CALIFORNIA'S SERPENTINE
by Art Kruckeberg

Californians boast of their world-class tallest and oldest trees, highest mountain and deepest valley; but that “book of records” can claim another first for the state. California, a state with the richest geological tapestry on the continent, also has the largest exposures of serpentine rock in North America. Indeed, this unique and colorful rock, so abundantly distributed around the state, is California's state rock. For botanists, the most dramatic attribute of serpentine is its highly selective, demanding influence on plant life. The unique flora growing on serpentine in California illustrates the ecological truism that though regional climate controls overall plant distribution, regional geology controls local plant diversity. Geology is used here in its broad sense to include land forms, rocks and soils.

Geologists of the early days in California were aware of serpentine to a greater extent than the early botanists. An 1826 geological map of San Francisco Bay area plots serpentine outcrops. The map, a work of naturalists with the H.M.S. Blossom, located serpentine on Tiburon Peninsula and Angel Island. The first major geological survey of California by Whitney in 1865 recorded serpentine too; yet the survey failed to connect serpentine with the barrenness of the vast landscape in their visit to New Idria in San Benito County, the most spectacular serpentine occurrence in the state. As the state began to extract mineral resources, serpentine became more widely recognized. Mercury, chromium, nickel, asbestos and magnesite were found in or adjacent to serpentine outcrops. In a 1918 report on quicksilver (mercury ore) deposits of the state, a photo of the New Idria landscape is captioned: “Serpentine surface near New Idria . . . showing characteristic sparseness of timber and brush growth.”

Serpentine rock was named for the likeness of the rock to the mottled pattern of a snake's skin. In Greek, the word “serpent” translates to ophidion, from which the species name is derived for the serpentine endemic grass, Calamagrostis ophitidis. The Greek physician Dioscorides apparently recommended ground serpentine rock for the prevention of snake bite, surely a rather extreme remedy. The word, serpentine, has come to be used both for the rock and for the soils derived from the rock.

Serpentine Rock

Traditional teaching in geology tells us that rocks can be divided into three major categories—igneous, metamorphic, and sedimentary. The igneous rocks, formed by cooling from molten rock called magma, are broadly classified as mafic or silicic depending mainly on the amount of magnesium and iron or silica present. Serpentine is called an ultramafic rock because of the presence of unusually large amounts of magnesium and iron. Igneous rocks, particularly those that originate within the earth's crust, above the mantle, contain small but significant amounts of
calcium, sodium, and potassium, along with small amounts of iron and magnesium. Serpentine, however, has only minute amounts of calcium, sodium and potassium, but unusually large amounts of nickel, cobalt, and chromium.

Deep in the mantle of the earth, the igneous precursor of serpentine, peridotite, is composed largely of two minerals, hard, greenish magnesium silicate olivine, and pyroxene, both of which contain large percentages of iron. Peridotite has nearly the same chemical composition as serpentine, namely a high magnesium and iron content. Thus peridotite and serpentine are both included in the category of ultramafic rocks. As presently understood, serpentine is a metamorphic product of peridotite in which water molecules are chemically incorporated into the rock matrix by a recrystallization process. Serpentinization is still poorly understood; however, it is known that
it can take place at temperatures less than 500°C down to ambient temperatures, as long as water is present.

This metamorphic process produces the following serpentine minerals depending on the temperature: chrysotile and lizardite (low temperature) or antigorite (high temperature). Serpentinization is a unique recrystallization process in that only water is added and the original ratios of the elements remain similar in the metamorphic serpentine as in parental peridotite. In spring waters associated with serpentinizing peridotites we find calcium-rich waters with pH of 11.5 that indicate that calcium is expelled during the process of serpentinization, but this represents less than 1% of the total rock. What is crucial for the weathered product of ultramafics, the soil, is the very low amounts of calcium and potassium, so essential for plant growth, and the excessive and potentially-toxic amounts of magnesium, nickel, and cobalt. Many exposures of these rocks on the earth's surface consist of a mixture of peridotite and serpentine though there is generally more serpentine. Because of their similar unusual chemical composition, these rock types yield similar unusual soils, and similar limitations to plants.

Geologists have debated over the poorly understood complex of ultramafic rocks for years. In recent years the revolutionary new plate tectonic theory has provided clues and perhaps answers as to how the ultramafic rocks, peridotite and serpentine, are transported to the earth's surface. In this theory giant plates of the earth's crust float over the hot plastic mantle of the earth. Mafic and ultramafic material forms oceanic plates which migrate toward continental plates where one crustal plate descends beneath another where they are recycled in the magma core. Occasionally a part of the oceanic crust rides up over the leading edge of the continental plate exposing the ultramafic rock in the form of peridotite and serpentine. This convergence and overlapping of oceanic crust and mantle is common in mountain-building zones and is part of the formation of most mountain belts.

The serpentine masses in California were probably first exposed at the surface during the middle Mesozoic (ca. 150 million years ago) as seen in the sedimentary record; some exposures may be as late as the last Ice Ages (Pleistocene). Western California under the influence of plate movements, as for example in the San Andreas fault, has been the site for redistribution of the serpentine exposures and in many cases on-going tectonic activity has been so intense that soil has not been able to develop on the surface of some exposures. On the other hand some of the serpentine's of the Klamath mountains and the Sierra foothill belt have deep, well-developed soil profiles where they have not been deformed by recent tectonic activity.
Distribution of Serpentine

From Oregon south to Santa Barbara and Tulare counties, eleven hundred square miles of serpentine and related rocks are distributed in numerous masses with discontinuous and northwest-trending orientation. There are gaps in its distribution with essentially no outcrops in southern California (a tiny outcrop in the Santa Ana Mountains), none in the high Sierra or their eastern flanks, and none in the Great Valley or desert areas. Serpentine is a familiar sight in the South and North Coast ranges, the Klamath-Siskiyou country and the lower western slopes of the Sierra.

A quick tour of California from north to south highlights the most important areas of serpentine or ultramafic rock occurrence. The Weed sheet of the state geologic maps covering the Klamath-Siskiyou area in northern California shows the most massive and extensive outcrops in the state. There is nearly every kind of terrain and exposure in northwestern California from arid to mesic, from the low elevations at Gasquet in Del Norte County to the summits of the higher peaks at Mt. Eddy, Preston Peak and Scott Mountain. Any west-east traverse of this complex mountain system provides the traveller with views of great expanses of sparse forest or chaparral clinging soils to the peridotites and serpentines. Serpentine outcrops are numerous on the east and west slopes of the Yolla Bolly Mountains and all the way from arid lowlands, bordering the Sacramento Valley across the summits of peaks like Dubakella, Snow, and Red mountains to the redwood belt where islands of serpentine intrude into the forest.

Serpentine occurs in many places in the North Coast Ranges, including Lake, Tehama, Mendocino, and Trinity counties, and supports some of the most unique flora tolerant to the substrate. A procession of nearly unbroken sequences of outcrops occurs from the Oregon border down to the Lake County side of the Mayacamas Mountains, the country east of Middletown, and around Clear Lake.

Although we think of the Sierra Nevada as a great granitic island perched over desert and the Great Valley, serpentine intrudes into many places along the western flanks of the range. Many a foothill of the Sierra contains serpentine, though much of it is covered in northern Plumas County by more recent lava flows from Mt. Lassen. Outstanding serpentine localities in the Sierra Nevada include the rich displays in the Feather River country, and the Coulterville-Bagby area of Tuolumne County near Chinese Camp. Major outcrops continue to the southeast in Tulare and Fresno counties.

North of San Francisco there are several well known serpentine areas including those in northern Napa County around Mount St. Helena; in Sonoma County, the Cedars area of upper Austin Creek, and Occidental; and in Marin County outstanding are the sites on Tiburon Peninsula, particularly at Ring Mountain, on Angel Island and in Mount Tamalpais State Park. Notable outcrops in and around San Francisco include the Presidio, and sites in the Oakland-Berkeley Hills, in San Jose, and in the Crystal Springs Reservoir area in San Mateo County.

To the south and southwest the Santa Lucia Mountains and the Diablo Range have serpentine outcrops; however, the most impressive ones are in the Inner South Coast Ranges of San Benito County, particularly the New Idria barrens and San Benito Peak. There are well-known serpentine exposures near the coast in San Luis Obispo County at the Cuesta Ridge and in the hills of San Luis Obispo. And to the south the last significant serpentine outcrops occur in the Figueroa mountain area of the San Rafael Mountains in Santa Barbara County.
Serpentine soils react to weathering primarily by going into solution. Deeper serpentine soils are punky, pigmented residuals of iron oxides released during intense weathering of serpentine rock. Often soils derived from other rock types will wash down and cover serpentine rock, providing a mistaken impression of a thick serpentine soil or of vegetative growth on serpentine soil and rock.

Considerable research has been done on the inability of serpentine soils to supply adequate nutrients for normal plant growth. Several University of California scientists, Hans Jenny, James Vlamis, Perry Stout, C.M. Johnson and Richard B. Walker, all attributed the infertility of serpentine soil for plants to an imbalance between calcium and magnesium. Levels of nitrogen, phosphate and potassium (NPK), and the essential micronutrient molybdenum are low in most serpentine soils, while some can contain toxic amounts of nickel. When grown on serpentine soils, cultivated plants are depressed in growth and exhibit other deficiency symptoms corrected only with massive, repeated additions of gypsum (CaSO₄) and NPK.

So inhospitable a medium for plant growth has not stopped colonization of serpentine by some of the California flora. Species from many different plant families are able to tolerate the unusual chemical and physical qualities of these soils. Explanations for the mechanisms that provide this inherited tolerance of serpentine plants are only partially satisfactory. We now know that serpentine tolerant species are able to extract calcium and other essential elements in low supply in the soil better than plants not found on serpentines. Hans Jenny reminds us that the complex relationships between plants and soil involves the interplay of many factors. For the network of factors that foster serpentine vegetation, Jenny has coined the term "serpentine syndrome," reminding us of the many linked strands of plant-soil interactions. In this concept the exceptional chemical composition of serpentine soil (low calcium, high magnesium, heavy metals, etc.) sets in motion a biological response that results in a low turnover of nitrogen and phosphorus. The low nutrient status and the cation imbalances result in a sparse plant cover and in turn a high heat budget at ground level. High temperature effects and moisture stress further check plant growth and survival. Since serpentine soils are usually derived from rock outcrops on steep or irregular topography, the habitats are often of unstable talus, adding a further stressful challenge to plants.

Plant Responses to Serpentine

Plants have a characteristic growth form on serpentine soils. Woody plants are either stunted or compact, and herbaceous species are often dwarfed. Leaves are
reduced in size, tough and narrow, with a glaucous "bloom" or pubescence, and frequently are purplish in color (anthocyanous).

Plants seem to accommodate to the exceptional chemistry of serpentines either by rejecting undesirable elements, or by accumulating them harmlessly in certain tissues. This individualistic reaction to serpentine is nicely illustrated in a recent study on *Streptanthus* species, in the mustard family. One serpentine endemic, *S. polygaloides*, was found to be a hyperaccumulator; that is, it can take up amounts of nickel in excess of 1000 parts per million. Yet other serpentine endemic species of *Streptanthus* are not hyperaccumulators.

Plants can be categorized in terms of degree of fidelity or restriction to serpentine soils. The narrow endemics, which grow only on serpentine, are perhaps the most intriguing. In a second group "indicator" species are those that may occur on other soil types elsewhere but are locally or regionally faithful to serpentine. A third category, the indifferent species, are those that occur both on and off serpentine, sometimes called "soil wandering" (or *bodenvag*, in German). In setting up these three discrete groups I am compelled to confess to a misgiving about precision, so well stated by G. Ledyard Stebbins: "The only 'law' that holds without exception in biology is that exceptions exist for every 'law'.'"

It is known that species have different responses to different environments throughout their range of distribution, and that these different responses are usually inherited. Such differentiation within a species was elegantly demonstrated in California by the Carnegie Institution of Washington group at Stanford when species like *Achillea lanulosa*, *Potentilla glandulosa* and *Zauschneria* spp. were found to have more or less distinct races in their distributions from sea-level to high altitudes. Later on, I found that serpentine soil, like climate, has a selective effect on populations within an "indifferent" species. Races within a species had evolved that were either tolerant or intolerant to serpentine. While many herbaceous species of an indifferent (*bodenvag*) nature probably have genetic differences in their ability to tolerate serpentine, not all species demonstrate genetic differences. Some woody species do not evolve into genetically different races; for example, Dr. Jim Griffin could find no such racial character for Digger pine (*Pinus sabiniana*). It is just possible that some indifferent species may have what Dr. Herbert Baker, Professor of Botany at the University of California, Berkeley, calls a "general-purpose genotype," a wide range of growth response with little genetic variation.

**Serpentine Vegetation**

Often, ecologists are preoccupied with total plant cover and less concerned about the kinds of plants making up that vegetation, a kind of reversal of the
old adage about not seeing the forest for the trees. It is hard to avoid taking some note of the species that make up a serpentine landscape, for, so often, the dominant species are serpentine endemics. In California, serpentine soils effect changes in four major types of vegetation: conifer, oak woodland, grassland, and chaparral. When serpentine crops out in any of these vegetation types, the effect is usually dramatic. Number and quality of trees per acre is reduced, and species distribution is different from that in the surrounding non-serpentine forest. In the North Coast Ranges, a high-yield mixed conifer forest gives way to open stands of jeffrey pine and incense cedar. Elsewhere, conifer forests on normal soils may be replaced by chaparrall on serpentine soils often with serpentine indicator or endemic shrubs such as Quercus durata, Ceanothus jepsonii and Garrya condonii.

In other situations, typical mesic forest is replaced by Digger pine, cypress, and chaparrall woodland with Sargent cypress, Cupressus sargentii and MacNab’s cypress, C. macnabiana essentially restricted to serpentine soil. The finest displays of Sargent cypress on serpentine are in the upper east Austin Creek area of northern Sonoma County, where the pure stands are locally known as “The Cedars.” Oak woodland on nearby non-serpentine soils is replaced by chaparrall, usually dominated by serpentine shrub species. The country around Middletown, parts of Napa and Lake counties, exemplifies well this mosaic of contrasting vegetation types. On serpentine, grassland becomes sparse, with a substantial component of indicator or endemic species. The grasslands on the serpentine outcrops at Jasper Ridge, part of the Stanford University reserve system, and on Tiburon Peninsula in Marin County provide good examples. The serpentine grassland on Tiburon Peninsula boasts three local endemics, Streptanthus niger, Calochortus tiburonensis and Castilleja neglecta.

A good source of descriptions of vegetation on serpentine is the indispensable guide to California vegetation by Barbour and Major (Terrestrial Vegetation of California). I paraphrase their description of serpentine chaparrall as follows. Serpentine chaparrall is an open, low type associated with serpentine soils from San Luis Obispo County northward through the Coast Ranges and foothills of the northern Sierra Nevada. The shrubs are characterized by apparent “xeromorphism” (plant parts adapted to drought stress) and dwarfed stature resulting from reduced productivity and growth. . . . The dominant shrubs are chamise (Adenostoma fasciculatum) and toyon (Heteromeles arbutifolia), but noteworthy are several localized endemic shrub species, white-leaf manzanita (Arctostaphylos viscida), Jepson’s ceanothus (Ceanothus jepsonii), Sargent cypress (Cupressus sargentii), Congdon’s silk-tassel (Garrya condonii), and leather oak (Quercus durata), which are unmistakable “indicator species” because of their typical restriction to, and numerical dominance on, serpentine soils. Serpentine chaparrall may be associated with foothill woodland Digger pine (Pinus sabinianna) or montane coniferous forest Jeffrey pine (Pinus jeffreyi), yellow pine (P. ponderosa), knobcone pine (P. attenuata), Douglas-fir (Pseudotsuga menziesii) as an understory. The thousands of hectares of serpentine chaparrall in the North Coast Ranges are easily distinguished from the oak-grasslands on hills of non-serpentine origin.

A classic study of Robert Whittaker on vegetation of the Siskiyou provides critical comparisons of vegetation types on contrasting rock types, from ultramafic to acid igneous. Whittaker found that the gradient from wet to dry on any particular kind of rock effects changes in vegetation. For serpentine, mesic forest of Port Orford cedar (Chamaecyparis lawsoniana) and western white pine (Pinus monticola) nearest water or in ravines shifts to xeric chaparrall at the dry ridgetop, usually with indicator shrubs like tanbark oak (Lithocarpus densiflorus var. echinoides), huckleberry oak (Quercus vaccinifolia), dwarf silk-tassel (Garrya buxifolia) and shrubby California bay (Umbellularia californica).

Gray’s study of vegetation along a sequence of changing rock types tells of the sharp break in community structure and composition. Gray looked at the elevational gradient and vegetation change on Snow Mountain in Lake County. Chaparrall woodland on serpentine at lower elevations abruptly gives way to montane coniferous forest on non-serpentine soils at higher elevations. The sharp break between the vegetation types is mirrored by the changes in species composition. Along the Snow Mountain transect, the common woody plants on serpentine soils are Digger pine, buck brush (Ceanothus cuneatus), leather oak, and chamise; on nearby non-serpentine substrates, common woody species are yellow pine, canyon oak (Quercus chrysolepis), hoary manzanita (Arctostaphylos canescens), sugar pine (Pinus lambertiana) and white fir (Abies concolor).

Ed’s note: The author would like to acknowledge the contribution of Dr. R. Coleman of Stanford University to the section on geology in this article. The second article in the series will deal with the variety of plants, some narrowly endemic, found on serpentine; the possible origins of our serpentine flora; and the status of conservation of serpentine plant life. Readers may be interested to know that the California Native Plant Society recently provided Dr. Kruckeberg with a grant to assist in the preparation of his monograph, California Serpentine Plants, soon to be published by the University of California Press.
Correcting Serpentine Soils
Trenching In Gypsum Provides Promising Results

By Pat Summers
Contributing Editor

High magnesium soils have not been a vineyard problem until recently. Viticulture text books address magnesium deficiency, but the black sticky serpentine soils, so high in magnesium, were simply avoided by viticulturists until recent vineyard expansion suggested a need to at least consider the possibility of correction.

In 1978 a University of California team started work with Andy Cangemi at Pope Valley Vineyards, Napa County, Calif., to see if it was possible to rectify a high magnesium problem. The experiment is not yet finished, but signs indicate this may be a problem with a solution.

Pope Valley Vineyards has a potential for about 2,000 planted vineyard acres. Only 700 acres have been developed so far. When it came time to develop one 250-acre block it was evident there was a problem.

A good sized "road" of serpentine soil wandered down through the block. Though the total involved soil measured only 2½ acres, it cut a swath covering about 125 rows by 50 vines, like a river through the block. Left uncorrected, it would have made management of the block a major headache. Cangemi could have chosen to isolate and plant around it, or farm an uneven vineyard.

University of California soil scientists agreed to run a test at the vineyard. Roland D. Meyer, soils specialist in plant nutrition headed up the group which included William E. Wildman, soil structure specialist, Amand Kasimatis, viticulture specialist and Keith Bowers, farm advisor for Napa County.

The soils were analyzed. The surface pH was near neutral and rose to a pH of 8 at the 30 to 36-inch depth. While normal soils have a ratio of one part magnesium to four parts calcium, this soil measured the reverse, the magnesium was 3.9 to 6.3 and the calcium one.

Meyer outlined a field trial that, using gypsum, might reverse the calcium/magnesium balance. Gypsum has been used for this purpose, in the past, but never in exactly this manner. Meyer's new concept was to apply gypsum only to the vine row. A trench two feet wide and by three feet deep was dug. This was deemed an adequate space for root development. Four treatments were used. First a control, which was trench only, and no gypsum. The gyp applications were 1.15 tons per acre, 11.5 tons per acre, and 115 tons per acre. The amounts are given in tons per acre, but because only the vine rows were actually treated, the total amount applied is only about a third that amount for each acre, and is concentrated in the vine growth area. That would make the heaviest application 115 tons per vineyard acre. The gypsum application was made Dec. 4, 1978.

The gypsum was applied by pouring it along the outlined rows. A trencher moved down the vineyard row, and as the dirt was excavated, it was turned over with the gypsum and placed beside the row. After a few months it was back into the trench, thus mixing the gypsum and dirt mechanically. The vineyard was planted the following spring.

The results so far show that all treatments produced results. According to Bowers, just trenching alone improved the apparent vigor of the plant. As Meyer wrote in a paper prepared for the Napa County Viticulture Technical group,

"The results of both the soil and plant tissue samples agree very closely in that the first three treatments are similar but quite different than treatment four."

The soil showed significant improvement with the highest application. Soil samples revealed that pH changed very little. The EC₆ increased by the 115 tons per acre rate. Exchangeable calcium and magnesium as well as the calcium to magnesium ratio changed very little from the previous year. The greater solubility of magnesium relative to calcium and magnesium.

The magnitude of the change in sodium concentration between treatments was large, but levels were in general, relatively small as compared to calcium and magnesium.

"The results of both the soil and plant tissue samples agree very closely in that the first three treatments are similar but quite different than treatment four."

"Observations of plant growth were, however, somewhat different than the soil and plant tissue analysis. Treatments one and two had similar but substantially less growth than treatments three and four, which were quite similar to each other. Although measurements were not taken to quantify this growth difference, photographs indicate the very dramatic contrast. This points out a dilemma with the use of plant and soil analyses which do not correlate well with differences in plant growth," Meyer said.

The pruning weight data and crop yields were more telling. In 1981 the pruning weight for control was 48.3 grams per vine. The 1.15 tons per acre was 61.0, 11.5 tons per acre it increased to 79.0 and the 115 tons per acre was 219.4 grams per acre. The Aug. 31, 1984, harvest underscored the rest. The control harvested at 23.7 degrees Brix yielded 3.6 tons. The 1.15 tons per acre at 23.8 degrees Brix gave 3.3, the 11.5 tons per acre at 24.0 degrees Brix gave 3.7 and the 115 tons per acre yield at 23.0 degrees Brix was near double, 5.8 tons.

Figures for 1984 were not yet available, but the 1983 figures showed that the total acids varied from a low of .66 for control to .70 for 11.5 tons per acre. The pH ranged from a low of 3.68 for the 115 tons per acre to a high of 3.70 for the control.

Of course the purpose of the exercise was to see if it could be made to work at all and it does look like it can. A question to be answered is what happens when and if those roots escape the trenched area. Another problem, 115 tons per acre is a lot of material to be applied. Would 50 work? Would 25 work? Cangemi is working to see if those roots escape the trenched area, less labor intensive method, on both sides of an established vine, will work. He indicated that at this time the method shows promise.
Management of Vineyard Soils with Adverse Chemical Characteristics:
Alkalinity, Salinity, Sodicity and High Chloride

By Stan Grant, Viticulturist

Occurrence in California
The occurrence of alkali soils is mainly a function of parent material from which they formed. Their persistence is mainly a function of climate. Alkali soils occur where rainfall is insufficient to leach carbonates. The Cajon, Calhi, Chino, Hilmar, Panoche and San Emigido series include areas of alkaline soils.
Saline, sodic and high chloride soils occur mainly in areas of poor drainage, areas irrigated by saline water (water SAR greater than 8.0), and areas affected by salt water intrusion (e.g., western portions of the Sacramento - San Joaquin Delta). Soil series that include areas of saline, sodic and high chloride soils include the Cajon, Chino, Columbia, Dinuba, Foster, Fresno, Hespeira, Hilmar, Marqueterie, Orestimba, Pachappa, Pescadero, and Solano.

Effects on Vines and Soils
Alkaline soils cause slow vine growth primarily due to the reduced availability of mineral nutrients. Zinc deficiency is most commonly associated with alkaline soils in California. Iron deficiency also occurs and is common in southern San Joaquin County, northeast of French Camp. Phosphorus, manganese and copper may also be low in alkaline soils.

The effects of high soil salinity are stunted growth, particularly growth of foliage and reduced fruit yield. These effects are due to the decreased ability of vines to acquire water (i.e. osmotic effects) and ion toxicities (i.e. specific ion effects).

Soil sodicity causes soil aggregates to breakdown and disperse causing surface crusts to form. As a result, water movement into and within the soil is restricted. In addition to effects on soils, high soil sodium can cause toxicity in grapevines. This occurs most commonly during hot weather while vines are transpiring large amounts of water. Sodium is taken up with the soil water and it moves as far as possible within the vines - to the margins of the leaves. At the margins the sodium accumulates and causes death of leaf tissue. This normally occurs when leaf sodium concentrations are greater than 0.25%.

High soil chloride causes vine foliage to become dark green. Chloride moves with soil water and accumulates in leaves in a manner similar to sodium.

Table 1. Definitions for 4 adverse soil chemical conditions

<table>
<thead>
<tr>
<th>Soil Condition</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Alkaline</td>
<td>pH &gt; 7.5 to 8.0</td>
</tr>
<tr>
<td>Saline</td>
<td>EC &gt; 2.5 to 4.0 mmhos/cm</td>
</tr>
<tr>
<td>Sodic</td>
<td>ESP &gt; 10%</td>
</tr>
<tr>
<td>High Sodium</td>
<td>Na &gt; 30 meq/l or 690 ppm</td>
</tr>
<tr>
<td>High Chloride</td>
<td>Cl &gt; 10 meq/l or 350 ppm</td>
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</table>

High soil sodium (Na), regardless of calcium or magnesium, can cause reduced vine growth and productivity. The concentration at which vines become affected is about 30 meq/l or 690 ppm. (These are the same sodium concentrations given in different units).

High soil chloride (Cl) will also cause reduced vine growth and productivity. Soils with concentrations greater than 10 meq/l or 350 ppm are excessively high in chloride.

These conditions - alkalinity, high salinity, high sodicity and high chloride - may occur alone. However, it is more common for them to occur in combination. Saline - alkaline and saline - sodic soils are examples.

Some soils have chemical characteristics that adversely affect vine growth and fruit production. Four such soils that occur in the San Joaquin Valley are alkaline, saline, sodic and high chloride soils (table 1). Management of these soils in vineyards may be difficult and expensive.

Alkaline soils are soils of high pH (pH > 7.5 to 8). These soils normally contain large quantities of carbonates which buffer the soil’s pH, that is, they act to maintain high soil pH.

Salinity refers to soil’s total salt concentration. A saline soil has a high salt concentration. The principle ions that contribute to soil salinity are calcium, magnesium, sodium, sulfate, bicarbonate and chloride. These ions are charged and have the ability to conduct electricity. This ability allows them to be easily measured. A saline soil with an electrical conductivity (EC) greater than 4.0 mmhos/cm or ds/m will greatly affect mature vines, although some yield reduction will occur at EC’s as low as 2.0 mmhos/cm. Soils with an EC > 1.6 mmhos/cm will affect young grapevines.
Chloride will cause marginal leaf burn when leaf concentrations are greater than 0.50%.

Young vines are much more sensitive to the toxic effects of high soil salinity, sodium and chloride than mature vines because they have much less biomass in which to distribute ions and therefore, ions accumulate to toxic levels much more rapidly.

Management:

Soil Modification

The most commonly used approach for managing these problem soils is soil modification, usually by applying soil amendments, to make the soil environment suitable for growth.

The pH of alkali soils may be lowered with sulfur, sulfuric acid, or other acidifying agents applied to the soil. Ideally, the amendments should be incorporated as deeply as needed to affect the alkaline portion of the soil. In some instances this is not possible, but the amendment may be incorporated into the upper portion of the root zone.

The amount of amendment required to lower soil pH is influenced by the initial soil pH, texture, and carbonate concentration (table 2). The higher the initial pH the greater quantity of amendment needed.

Acidifying fertilizers (e.g., urea and ammonium) and acids injected to prevent chemical clogging of drip emitters also act to lower the pH of alkaline soils, but only in the soil volume wetted by the emitters. Anhydrous and aqua ammonia fertilizers will increase a soil's pH.

Reducing soils' salts, sodium and chloride requires adequate drainage, leaching and maintenance of soil moisture with water low in salts, sodium and chloride. Leaching is accomplished by applying water in excess of what is required for vine use during each growing season. The amount of excess water (in percent) required for leaching can be calculated using the formula for Leaching Requirement (LR) developed by the USDA.

\[
LR = \frac{EC_{water}}{5EC_{se} - EC_{water}}
\]

\(EC_{water}\) = EC of the irrigation water. 
\(EC_{se}\) = target soil EC for the root zone.

The value of \(EC_{se}\) is selected from table 3. Obviously a small yield reduction is desirable and therefore, the target \(EC_{se}\) is usually between 1.5 and 2.0. Adequate drainage is essential for leaching to be effective.

Prior to leaching, sodic soils normally receive an application of an amendment that displaces sodium from the soil directly, acidifies the soil, or does both. The amendment is incorporated as deeply as possible or as deeply as needed.

| Target EC<sub>se</sub> for Calculating leaching requirement and association grape yield reductions |
|------------------|------------------|
| Target EC<sub>se</sub> (mmhos/cm) | Yield Reduction (96%) |
| 1.5 | 0 |
| 2.0 | 5 |
| 2.5 | 10 |
| 3.0 | 15 |
| 3.5 | 20 |
| 4.0 | 25 |

| Table 4. Soil amendments for lowering soil sodium and their effectiveness relative to sulfur |
|------------------|------------------|
| Amendment | Tons equal to 1 ton sulfur | lb./acre to replace 1 meq/1 sodium |
| Sulfur | 1.00 | 320 |
| Gypsum | 5.38 | 1720 |
| Potassium thiosulfate | 5.87 | 1880 |
| Ammonium polysulfide | 1.59 | 510 |

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Gypsum is frequently used to amend sodic soils. It serves as a source of calcium. Soils retain calcium more readily than they do sodium. This characteristic of calcium allows it to displace sodium from the soil. Application rates of gypsum are usually between 1 and 4 tons/acre and are rarely greater than 10 tons/acre. The amount of gypsum required to replace soil sodium can be estimated with a laboratory test called the Gypsum Requirement. Gypsum may be either applied directly to the soil or with irrigation water.

If sodic soil contains high levels of carbonates, calcium is already present in the soil and may be released from the carbonates with the addition of sulfur or other acidifying amendments. Sulfur is more effective than gypsum in reducing soil sodium (table 4). An agricultural laboratory can determine if carbonates are present in the soil.

Amendments that both displace sodium directly and acidify the soil include potassium thiosulfate and ammonium polysulfide.

Management:

Tolerant Rootstocks

Tolerant rootstocks are another important component of managing alkaline, saline, sodic, and high chloride soils. Tolerant rootstocks will rarely substitute for modification of these problem soils, but they lower the amount of amendments required.

To my knowledge, no studies on rootstock tolerance to soil alkalinity have been reported in the United States. However, in France many soils contain high levels of lime and vines grown in these soils frequently suffer from iron deficiency. Given that lime is another name for calcium carbonate, it seems highly probable that these soils are alkaline. Rootstocks that have been shown to tolerate high lime soils in France include 5BB, 420A, and 140Ru. Rootstocks that do poorly in these soils include 3309, 44-53 and 101-14.

Salt Creek, Dogridge, 101-14 and 140Ru are tolerant of saline soils. In southern France, 1616 is used successfully on saline soils. Own rooted vines and vines on Freedom, 420, and SO4 poorly adapt to saline soils.

Rootstocks are practically the same. Salt Creek, Schwarzmann, SO4, 5BB, 99R, St. George and 101-14 are well adapted to high chloride soils. Own rooted vines are poorly adapted to high chloride soils.

Rootstock Summary:

1. 140Ru is well adapted to alkaline and saline soils.
2. 101-14 is well adapted to saline and high chloride soils, but poorly adapted to alkaline soils.
3. 420 is well adapted to alkaline soils, but poorly adapted to saline soils. 420A is a low vigor rootstock and may not be appropriate for production-oriented vineyards in the San Joaquin Valley.
4. Salt Creek and Schwarzmann (and probably 99R) are well adapted to saline, high sodium and high chloride soils.
5. Avoid own rooted vines and Freedom for use in saline, high sodium and high chloride soils.

Summary

Management of alkaline, saline, sodic and high chloride vineyard soils normally involves multiple viticulture practices including the use of tolerant rootstocks, soil amendments and thoughtfully applied irrigations. The combination of tolerant rootstocks and careful irrigation management may be sufficient when these adverse chemical conditions are very mild. Both practices are a part of normal vineyard operations, and, therefore, require little additional expense. Drainage improvement prior to planting may be needed, which adds greatly to development costs.

More severe soil chemical conditions require soil amendments. Soil amendments have to be reapplied when their effects diminish and chemical conditions worsen. Soil testing at regular intervals will reveal if and when reapplication is necessary. Management of extreme conditions may not be practical or economically feasible.

Vines growing in soil with adverse chemical characteristics are frequently smaller than normal. Spacing vines closer in the row will compensate for smaller vine size and maximize fruit production.
Soil Compaction:

Soil compaction is a problem that is often overlooked when attempting to identify causes of reduced production. Compaction is simply the arrangement of soil particles to create a density that is high enough to limit root growth, soil moisture, and aeration. A compacted condition can be naturally occurring; however, management is the cause of most compaction. Larger equipment, tillage, and early planting are thought to be reasons for soil compaction. Rotation without perennial crops could also add to compaction. It should be noted that the use of anhydrous ammonia has not been linked with increasing soil compaction.

Compaction can have many effects on the soil. The soil structure is an equilibrium of solids such as sands, silts, clays, and organic matter along with liquids and gases. The soil is comprised of 50% solids, and 50% air and water pore spaces. Compaction will cause the aggregates to be realigned, and the pore spaces are reduced. The larger pore spaces will be reduced first into smaller pores; however, the equilibrium of air and water is disrupted and most of the air is removed from the pore spaces and the water is retained. This leads to slower water infiltration, poor drainage, and aeration. These factors will limit root growth and nutrient uptake.

Soils that are made up of equal mixtures of sands, silts, and clays can compact easier than a more uniform soil made up of one type of particle. Figure 1 indicates the potential of compaction on two different soil types.

The moisture in the soil has the greatest influence on compaction. When field capacity is reached, compaction will occur at its maximum. Soil particles are easily arranged when there is moisture present.

The soil's bulk density will also be changed from compaction. Bulk density can be defined as the weight of a unit volume of dry soil that includes both the solids and pore spaces. Bulk density will generally increase as soils become compacted.

The amount of organic matter a soil contains will affect the soil's capability to be compacted. Generally, the higher the organic matter, the less the soil will compact. The soil aggregate will be coarser, which will allow for better movement of moisture through larger pore spaces. Also, the density of organic matter is less than the soil, which means it will not compact as easily. Figure 2 indicates the inverse relationship between soil organic matter and bulk density.

Soil Symptoms

Soil symptoms can be seen in the field when compaction occurs. The following conditions can be indications of compaction:
- Surface crusting is the deterioration of soil structure on the soil surface. This can often occur from too much soil preparation. Crop emergence will be a problem.
- Erosion may become more severe. Since infiltration is reduced, there will be greater soil runoff. Erosion will increase compaction since the organic matter decreases as the subsoil becomes exposed.
Standing water is also a symptom of compaction. The porosity is decreased from compaction, which reduces infiltration. Infiltration can be reduced by up to 16 times when these pore spaces are compacted. Herbicide problems can also occur when a soil is compacted. The movement of the herbicide into the soil can be slowed since porosity is reduced. There can also be higher rates of carryover with herbicides that rely on microbial activity for breakdown. The efficiency of the microbes under compacted conditions is reduced considerably.

Plant Symptoms

The condition of the plants will show the effects of compaction and soil symptoms described earlier. There are many plant symptoms of compaction. These can be seen in both the above-ground portion and root system.

Slow emergence will often occur when soils are compacted. The surface crust will stress the young seedlings and delay emergence. The soils may also be wet and cool due to poor internal drainage from compaction. This will lead to disease associated with the seed.

Uneven growth early in the season will also be a symptom of compaction. This is also due to poor aeration and reduced nutrient uptake when soils are wet and cool. This uneven growth will often continue through the season. Figure 3 indicates the difference in plant height at various rates of compaction.

Purple color in corn plants is also a symptom of compaction. Poor internal drainage will reduce production of sugars in the plant. When this occurs, the plant will begin to produce a more prominent red pigment. Certain hybrids may tend to show this symptom more often.

Rooting patterns are also affected by compaction. Often, a fibrous root system will grow horizontally along a compacted layer. This root system will generally be shallower, and moisture stress can be a problem under dry conditions. Lodging can also be a symptom when compaction is present. The uptake of the potassium will often be reduced in compacted soils. Research has shown an increased rate of lodging as the potassium decreases in relationship to the nitrogen level.

Measuring soil compaction can be very difficult since there are many parameters that will affect the compaction. A soil penetrometer can be used to measure compaction in the field. This is the measurement of pressure required to move the tip of a shaft through the soil at a constant rate. The moisture content of the soil will have an effect on compaction readings. As the soil moisture increases, the amount of pressure required to move through the soil will be reduced. Figure 4 indicates the lower amount of pressure required as the soil moisture increases at various bulk densities.

To determine the actual amount of compaction with a penetrometer, additional analyses such as soil moisture and bulk density must be performed. However, a penetrometer can be used to compare areas in a field that would be similar in soil moisture and bulk density for compaction. Crops may be affected differently in terms of root restriction and crop yield. Figure 5 shows an approximate reduction curve for most fibrous root crops such as corn and small grains. However, this will shift, depending on the rooting nature of various crops.

Compaction can reduce crop yields as shown in Figure 6. Corn yields were reduced significantly in compacted areas in comparison with noncompacted fields.

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Soil Compaction
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Solutions to Compaction Problems
Soil compaction can be minimized once the causes of compaction have been determined. The following are ways to minimize compaction:

- The types of tillage equipment and number of passes should be examined for sources of potential compaction.
- Disc harrows along with large tractors and combines will cause compaction.
- Flotation tires will allow for the compacted area to spread horizontally instead of vertically, and can be broken up much easier.
- Freezing and thawing will break up compaction on the surface. However, there would be very little effect on deep subsoil compaction. Subsoiling can be used to correct these deeper layers, although for the best results the ground should be fairly dry.

The addition of organic matter can also reduce compaction, so crop rotation is essential.

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SPECIAL NOTICE TO OUR READERS
Recently, there have been changes in the responsibilities within the technical support groups of Unocal Chemicals Division, Nitrogen group. Dr. Dale Rush, who initiated the Solution Sheet New Series, and was technical editor and frequent author, has been assigned to Unocal's new product development program. The responsibilities of the Solution Sheet content and technical editing have been taken over by Dr. Steven Petrie of Agronomy Services, and Mr. Jim Saake, Manager of Domestic Marketing.

Any correspondence regarding the Solution Sheet should continue to be directed towards Patrice Moore, editor.

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