The basalt is richer in calcium, and iron, and the rhyolite is richer in sodium, potassium, and aluminum. The cinders, which came out of the cinder cones, were made of basalt, as were the little basalt lava flows, which came out of the cones just before they plugged themselves up. The last lava flow in our region occurred at the base of the road to the preserve, on the south side of Lichau Road, just between the “Private Estates” subdivision, and Gray’s dairy farm. The “snout” or “toe” of the flow is just at the kink in Lichau Road within sight of the stop lights on Petaluma Hill Road. If you look down on this area from Sonoma Mountain, you can see it is a tongue covered with oak trees. The rocks here are rather young, and the soil is very thin in places, so it was not worth clearing for grazing, in the days when the rest of the land at the base of the hills was cleared of its oak woodlands. The people who live on this low ridge find, however, that some places the soil is six feet deep or more. These are the places where the lava flow was uneven, and which filled with soil from the nearby land.

Sometimes, at the end of its eruption, the lava from the cinder cone became lighter in color, and richer in sodium, potassium, and aluminum, and became rhyolite. Rhyolite is very sticky; it does not flow very well. It tends to plug up the volcanic works and so some of the plugs are made of white lava, whereas other volcanoes became plugged by the basalt early in the cycle. The liquid rock, which makes rhyolite, takes on several very different appearances. The white solid rhyolite lava is not very common but it is hard and the density of most familiar rocks. Rhyolite lava is generally too viscous to flow; it just comes up and sits there. It cooled in a matter of weeks, and so it has crystals, but the crystals are generally too small to see without a microscope. Deep in the earth, the same liquid takes several million years to cool, and so it has very big crystals, the size of your thumb, and it is granite. There is no granite on Sonoma Mountain. In fact, there is no granite on the surface, east of the San Andreas fault, but there may be granite several miles down from liquid rock, which got caught before it could get to the surface. If rhyolite magma comes out and is in very small pieces or very thin layers, it cools in a matter of hours, it has no crystals, and makes obsidian. Or, rhyolite and obsidian may have a few large crystals which grew slowly for a while, but then the magma was erupted and cooled rapidly. Many people find it hard to imagine that obsidian is the same chemical composition as granite and rhyolite, because the latter are white or gray, and obsidian is black, but it is so. In fact, if you melt granite or rhyolite with a blow torch, you get a black glass. We have not yet found a natural body of obsidian on Sonoma Mountain at Osborn Preserve. The little pieces we found appear to have been brought here by indigenous people who got it from a quarry at what is now the north east side of Annadel Park.

There are several other forms of rhyolite, but they usually are formed by the stratavolcanoes, not the cinder cones. The stratavolcanoes also have eruptive cycles, something like that of cinder cones, but they take tens of thousands of years. Classical stratavolcanoes like Shasta and Lassen generally do not produce just basalt. Their most voluminous lava is a gray rock called "andesite". In truth, our stratavolcanoes produce basalt, which is low (for basalt) in calcium and iron. It can be called "andesitic basalt". They also produce some rocks, which are technically andesite, but the chemical composition is very close to basalt, so they are called "basaltic andesite". It is hard to tell without a chemical analysis, and so the best thing to say about the black rocks on Sonoma Mountain, is to call them "basaltic rocks", which is always true. They certainly do look like basalt, and they do not look like typical andesite.

The Sonoma Volcanic field stratavolcanoes also produced great eruptions, and with them other forms of rhyolite. What happened was that the great vent of the stratavolcano, much larger than cinder cone vent, became plugged when the volcanic cycle came to the rhyolitic phase. But it did not just stop the way the cinder cone did. Rhyolite lava is double trouble. It is much more viscous than basalt, and has four times as much gas dissolved in it. So when a plug formed, there was enough gas to blow it out of the way. But when that happened, the pressure, which had built up in the liquid rock caused the top portion of the magma chamber to turn into a froth, like shaking, and then uncorking a coke bottle. Mount Saint Helens, in southern Washington was the most recent eruption of this sort in the U.S. Some of this rock froth was blown high into the air, and far across the landscape and cooled as it fell. If the rock only froths a bit, it becomes pumice, which can be so light that it floats in water. Most of the froth, however, expands so that the bubbles burst, and the fine glass walls of the bubbles fall through the air and pile up as soft white volcanic ash. I have also found a place, on Taylor Mountain, just north of Sonoma Mountain, that is made of tiny spheres of solid obsidian, which did not bubble. Over the years the bubble shards or spheres were cemented together and it became tuff, a white, very light, soft, rock which is often misidentified as chalk. Tuff is a misnomer because it is anything but tough. Some of this tuff was washed off the hills by rain and washed into creeks and valleys and became sedimentary tuff. There are also volcanic breccias caused by explosions blowing large quantities of broken rock out from the volcano into the valley below.

Some of the of the eruptions were not as violent, and the froth mixed with the air in the atmosphere, and formed a glowing cloud of red hot rock dust which flowed down the sides of the volcanoes and settled at the bottom in a dust, which was so hot that the little particles of red hot glass fused together to make a white, hard, rock called "ignimbrite". This is very hard, and strong. Sometimes there are layers of soft tuff, interbedded with hard layers of ignimbrite. As the years went on, the volcanoes along San Pablo Bay became extinct, and a new set of volcanoes appeared east of what is now Petaluma, say 8 million years ago. These are the first true Sonoma Volcanics. Then this set of volcanoes died, and a new set appeared about in this area about 4 million years ago. These in turn died out, and a newer set appeared in the Santa Rosa area. At last, these too died and now there are is an active field of volcanoes at Clear Lake. These volcanoes are dormant now, but we know they produce the heat for the Geysers geothermal field. They will erupt again, and when they do, if there is a north wind, we will smell them, and breath the white rhyolite ash they will no doubt produce. This will not kill people, but it will cover the landscape with white ash, as at Mount Saint Helens.

So the Tolay, Sonoma, and Clear Lake volcanic fields make a time line on the surface of the earth. The north end of the line has new volcanoes. One theory says that the volcanic materials are older as you go south along the line because, the continental plate moved southeast over a relatively stable and geographically stationary hot spot deep in the mantle of the earth, far below the moving crust, during the last 13 million years. Another theory says that as the tectonism changed from moving down to moving horizontally, there was a low pressure area formed which moved north at the end of the last subducting plate. This low pressure zone caused the crust to melt in a spot which moved north with the new San Andreas fault. It is important to remember, and emphasize, that a volcano is a hill or mountain made by the piling up of volcanic matter. The only volcanoes in our region are at Clear Lake. All of the volcanoes which existed here in Napa, Sonoma and Marin counties were eroded away to small hills. No mountain in our region, south of Clear Lake is a volcano. If so, how did Sonoma Mountain form?

The Fault Block and Mass Wastage

The San Andreas Fault moves horizontally. The Pacific side of the fault moves northwest, and the continental side moves southeast. It is generally assumed that the secondary faults in the San Andreas system move in the same way, but this is not always a good guess. The Rogers Creek fault may have significant horizontal displacement. Some geologists believe that it has moved like the San Andreas many tens of miles but there are no good markers so this is still a question. What is clear, is that the Rogers Creek fault has much more vertical movement, as a percentage of its displacement, than the San Andreas fault has.

The Rogers Creek fault is not a single crack, but a set of more than a dozen cracks, which geologists call "splays". The western most splay is at the base of Sonoma Mountain. There is a large splay on the way up the road to Osborn Preserve. You can recognize it by the spring which supports the patch of dark green reeds just below the house with the large white gate which says "Gracias San Antonio". This spring is caused by the fault which has moved enough to form a gouge zone, a band of finely ground rock powder. Water can not percolate through this fine material, so it backs up in the ground, sort of like a dam, inside the rock. In this place, the water overflows on the surface as a spring which is an important source of water for wildlife.

The next major splay of the Rogers Creek fault further up the mountain, runs through the vernal pool on the Preserve, and through two more vernal pools in a line south from the Preserve. Geologists call pools along a fault "sag ponds". They form where the fault is not quite straight, and so when it moves, it leaves an opening along the fault. This opening fills with broken rock and soil from the surface, within a few seconds during which it is formed. But there is still a sag in the surface of the earth, and this holds water. Such sag ponds are a sure sign of an active fault, because, they fill rapidly with soil, and so they can not be very old in geologic terms; a thousand years perhaps. It is possible that the sag pond fills over the hundreds of years between major seismic events, over and over again. That is the main way that geologists can determine the history of faults: by excavating and dating the fill which has been deposited in sag ponds. Some day, a geologist will ask to dig a trench in the sag pond on the Preserve. It might be harmful to the life there, or perhaps, it could be done in the summer and repaired by the time water rose again in December.

There are several splays on the east side of the mountain as well. In fact, the ridge, of which Sonoma Mountain is the highest point, is really a block of rock squeezing up between the splays of the Rogers Creek fault. The fault breaks and folds the rocks into such a mess that few geologists have tried to study them here, especially at the north end of the ridge, and particularly on the west side. But it is important to remember that the present ridge is a recent development in the last one or two million years. The U.S. Geological Survey staff have estimated that the ridge is rising about one half millimeter per year.

$$\frac{0.5\text{mm}}{\text{year}} \times \underline{1{,}000{,}000\text{years}} \times \frac{1\text{ meter}}{1000\text{mm}} \times \frac{39\text{in}}{\text{meter}} \times \frac{\text{foot}}{12\text{in}} = 1625\text{ ft}$$

Sonoma Mountain is about 2000 feet high, and we suspect the ridge has been rising for a million or two million years.

One of the reasons the geology here is so complex, is that there are such great thicknesses of soft volcanic rhyolite tuff. Furthermore, even the strong basalt is broken and in places ground to a powder in the many splays of the Rogers Creek fault. If you can imagine cutting a gash in a tube of tooth paste and squeezing, you can imagine the long thin line of weak rock and soil which is rising. But it is not strong enough to support itself as a ridge, so it flows sideways into the valleys as great slow slides and flows. Geologists differentiate between a landslide, which is a coherent block which slides down hill along a fracture, and a flow of soil or broken rock, which moves like a fluid, or like putty, or like the flow of dry sand poured from a bucket. The soft white rhyolite tuff flows slowly down Sonoma Mountain. As it flows, the harder basalt flows, which are interlayered with the tuff, stretch and break, and become blocks surrounded by tuff. Landslides and flows are both forms of what geologists call "mass wastage".

If you stand at the intersection of Roberts Road, Presley Road and Lichau Road, and look east, you can see a great slab of rock, on the north east side of Sonoma Mountain, which is sliding west. If you think about the shape of the mountain around this giant block, it is a sort of bowl. There are several large bowl shaped valleys, which geologists call "amphitheaters". The valley which has the marsh by the old barn is one, and the valley which contains the large reservoir on the Roth property north of the preserve, is another. It is hard to prove, but these look as if large slides or flows have come from these areas, and left them with this unusual geometry. Normally, we expect a valley at the head of a creek to get narrower, and narrower as we walk up stream, but that is not the case of these bowl shaped valleys.

All of this sliding and flowing, causes the block of rock which is rising, to form the ridge to spread out at the top. Geologists call this sort of block a "palm tree structure" because in cross-section, it looks a bit like a palm tree as the rock rises and spreads side ways. Palm tree structures are common along faults, but hard to detect. They are well known along the main San Andreas fault, in southern California, but this is the only one which is known in our area so far.

The landslides and flows on Sonoma Mountain may be responsible for one of the most important biological features of the area: the fishless upper reaches of Copeland Creek. This is unusual because it is a perennial stream and they almost always have fish. But the highest predator in the stream ecosystem is the Pacific Giant Salamander, *Dicamptodon tenebrus*. This has been documented to cause very unusual ecological relations among the other animals which live in the creek.

The creek may be fishless in its upper reaches because of the debris flows which enter it every few years, and landslides which dam it. For example, in the early morning dark of Valentine's day, 1986, there was a landslide into the creek from the south side of Copeland Creek, near the site of the old summer dam, and a mud flow from the cliff at the old barn on the lowest portion of the preserve. The creek may have been dammed for a few minutes or an hour or so by the slide and or the mud flow. When the dam broke, a wall of debris, which was more soil and tuff than water, flowed down the valley for about two miles. It got as far as the first bend in Lichau Road east of the corner with Presley and Roberts Roads.

You can see this material as you drive to the preserve if you look to the left as you drive up Lichau Road past Gray's Dairy. The debris flow completely filled in Copeland Creek. For a few days the water just ran in thin streams all over the valley. After the water went down (it took a few days) the Sonoma County Water Agency sent out a man in a D8 Caterpillar tractor, and he pushed the debris out of the creek. He did a pretty good job of recreating the creek channel, so the amount of material in the big piles along the north side of Lichau Road are a good measure of the coarse material which came down the creek early that morning. I say course material, because the sand, silt, and clay traveled down through our campus and Rohnert Park, and finally filled in more of the Laguna de Santa Rosa.

There are many other slides and a few flows on the Preserve. The whole marsh is flowing down hill toward the creek, which is undermining its banks and causing the mud to move. There are strange swales a few feet deep and running perpendicular to the creek, on the side of the marsh nearest the old barn. These formed in the late 1980s. The soil was smooth there before that. They are fractures in the mud, made when the deep wet mud flows, but the surface is dry and cracks as it moves.

There were once two barns, side by side, on the lower portion of the Preserve, but a rotational block slide formed under the northern most of the two. A rotational block slide is the most common type of slide. Its fracture is curved, concave up, so that the block rotates as it slides down the hill. The slide and the north barn slid down the hill several feet and were irreparably broken apart about 1980. My daughter and I were on the work crew that helped dismantle it board by board. The lumber was later used to help rebuild the remaining barn, but the creek continues to undermine its banks, as you can see by the exposed roots of trees which do not usually push their roots out of the ground. Eventually, probably in the next few decades, we will lose the other barn.

Another rotational block slide has deformed the old stone fence and the road to the upper Preserve. The head scarp (the uppermost crack of the slide) cuts at right angles across the road. At one point recently, the road became so steep that school busses going to the Preserve bottomed out. The county was rapidly convinced to come and regrade the road because school children were involved.

The steep hill on Moving Mountain Trail, above the vernal pool sag pond, is still sliding, and one can see the scarps which make terraces on the hill, which are the resting places for most of us as we go up that hill. There are signs of scarps all the way up that path, through the woods until one reaches the meadow north of the pond.

The Giant Mole Track

One of the most unusual features at Osborn Preserve is a strange long low hill on the south side of the valley of Copeland Creek. It extends from the visitor center, down to the marsh. This feature is called a "giant mole track" by geologists. It is a low ridge along a fault. The fault is grinding up the rocks, and extruding the rock paste. You can think of it as a miniature of the whole Sonoma Mountain ridge. I have not excavated the feature but the rock flour at the middle of the giant mole track is probably very fine and impermeable to water. The broken rocks around the edges of the giant mole track are probably large broken rocks, called a breccia. Ground water percolates down the hill through the normal soils and rocks, and meets the breccia zone which funnels it out into the air, which is the cause of the spring at the head of the marsh.

It is not clear whether the giant mole track is tectonic or part of the large land slides. If it is tectonic, the crack may reach down into the earth several miles. But most of the splays of the Rogers Creek fault run north west, whereas the giant mole track runs north and south. It is more likely that the giant mole track is caused by two blocks sliding past each other, grinding up the border area, and extruding the paste where they meet. During the winter of 1986, the giant mole track rose up on its east side, a maximum of 7 inches over a period of less than a month. This was a very wet winter, and it suggests that the blocks were sliding more, which caused the marked extrusion. On the other hand, the motion was entirely vertical, which suggests the giant mole track is tectonic. In any case, the upper trace of the giant mole track runs just east of the visitor center, and any more construction there should not extend over the feature.

Franciscan Pebbles and Previous Topography

At the top of the ridge, above the northern reservoir, along the old road, there is a deposit of soil, which has pebbles from the Franciscan Complex. The hard red chert, and hard white quartzite are particularly obvious. The road cuts into this deposit, and it does not seem to have bedding. It may be a debris flow deposit. The Franciscan Complex is several thousand feet down below the surface, how did these pebbles come here? The late geomorphology professor in the Geography Department at Sonoma State University, Claude Minard, pointed out that there are voluminous Franciscan Complex exposures east of the Preserve, on the other side of the Valley of the Moon, at Sugar Loaf State Park, for example. He pointed out that until a million years ago, there was no mountain here. The land which is now the Cotati Valley, was a bay, and what is now Sonoma Mountain was the shore of that bay. Rivers flowed from east to west, across the coastal plain, and brought Franciscan pebbles. I can only add, that since this appears to be a debris flow, the hills could not have been more than a mile or so east of here. So, today, when we stand on the saddle above Kelly Pond, and look east at Kenwood and Sugar Loaf, we are about two thousand feet higher than we would have been a million years ago. Then, we would have been near sea level, and we would have been looking east, up at steep hills where Kenwood is now.

This brings up an interesting point about the drainage today. Most valleys on this earth are excavated by the rivers which run down their middles. For this reason, most of the rivers in coastal California, from the Salton Sea, to Oregon, run parallel to the coast much of the time. That is because they excavate the soft materials which are broken along the faults of the San Andreas fault system. Think of the Salinas, Russian, Garcia, or Eel rivers. They run northwest, parallel to the coast, and then break across the coast range hills to the sea.

But there is an even more compelling force at work in the California Coast Range. Many of the valleys are not carved by water. They are "graben', the technical name of down dropped fault valleys. There are also giant folds in the earth, and the down folds, called "synclines" are valleys. The Sacramento – San Joaquin Valley is a syncline, and so is the Cotati Valley. Even San Francisco Bay fills a tectonic valley which is either folder or faulted down below sea level. The Napa Valley, and the Valley of the Moon, however, seems to be faulted, rather than folded. Actually everything around here is both folded and faulted, but one or the other forms of deformation may predominate in any one place.

We do not yet have a way to determine the age of the Franciscan pebble deposit on Sonoma Mountain. It is probably one of thousands, which were deposited in the streams which ran from east to west at a time before the San

Andreas fault system dominated the topography of this region. It is likely that the deposit was buried by volcanic material after it was laid down, and has only just recently been exposed by natural erosion. We can tell this because if it had been exposed for more than a few thousand years, the deposit would have developed into a more mature soil.

Present Topography of Sonoma Mountain

The present topography (the shape of the land) on Sonoma Mountain is based upon the past processes which made the rocks and moved great masses of them along faults, slides and flows, all of which are still ongoing. Then the rain fell on the land, and eroded ordinary streams into the soil and rock. Most of the streams on the Preserve are armored, that is, they have eroded down through the soil, and washed the fine material away, and left the boulders behind. Eventually, in a few thousand years, they become entirely lined with boulders, and the rate at which they "entrench" (that is, erode down) decreases. After that, the rate of downcutting becomes dependent on the rate at which the boulders are undermined and slowly roll down hill, and the rate at which the boulders weather into soil, and no longer protect the underlying soil from erosion. The small creeks on the Preserve probably excavated their small valleys over the last several hundred thousand years.

One of the things which people do to harm nature is to accelerate otherwise natural processes. Twenty thousand years ago, when there was an ice age in the Sierra and Canada, there was a pluvial (Latin for rainy) period here in western North America. The climate here was something like British Columbia, with spruce, and hemlock forests, and the climate in southern California was like the one we have here now. Nevada and Utah here also much wetter. The Great Salt Lake was much greater (about 3 times larger) and not salty. Much of Nevada was covered by lakes, as was the Mojave. Death Valley was a lake. The climate became warmer and drier slowly between 20 thousand, and 6 thousand years ago, when the climate stabilized, about what it is now. After that it was probably mostly a Douglas fir forest, with redwoods along the creeks.

Interestingly, the indigenous people showed up about that time. They probably practiced controlled burning. At least many California native cultures did but we do not know about the Miwoks, and Pomo speakers. They burned the firs to give preference to the oaks and other trees which were their main food sources. They also like to eat venison, and burning increased grazing for the elk and browsing for the deer. It may also have increased erosion and runoff. The increased runoff almost certainly caused some soil erosion, and probably accelerated entrenchment along the creeks.

When the Spanish and English speaking colonists took over the region, they greatly increased deforestation, partly by logging the redwoods and remaining firs, but largely by removing the forest for grazing by cattle and sheep. They removed the trees in several different ways besides cutting them down with axes. They set fires. I have met old Sonoma County men who told me, as boys, their parents sent them off with matches and told them to set fire to the hills. Another technique was girdling. They twisted some bailing wire around a tree and let it strangle itself as it grew. There was also a great deal of charcoal make to be sold to city people who did not want the smoke of wood fires. Strangest of all, perhaps, people went out into the forest with ladders and axes, and stripped the bark off the oak trees, especially the tan oak. They dragged the bark down to the railroad track, and sold it to wholesalers who sold it in turn to leather tanning factories, in the days before artificial sources of tannin. The invention of an inorganic way to make tannin in a chemical factory finally saved the last of the oak trees in California. As you walk along the creeks of the Preserve, you can see places where the tree roots are exposed. These are very likely places where the creek is entrenching rapidly due to deforestation.

There are also places where the creeks and ponds are aggrading, that is filling in with sediment which is the soil eroded from other places. The marsh is noticeably shallower than when I first saw it in 1974. There are probably other horizontal areas which have filled with sediment over the decades. These are the areas in which we find depositional soils.

Soils

The main soils at Osborn Preserve on Sonoma Mountain are the Goulding, Toomes, Spreckles, and Raynor series. It is interesting to think that the soils formed over the last hundred thousand years, when the climate was wetter than present, and therefore weathering was more rapid, and the soils are deeper than they would be if they had formed over the same amount of time, and the present climate. All of these soils are said to be "residual" as opposed to "depositional", that is, they formed on the spot by weathering. Vern Miller's work in the Soil Survey of Sonoma County (1972) is rather general. It is a good outline of what to expect on the Preserve but it can not be used to predict what the soil will be like at any specific place.

The top horizon of a soil is the O (for organic) horizon. In the past, the fires and overgrazing on this property removed this horizon. The good practices of the Preserve and the Roth family are now allowing nature to heal itself, and the O horizon is thickening. The O horizon is made of dead plant (and a few animal) parts, which have rotted and covered the land. It acts like a sponge, and is a sure way to prevent erosion. In a natural state, the O horizon would thicken until the rate at which organic matter fell on the ground would be equal and opposite to the rate at which the decomposers "ate" the detritus. As the years go on, the O horizons at Osborn Preserve will surely thicken. It might be valuable to set up some monumented sample sites or transects, which can be resurveyed every decade to document the good changes in the soil over the years.

The Goulding clay loam, and the Goulding cobbly clay loam, develop *in situ* from the weathering of the basaltic rocks. Clay rich soils can be very impermeable to water, but these are pretty well drained, because they have good aggregation. That is, the plant, and microbial gums which have been added to the soil by living things, cause the soil to flocculate into clumps, and water can flow through the soil between the little clumps. If the soil is overgrazed, the cattle will trample the soil, and compress, and break the little clumps. Then the soil will be much less infiltratable and less permeable by water. When it rains, little water will flow into the soil, more water will run off. There will be more floods, and there will be less groundwater for the plants in the summer. The top horizon of the Goulding is an O horizon. Below this there is an A horizon of dark brown clay loam. The pH is about 6. When wet, the A horizon is slightly sticky and plastic. About a foot down, the soil is noticeably richer in clay when wet. This is the B horizon. It formed by clay washing down the holes in the soil as rain infiltrated the soil and percolated into the rock. A foot or so below this is rather soft rock, weathered a reddish brown.

The Toomes series soils, are even rockier, and thinner than the Goulding. It also forms on the basalt. It seems to be a very young soil. It is rarely more than a foot total thickness, and it has only one horizon, a sure sign of recent development. It is rather similar to the Goulding in other respects. The pH is about 6.5, which is consistent with being younger. The basalt rock below it is generally much fresher than that under the Goulding. The microtopography of Toomes soil is usually very distinctive, with boulders spaced a few feet apart. Many of these places were too infertile to provide much grazing for cattle in the bad old days before the Preserve, and so they may be little changed from precolonial times. They are often covered with lichen and in moist places, even moss.

The Spreckles series form on the rhyolite tuff. I believe there is much more of it on the Preserve than suggested by Miller's report. The A horizon is about two feet thick, and grayish brown. It is not very sticky or plastic when wet. The pH is 6.5 or so. The B horizon is quite sticky and plastic when wet. It is a yellowish brown, and has pH 5.5, which is much more acid (remember the pH scale is logarithmic, so going down one unit is really going 10 times). Three feet down or so there is a layer of weathered tuff, which is called the C horizon. As if the tuff was not weak enough, the Spreckles soils are even weaker, and they often landslide or flow as a muddy flux in the spring. In the worst cases, such as the failure of the hillside near the barn on the lower portion of the Preserve, Spreckles soil turned into a slurry on the night of the great rainfall of 1986, and flowed down the hill into the creek like ovaltine from a jar; and just about the same color too.

Most of the soil along the creeks, under the marshes, and at the springs on the Preserve, are variations of the Raynor series. As Miller says, it occurs in small patches in the Goulding. The A horizon is a dark black clay which is very hard when dry and very sticky and plastic when wet. The pH goes from 6.5 in the A horizon, to 8 in the C. There is no B horizon according to Miller because it is clay from top to bottom. The C horizon is four or five feet down, and is cobbly. The Raynor is the soil most likely to cause a mudflow. It is wet even in the summer, and very wet during the winter and spring.

The soil at the marsh appears to be a high elevation phase of the Clear Lake clay, which is found in great abundance on the floor of Cotati Valley where there is Spreckles series uphill. The Clear Lake forms when Spreckles erodes and is redeposited. In a way, the marsh is a microcosm of the Cotati valley.

Dynamic Equilibrium in the Non-living Environment

Standing at Copeland Creek we can look at a pool of water, and realize that the creek is in equilibrium. The rate at which the water flows into the pool is equal and opposite to the rate from which water flows from the pool. This equilibrium is slowly changing with the seasons but over a matter of minutes, hours, or even days, it has output which is equal to the input. The ancient Greeks thought that the balance and fertility of nature was managed by in intimate intervention of local nature goddesses, called Nymphs, but one does not need to invoke deities to understand natural equilibrium. The key to creek flow is the cross sectional area of the outlet of the pool. If it rains, and the water begins to flow into the pool at a greater rate, the water in the pool will rise until the cross sectional area is great enough to discharge the amount of water which is entering the pool, and equilibrium will be reestablished.

By the way, it is interesting to notice the pool and riffle structure of a creek. The riffle is the portion of the creek between pools. It is more shallow by definition, and usually has coarser sediment at the bottom. All creeks have pools and riffles. The more water there is flowing, the larger the creek or river will be, and the further apart the pools will be. When engineers design channels which are smooth on the bottom, it usually only takes a couple floods for the water to reorient itself with an appropriate pool and riffle structure.

Not only is the input and output of water in equilibrium in each pool and riffle, the Copeland Creek (and most creeks on mountains) is fed by groundwater roughly at dynamic equilibrium. You can think of the creek as a long thin spring. At each point along the creek, water enters by surface flow from upstream and from groundwater at that point, and that input is in equilibrium with the flow of surface water away from that point. The ground water flow into the whole creek also is in equilibrium with the flow of the creek away from the mountain.

The rain falls intermittently, and infiltrates through the duff, then the soil, and finally through many hundreds of feet of rock. During the winter, the water builds up in the soil and rock. Over the summer and fall there is no rain in our region, and the groundwater presses down under its own weight. It takes several years or decades for a drop of water to infiltrate the soil and discharge into the creek. Even the rain is in dynamic equilibrium if you consider the rate of rain fall averaged over several years.

A much more mysterious dynamic equilibrium occurs in rivers and creek. The rate at which the potential energy of the water in the creek becomes kinetic energy, which becomes heat energy, is in equilibrium. This is not true of other objects falling in nature. For example, when a squirrel drops an acorn out of a tree, its potential energy becomes kinetic energy, which builds up (that is the acorn goes faster and faster) until it hits the ground. Water, however, does not accelerate. In fact, the water in Copeland Creek goes faster on Sonoma Mountain than it does when it passes Sonoma State University, and even more slowly when it enters the Laguna de Santa Rosa. Measurements on many streams have shown that the rate at which the potential energy turns into kinetic energy, is roughly equal to the rate at which the kinetic energy turns into heat. I say "roughly" because, obviously, Copeland Creek is actually slowing down, so it is losing a little more kinetic energy than it gains as it falls down the hill.

A much more obvious equilibrium occurs along creeks, although it is hard to see it happening. The rate at which sediment is added to any spot along the creek is roughly equal and opposite to the rate at which sediment is removed from that spot. Given the size of the watershed, the kind of rain storms, the types of soils, the size of the sediment and the meandering of the stream, there will be an steepness at which the sediment will be in equilibrium. Of course, this is only true when sediment is being moved by the creek, and at that time, the water is too dirty to see much. Furthermore, the creek can be out of equilibrium for hours or weeks, depending on the rate of sediment movement. But you can easily understand that if we pile up some soil or gravel in the creek, as a summer dam or similar alteration, the creek will overflow the dam, and wash it away, and decrease the slope on the front of the dam until the bottom is at the equilibrium slope. Or, consider digging a hole in the creek in the summer. When high water came, the water would fill up the hole, not just to horizontal, but to the dynamic equilibrium slope, at which time, the rate of sediment input and output will be equal.

It is also true that the creek is roughly in equilibrium at each point. The rate of soil moved to that point by the creek, from up stream, and soil washed into the creek from its banks, or from a tributary is equal to the rate of soil removal by the creek at that site. Likewise, the whole creek is roughly in equilibrium; the total rate of sediment input is equal to the total rate of sediment removal.

In many places on the earth, the soil on the hillsides is also in equilibrium with the natural rate of erosion. The total erosion for the hillside is equal to the total rate at which rock turns into soil, and the total rate of sediment removed by the river or creek is equal to the rate at which soil is washed into the creeks. However this is probably not true on Osborn Preserve, because it is so tectonically active and mixed up by landsliding and mud flowing, that it is out of equilibrium. The places which are in soil equilibrium have smooth convex up hilltops and smooth concave up bases to the hills, and thick soil all over. There are no rock outcrops where soils are in equilibrium.

Fairfield Osborn Preserve is a beautiful place. It is named for Fairfield Osborn, the most important environmental author and activist between Teddy Roosevelt and Rachel Carson. He had two main interests in nature, the preservation of endangered species and soil conservation, the place where the inorganic and organic parts of nature are most obvious. It is an interesting accident that this place, named in his honor, has a rare fishless creek ecosystem because of the complex tectonic, and topographic processes, which cause the debris flows and landslides, which prevent fish from living in the upper reaches of the creek. This is an unusually obvious example of the connectedness of all of nature.

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