4.0 GEOLOGY AND SOILS

The following sections describe the geologic setting, impacts, and mitigation recommendations. They are abstracted from the *Geologic*, *Hydrologic, and Hydrogeologic Technical Appendix for Draft EIR, Bonny Doon Quarry Proposed Expansion* (Nolan Associates, 2007), referred to hereafter as the Geology and Hydrology Technical Appendix (Appendix F).

The geologic environmental setting also provides necessary background information for the analysis of hydrologic and hydrogeologic conditions at the project site that are discussed in Hydrology, Section 5.0.

4.1 ENVIRONMENTAL SETTING

Because of its importance in understanding the hydrology and hydrogeology of the project in a regional context, the area evaluated for the geologic portion of the environmental impact analysis extended well beyond the boundaries of the quarry and proposed Boundary Expansion Area. The following discussion will therefore refer to the geologic/hydrologic study area, bounded on the north by Ice Cream Grade, on the west by Bonny Doon and Pine Flat Roads, on the east by Laguna Creek, and on the south by an east-west line drawn approximately through Liddell Spring (Figure 16, Geologic/Hydrologic Study Area Topographic Index Map).

The Environmental Setting for Soils and Geology is based on:

- a review of available geologic literature describing the geologic/hydrologic study area and previous geologic and geotechnical consulting reports, maps, and other documents prepared for the quarry;
- inspection of stereographic aerial photos ranging in age from the 1930’s to the present;
- field collection of geologic information in the quarry and throughout the geologic/hydrologic study area; and
- review of geologic information from drilling records in the area.

The information obtained from these sources was used to develop an updated geologic map of the geologic/hydrologic study area to serve as a basis for the geologic, geotechnical, and hydrological evaluation of the project impacts. Regional and local scale sources of geologic information included Brabb (1997), Clark (1981), Leo (1967), and Wisser and Cox (1958).

Portions of the following discussion of the geologic setting refer to the geologic time scale. A summary of the geologic time scale is included as Table 4-1 for reference.

Table 4-1
Geologic Time Scale

Eon	Era	Period	Epoch	Time Span (Ma*)	Duration (My**)
Phanerozoic	Cenozoic	Quaternary	Holocene	–0.01	0.01
			Pleistocene	0.01–1.6	1.59
		Tertiary	Pliocene	1.6–5.3	3.7
			Miocene	5.3–23.7	18.4
			Oligocene	23.7–36.6	12.9
			Eocene	36.6–57.8	21.2
			Paleocene	57.8–65	7.2
	Mesozoic	Cretaceous		65–140	75
		Jurassic		140–205	65
		Triassic		205–250	45
	Paleozoic	Permian		250–290	40
		Carboniferous		290–355	65
		Devonian		355–410	55
		Silurian		410–438	28
		Ordovician		438–510	72
		Cambrian		510–540	30

* millions of years before present
** millions of years
Source: Nolan Associates, 2007.

4.1.1 Physiographic Setting

The Bonny Doon Limestone Quarry site is situated on the southwestern flank of Ben Lomond Mountain, a large, eroded mass of granitic rock that has been uplifted by vertical movement on the Ben Lomond fault, located along its steep northeast flank (Figure 17, Regional Topographic Index Map and Figure 18, Regional Geologic Map). The quarry presently occupies about 80 acres between native (pre-quarry) elevations of about 752 and 1,100 feet above mean sea level (msl) (Figure 16). Due to quarrying, the original topography has been modified into a large open pit with a floor between 750 and 760 feet msl. The proposed 17.1 acre Boundary Expansion Area would extend easterly from the present quarry into an area with native elevations between 1,100 and 1,250 feet msl (Figure 18).

The southwestern flank of Ben Lomond Mountain, overlooking the Pacific Ocean, is a relatively broad, gently sloping surface displaying a series of ascending, stair step-like topographic benches that were cut by marine wave erosion at a time when the land was lower relative to sea level than at present. These benches, referred to as marine terraces, were preserved by gradual uplift of the mountain. Visible marine terraces are identified up to about 800 feet in elevation, and the effects of marine erosion probably extend much farther up the mountain (Figure 19, Local Geologic Map).

The broad surface that forms this side of Ben Lomond Mountain is cut by a series of southwest flowing streams occupying narrow, V-shaped stream valleys separated by flat-topped ridges (Figure 17). This drainage pattern is locally interrupted where large bodies of marble bedrock crop out. Marble is unique among the rock types in the geologic/hydrologic study area because it can dissolve in water. Therefore, in areas underlain by marble, dissolution of the marble by percolating water leads to the formation of underground caverns. This type of setting can inhibit the formation of interconnected surface streams, because surface water may disappear underground rather than flowing off in streams.

The topography of Ben Lomond Mountain can be highly irregular where it is underlain by marble, appearing as knobs or short ridges separated by short, intersecting valleys (Figure 20, Quarry Area Fracture Map). This topographic pattern is due to dissolution of the marble by water flowing through fractures in the rock and is readily apparent in the geologic/hydrologic study area on aerial photographs taken prior to development of the quarry. This type of landscape is common in areas underlain by marble or limestone and it referred to as *karst*. The dissolution-widened fractures can act as conduits for the flow of ground water.

4.1.2 Regional Geologic Setting

The quarry property is situated on the western slope of the central Santa Cruz Mountains, part of the Coast Ranges physiographic province (Figure 17). The northwest-southeast structural grain of the Coast Ranges is controlled by a complex of active faults within the San Andreas fault system (Figure 18). Southwest of the San Andreas fault, the Coast Ranges, including the Santa Cruz Mountains, are underlain by a large, northwest-trending, fault-bounded, elongate prism of granitic and metamorphic basement rocks (Figure 18). The marble being mined in the quarry is part of the metamorphic rock unit that also includes schist and quartzite (Figure 19). The granitic and metamorphic rock basement is overlain by a sequence of dominantly marine sedimentary rocks of Paleocene to Pliocene age and non-marine sediments of late Pliocene to Pleistocene age (Figure 19).

The region around the quarry is tectonically active, that is, it is subject to forces causing the earth's crust to deform. The deformation can occur as movement on active faults, folding of layered rocks, or down warping or uplifting of portions of the crust. The Santa Cruz Mountains are cut by several active faults, of which the San Andreas is the most important (Figure 21, Regional Seismicity Map). Along the coast, the ongoing tectonic activity is most evident in the uplift of the southwest slope of Ben Lomond Mountain, as indicated by the series of uplifted marine terraces that sculpt the surface. The Loma Prieta earthquake of 1989 and its aftershocks are recent reminders of the geologic unrest in the region.

4.1.3 Regional Seismic Setting

California's broad system of strike-slip faulting has a long and complex history. Locally, the San Andreas, Zayante-Vergeles and San Gregorio faults and the Monterey Bay-Tularcitos fault zone present a seismic hazard to the subject project (Figure 21). These faults are associated with Holocene activity (movement in the last 11,000 years) and are therefore considered to be active. The most severe historical earthquakes to affect the project site are the 1906 San Francisco earthquake and the 1989 Loma Prieta earthquake, with Richter magnitudes of about 8.3 and 7.1, respectively.

For the purpose of evaluating seismic shaking at the site, this study focuses on the San Andreas, Zayante-Vergeles, San Gregorio, and Monterey Bay-Tularcitos fault systems (Figure 21). These faults are considered active seismic sources by the State of California (Petersen et al., 1996; Cao et al., 2003). While other faults in this region may be active, their potential contribution to seismic hazards at the site is overshadowed by these four faults. The distances between these faults and the proposed Boundary Expansion Area are listed in Table 4-2.

Table 4-2
Distances and Directions to Local Faults

Fault	Distance from site (km)	Distance from site (miles)	Direction from site
San Gregorio	7.5	4.7	Southwest
Zayante-Vergeles	11.5	7.1	Northeast
Monterey Bay-Tularcitos	12	7.5	Southeast
San Andreas	21	13.1	Northeast

Source: Nolan Associates, 2007.

4.1.3.1 San Andreas Fault

The San Andreas fault is active and represents the major seismic hazard in northern California (Jennings, 1994). The main trace of the San Andreas fault trends northwest-southeast and extends over 700 miles from the Gulf of California through the Coast Ranges to Point Arena, where the fault passes offshore and merges with the Cascadia fault zone.

Geologic evidence suggests that the San Andreas fault has experienced right-lateral, strike-slip movement throughout the latter portion of Cenozoic time, with cumulative offset of hundreds of miles. Surface rupture during historical earthquakes, fault creep, and historical seismicity confirm that the San Andreas fault and its branches, the Hayward, Calaveras, and San Gregorio faults, are all active today.

Historical earthquakes along the San Andreas fault and its branches have caused substantial seismic shaking in Santa Cruz County. The two largest historical earthquakes on the San Andreas to affect the area were the moment magnitude (Mw) 7.9 San Francisco earthquake of 18 April 1906 and the Mw 6.9 Loma Prieta earthquake of 17 October 1989. The San Francisco earthquake caused severe seismic shaking and structural damage to many buildings in the Santa Cruz Mountains. The Loma Prieta earthquake may have caused more intense seismic shaking than the 1906 event in localized areas of the Santa Cruz Mountains, even though its regional effects were not as extensive. There were also major earthquakes in northern California along or near the San Andreas fault in 1838, 1865, and possibly 1890 (Sykes and Nishenko, 1984; WGONCEP, 1996).

Geologists have recognized that the San Andreas fault system can be divided into segments with "characteristic" earthquakes of different magnitudes and recurrence intervals (WGCEP, 1988 and 1990; WGONCEP, 1996). Two overlapping segments of the San Andreas fault system represent the greatest potential hazard to the project site. The first segment is defined by the rupture that occurred from the Mendocino triple junction to San Juan Bautista along the San Andreas fault during the great Mw 7.9 San Francisco earthquake of 1906. The WGONCEP (1996) has hypothesized that this "1906 rupture" segment experiences earthquakes with comparable magnitudes about every 200 years.

The second segment is defined approximately by the rupture zone of the Mw 6.9 Loma Prieta earthquake. The WGONCEP (1996) has posited earthquakes of Mw 7.0 on this segment of the fault, with an independent segment recurrence interval of 138 years.

Modified Mercalli Intensities (see Table 4-3) of up to VII (7) due to an earthquake on the San Andreas fault are possible at the site, based on the intensities reported by Lawson et al. (1908) for the 1906 earthquake and by Stover et al. (1990) for the 1989 Loma Prieta earthquake.

Table 4-3
Modified Mercalli Intensity Scale

The modified Mercalli scale measures the intensity of ground shaking as determined from observations of an earthquake's effect on people, structures, and the Earth's surface. This scale assigns to an earthquake event a Roman numeral from I to XII as follows:

I	Not felt by people, except rarely under especially favorable circumstances.
II	Felt indoors only by persons at rest, especially on upper floors. Some hanging objects may swing.
III	Felt indoors by several. Hanging objects may swing slightly. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV	Felt indoors by many, outdoors by few. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing automobiles rock. Windows, dishes, doors rattle. Wooden walls and frame may creak.
V	Felt indoors and outdoors by nearly everyone; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset; some dishes and glassware broken. Doors swing; shutters, pictures move. Pendulum clocks stop, start, change rate. Swaying of tall trees and poles sometimes noticed.
VI	Felt by all. Damage slight. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks and books fall off shelves; pictures off walls. Furniture moved or overturned. Weak plaster and masonry cracked.
VII	Difficult to stand. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary buildings; considerable in badly designed or poorly built buildings. Noticed by drivers of automobiles. Hanging objects quiver. Furniture broken. Weak chimneys broken. Damage to masonry; fall of plaster, loose bricks, stones, tiles, and unbraced parapets. Small slides and caving in along sand or gravel banks. Large bells ring.
VIII	People frightened. Damage slight in specially designed structures; considerable in ordinary substantial buildings, partial collapse; great in poorly built structures. Steering of automobiles affected. Damage or partial collapse to some masonry and stucco. Failure of some chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed pilings broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX	General panic. Damage considerable in specially designed structures; great in substantial buildings, with some collapse. General damage to foundations; frame structures, if not bolted, shifted off foundations and thrown out of plumb. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground; liquefaction.
X	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Landslides on river banks and steep slopes considerable. Water splashed onto banks of canals, rivers, lakes. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI	Few, if any masonry structures remain standing. Bridges destroyed. Broad fissures in ground; earth slumps and landslides widespread. Underground pipelines completely out of service. Rails bent greatly.
XII	Damage nearly total. Waves seen on ground surfaces. Large rock masses displaced. Lines of sight and level distorted. Objects thrown upward into the air.

Source: Nolan Associates, 2007.

4.1.3.2 Zayante-Vergeles Fault

The Zayante fault lies west of the San Andreas fault and trends about 50 miles northwest from the Watsonville lowlands into the Santa Cruz Mountains (Figure 21). The postulated southern extension of the Zayante fault, known as the Vergeles fault, merges with the San Andreas fault south of San Juan Bautista.

The Zayante-Vergeles fault has a long, well-documented history of vertical movement (Clark and Reitman, 1973), probably accompanied by some right-lateral, strike-slip movement (Hall et al., 1974; Ross and Brabb, 1973). Stratigraphic and geomorphic evidence indicates that the Zayante-Vergeles fault has undergone late Pleistocene and Holocene movement and is potentially active (Coppersmith, 1979).

Some historical seismicity may be related to the Zayante-Vergeles fault (Griggs, 1973). The Zayante-Vergeles fault may have undergone sympathetic fault movement during the 1906 earthquake centered on the San Andreas fault, although this evidence is equivocal (Coppersmith, 1979). Gallardo et al. (1999) concluded that a magnitude 4.0 earthquake in 1998 in the Santa Cruz Mountains occurred on the Zayante fault.

In summary, the Zayante-Vergeles fault should be considered active for design purposes. Cao et al. (2003) concluded that the Zayante-Vergeles fault is capable of generating an Mw 6.8 earthquake, with a recurrence interval of almost 9,000 years.

4.1.3.3 San Gregorio Fault

The San Gregorio fault skirts the Santa Cruz County coastline seaward of Monterey Bay and intersects the coast at Point Año Nuevo. North of Año Nuevo it passes offshore, intersecting the coast again at Half Moon Bay (Figure 21). North of Half Moon Bay, the San Gregorio fault lies offshore until it connects with the San Andreas fault near Bolinas. Southward from Monterey Bay, the San Gregorio fault intersects the coast at Point Sur and eventually connects with the Hosgri fault in south-central California (Dickinson et al., 2005).

The onshore segments of the San Gregorio fault at Point Año Nuevo and at Half Moon Bay show evidence of late Pleistocene and Holocene displacement (Weber and Cotton, 1981; Weber et al., 1995; Simpson et al., 1997). In addition to stratigraphic evidence for Holocene activity, the historical seismicity in the region is partially attributed to the San Gregorio fault. Due to inaccuracies of epicenter locations, the magnitude 6+ earthquakes of 1926, tentatively assigned to the Monterey Bay fault zone, may have actually occurred on the San Gregorio fault (Greene, 1977). Recent stratigraphic studies of the fault document 97 miles of horizontal offset on the fault (Dickinson et al., 2005).

Petersen et al. (1996) divided the San Gregorio fault into the “San Gregorio” and “San Gregorio, Sur Region” segments. The segmentation boundary is located west of Monterey Bay. Petersen et al. (1996) assigned the San Gregorio fault in the Santa Cruz County area a recurrence interval of 400 years. Cao et al. (2003) consider the fault capable of an Mw 7.2.

4.1.3.4 Monterey Bay-Tularcitos Fault Zone

The Monterey Bay-Tularcitos fault zone is based on a postulated connection between the Tularcitos fault, located on land near the Monterey Peninsula, and the offshore Monterey Bay fault zone (Figure 21). The Monterey Bay fault zone is 6 to 9 miles wide and about 25 miles long, consisting of many northwest-trending, en échelon faults identified during shipboard seismic reflection surveys (Greene, 1977). The fault zone projects toward the coastline in the vicinity of Seaside and Ford Ord. At this point, a principal offshore fault trace in the heart of the Monterey Bay fault zone is tentatively correlated by Greene (1977) with the Navy Fault, a postulated westward extension of the Tularcitos fault. It should be emphasized that this correlation between onshore and offshore portions of the Monterey Bay-Tularcitos fault zone is only tentative; no concrete geologic evidence for connecting the Navy and Tularcitos faults under the Carmel Valley alluvium has been observed, nor has a direct connection between these two faults and any offshore trace been found.

Outcrop evidence indicates a variety of strike-slip and dip-slip movements associated with the onshore and offshore traces. Earthquake studies suggest the Monterey Bay-Tularcitos fault zone is predominantly right-lateral, strike-slip in character (Greene, 1977). Both offshore and onshore fault traces in this zone have displaced Quaternary age rock layers and, therefore, are considered potentially active. One offshore trace, which aligns with the trend of the Navy fault, has displaced Holocene beds and is therefore considered active (Greene, 1977).

Seismically, the Monterey Bay-Tularcitos fault zone may be historically active. The largest historical earthquakes tentatively located in the Monterey Bay-Tularcitos fault zone are two events, estimated at 6.2 on the Richter Scale, in October 1926 (Greene, 1977). Because of possible inaccuracies in locating the epicenters of these earthquakes, it is possible that these earthquakes actually occurred on the nearby San Gregorio fault (Greene, 1977).

Another earthquake in April 1890 might be attributed to the Monterey Bay-Tularcitos fault zone (Burkland and Associates, 1975); this earthquake had an estimated Modified Mercalli Intensity of VII (Table 4-3) for northern Monterey County.

The WGONCEP (1996) has assigned an expected earthquake of Mw 7.1 to the Monterey Bay-Tularcitos fault zone, with an effective recurrence interval of 2,600 years, based on Holocene offsets noted on an offshore strand of the fault. Cao et al. (2003) chose a 7.3 expected earthquake magnitude, but with a recurrence interval of 2,841 years. Their expected earthquake is based on a composite slip rate of 0.5 millimeters per year (after Rosenberg and Clark, 1994).

4.1.4 Study Area Geologic Setting

The geology of the geologic/hydrologic study area is complex, a result of over 100 million years of geologic history, including collisions of crustal plates and multiple cycles of tectonic upheaval and erosion of the land surface. These episodes of tectonic deformation are recorded as metamorphism of older sedimentary rocks, intrusion of plutonic igneous rocks, folding and faulting of sedimentary layers, and by erosional remnants of once extensive geologic formations.

The following sections reference Figures 16 through 22. Detailed geologic maps and cross sections for the geologic/hydrologic study area are included in the Geology and Hydrology Technical Appendix (Appendix F).

4.1.4.1 Geologic Units

Rock units in the geologic/hydrologic study area are separable into three major groups: granitic intrusive rocks of Late Cretaceous age, pre-Cretaceous metasedimentary rocks, and sedimentary rocks of Tertiary and Quaternary age. The granitic intrusive rocks form the core of Ben Lomond Mountain. These rocks formed from molten rock (magma) that melted its way up into the crust and then cooled deep underground, forming granitic rock. The magma intruded older sedimentary rocks buried in the crust and metamorphosed them through heat and pressure into schist, quartzite, and marble (Geology and Hydrology Technical Appendix, Appendix F). Layering in the schist and marble express the original layering in the sedimentary rocks.

The younger sedimentary rocks (Tertiary age) occur in isolated bodies on and around the quarry property overlying the older granitic and metamorphic rock. The Tertiary rock units include the Monterey Formation, Santa Margarita Sandstone, and Santa Cruz Mudstone, while the surficial Quaternary deposits include marine terrace deposits, doline (sinkhole) fill, alluvium, colluvium, landslide deposits, and soil (residuum) (Geology and Hydrology Technical Appendix, Appendix F).

4.1.4.2 Geologic Structure

Geologic structure in the geologic/hydrologic study area is a result of intrusion of granitic magma at depth into the surrounding sedimentary rock during the Cretaceous period, resulting in metamorphism of the sedimentary rock, followed by uplift and erosion of the igneous and metamorphic rock and repeated cycles of sedimentary deposition and tectonic deformation throughout the Tertiary Period. Metamorphic rocks in the geologic/hydrologic study area appear as a regularly layered, but faulted, sequence of moderately to strongly metamorphosed sedimentary rock. The layering in the metamorphic rocks shows a regular, approximate east-west alignment, but may be tilted to the north or to the south. These rocks are, however, broken into a series of discontinuous blocks by faulting.

In areas with substantial marble, the metamorphic rocks are cut by fractures that have been etched out by water flowing along the fractures. The fractures are visible in the landscape as aligned valleys, swales, or notches in ridges (Figure 20). The fracture valleys are often short and intersecting. In areas of karst, the fracture intersections are frequently marked by sinkholes. In some cases, these fractures are clearly faults with major displacement. In other cases, the fractures appear to have little displacement but have been etched into the landscape by preferential dissolution of the marble bedrock (Figure 20).

Many faults are exposed in the quarry. These faults included both low-angle thrusts and high-angle faults, with the amount of total offset usually indeterminate, although a few of the faults were clearly associated with large offsets. A structural discontinuity was noted trending southwest to northeast through the central portion of the quarry. Layering in the marble and schist is tilted to the north or west on the northwest side of the discontinuity. Layering on the southwest side of the discontinuity is tilted to the south. Along with the change in the orientation of layering is a change in the orientation of fractures in the rock. These changes define two separate structural “domains” in the quarry that are important in analyzing the stability of the quarry walls, as will be discussed later in this section. The northerly of the two domains also appears to be separable into two less distinct structural domains.

The rocks exposed in the quarry are universally jointed (fractured). Many of the joints in the quarry show evidence of dissolution, including raspy “meringue” weathering patterns and thick linings of terra rosa sediment, a residuum left behind after dissolution of the marble. In visual inspection, concentrations of solution fractures in the walls of the quarry stand out as dark, steeply dipping zones separated by relatively lighter colored marble. The darker color of these zones derives from the concentration of terra rosa on the fracture surfaces.

Geologic structure within the Tertiary sedimentary section is relatively simple. Rocks older than the mid-Miocene, including the Monterey Formation and Lompico Sandstone, are moderately folded and faulted; these units crop out east of the quarry (Figure 19). The younger formations in the quarry area, the Santa Margarita Sandstone and Santa Cruz Mudstone, cover the older Tertiary sedimentary rocks and are relatively undeformed, showing only a shallow tilt to the southwest (Figure 19).

4.1.4.3 Surface Processes

Surficial geologic processes in the geologic/hydrologic study area include weathering, erosion, and mass wasting (landsliding). Weathering of surficial materials and erosion by wind and water are the principal processes active in developing natural landscapes. When erosion leads to the development of steep slopes, landsliding may occur. In turn, landsliding breaks up the rock formations on the slope, leading to additional weathering and erosion.

Erosion related to quarrying occurs during removal of the overburden, that is, the soil and sedimentary rock covering the marble, and during the mining process itself. The overburden is stripped away so the marble can be mined, which disrupts drainage patterns and generates large amounts of loose sediment, which can lead to massive amounts of erosion if not carefully controlled.

The most potential for erosion probably occurs during removal of the overburden, but it also occurs during the mining process as well. During the site investigation undertaken for preparation of the project EIR, abundant turbid runoff from the quarry area was observed during storm events. The sediment carried by the runoff is derived from erosion of exposed slopes cut in the sedimentary units overlying the marble, from weathered schist or diorite exposed in and around the quarry, from residuum left behind after dissolution of the marble (terra rosa), from doline fill, and from spoils deposited following removal of overburden from the marble.

Landsliding

Landsliding is a natural process that accompanies erosional downcutting and oversteepening of slopes. Like erosion, it can also be exacerbated by cultural activities. Road building or earth-moving results in steep cut slopes and loose fill soils, both of which can be prone to landsliding. Roads can also collect naturally dispersed runoff and concentrate it into a rapidly flowing stream that can trigger erosion or landsliding.

Nolan Associates observed two landslides of significance in the area of the quarry. One of the landslides, adjacent to Liddell Spring, has been studied extensively by Pacific Geotechnical Engineering (PGE, 2001), because of its potential impact on Liddell Spring. The landslide complex was classified by PGE as the combination of an earth flow and several debris flows (Geology and Hydrology Technical Appendix, Appendix F). The debris flow component is considered to have been caused in part by stockpiled spoils from the quarry. This landslide complex poses some hazard to the springbox at Liddell Spring and to the water quality of the spring.

The second landslide occurred in the winter of 2006 on the quarry face in the southeastern quadrant of the quarry (Geology and Hydrology Technical Appendix, Appendix F). This landslide was about 150 feet wide and 320 feet long. It moved as a rock and debris slide in weathered marble, along with a substantial soil component. The detachment surface exposed in the headscarp was an older shear zone of undetermined thickness, striking about N55°W and dipping steeply to the southwest (roughly parallel to prominent joints in this wall of the quarry).

A few minor rock falls or topples were also observed. The rock falls or topples generally involved several cubic yards to a few tens of cubic yards of fractured rock, usually derived from the crest of freshly worked benches.

Karst Processes: Geologic Influence on Ground Water Flow

The geologic/hydrologic study area has experienced alternating episodes of erosion and deposition throughout its geologic history, as indicated by the middle to upper Tertiary age sedimentary sequence overlying the granitic and metamorphic basement. Beginning during the mid Pleistocene (about the last 800,000 years) or earlier, the geologic/hydrologic study area was subject to sea level fluctuations of 300 to 400 feet every 100,000 years, on average, caused by worldwide climatic variations and episodic glaciation in the higher latitudes. Since about 500,000 years ago, it has been elevated hundreds of feet above sea level and exposed to erosion, based on estimated uplift rates for this section of the coastline (Bradley and Griggs, 1976). In other words, over the last 25 million years, the marble body in the geologic/hydrologic study area has had an extraordinarily complex hydrogeologic history, characterized by dramatic fluctuations in climate and base (sea) level.

Ground water flow in areas underlain by soluble rock, such as marble or limestone, is substantially different than ground water flow in most other types of rock. In marble, the initial permeability may be quite low, but even slight downward flow over time will gradually dissolve the rock, forming solution channels through which water can flow more readily. In some cases, the solution channels enlarge to form caverns with underground ponds and streams. These solution cavities usually begin forming along bedding planes, fractures, or faults. In the quarry area, solution of the marble is strongly controlled by the fracture patterns. The influence of the fracture system on dissolution of marble bedrock and ground water circulation is well documented by the alignment of sinkholes along major fractures (or faults) -- and particularly by the preferential location of prominent sinkholes (open or buried) at the intersection of two or more fractures (Geology and Hydrology Technical Appendix, Appendix F).

The exposure afforded by the quarry walls provides a view of the hydrogeologic character of the marble over a vertical distance of 350 feet. Solution-widened fractures in the quarry walls are steeply dipping to vertical and commonly form continuous zones of solution channeling from the original ground surface through the quarry floor.

Although there is interbedded schist throughout the marble section (as well as igneous sills and dikes), SECOR (1997) concluded that these interbeds do not have a substantial effect on flow paths through the marble. This conclusion is reasonable because the formation of solution channels has been guided by fractures and faults that cut across the rock layering.

Prominent topographic lineaments in the Bonny Doon Ecological Preserve, an area largely underlain by the Santa Margarita Sandstone, are consistent with the pattern of fractures mapped in the marble terrane (Geology and Hydrology Technical Appendix, Appendix F). These lineaments strike northeast to east-northeast from the quarry area across the Ecological Preserve, with the two southernmost lineaments trending toward marble outcrops mapped in Laguna Creek. These lineaments imply the presence of solution-widened fractures in marble underlying the Santa Margarita Sandstone in the Ecological Preserve. Mapping in Laguna Creek indicates that marble layers within the schist are relatively common throughout this area. These observations, in conjunction with the dye tracer test results, to be presented in Section 5.0, indicate the existence of karst solution channels beneath Laguna Creek and the Ecological Preserve.

4.2 REGULATORY SETTING

The SMARA was passed in 1975 to balance the need for a continuing supply of mineral resources with the assurance that significant adverse impacts of mining would be mitigated. The State Mining and Geology Board provide technical information; the Board does not regulate local land use.

SMARA requires that all mining operations have an approved reclamation plan of all lands mined after January 1, 1976. Reclamation is defined by SMARA as:

> "…the combined process of land treatment that minimizes water degradation, air pollution, damage to aquatic or wildlife habitat, flooding, erosion, and other adverse effects from surface mining operations, including adverse surface effects incidental to underground mines, so that mined lands are reclaimed to a usable condition which is readily adaptable for alternate land uses and create no danger to public health or safety. The process may extend to affected lands surrounding mined lands, and may require backfilling, grading, resoiling, revegetation, soil compaction, stabilization, or other measures."

The reclamation plan must contain specific details that describe the type of mining operation, the mining boundaries, duration of mining operation, the manner in which reclamation would be accomplished, and potential uses of the site after reclamation. The plan must also reflect the characteristics of the site and surrounding area such as soil stability, topography, geology, climate and principal mineral commodities. Reclamation Regulations (Article 9) sets forth reclamation standards for mining operations with reclamation plans approved after January 15, 1993.

Every lead agency must adopt ordinances in accordance with SMARA, which establishes procedures for the review and approval of a reclamation plan and the issuance of a permit to conduct surface mining operations. Accordingly, the County of Santa Cruz has adopted Mining Regulations that have been certified by the State Mining and Geology Board as being in conformance with state mining regulations. Provisions of the County Mining Regulations are presented in County Plans and Policies, Section 3.0.

4.3 PROJECT IMPACTS

4.3.1 Thresholds of Significance

According to the CEQA Guidelines (Appendix G), a project will normally have a significant effect on the environment if the following conditions occur:

- Exposure of people or structures to potential significant effects, including the risk of loss, injury, or death, as a result of rupture of a known earthquake fault as delineated by the State Geologist on the most recent Alquist-Priolo fault zoning maps or based on other substantial evidence; strong seismic groundshaking or seismically induced ground failure, including liquefaction; or landslides.
- Result in substantial soil erosion or the loss of topsoil.
- Be located on a geologic unit or soil that is unstable, or that would become unstable as a result of the project, and potentially result in on- or off-site landslide, lateral spreading, subsidence, liquefaction or collapse.
- Adversely impact unique or valuable geological or paleontological features or resources.
- Change in topography or ground surface relief features.
- Affect steep slopes (over 30 precent gradient).

4.3.2 Seismic Shaking Hazards

Seismic shaking at the project site will be intense during the next major earthquake along one of the local fault systems. It is important that seismic shaking be considered in evaluating project impacts. The intensity of seismic shaking has the potential to destabilize slopes, whether natural or man-made, and to damage or destroy structures.

The seismic shaking evaluation for the proposed Boundary Expansion Area conducted by Nolan Associates included an estimate of expected seismic shaking intensities based on both deterministic and probabilistic methods. A deterministic assessment considers the effects of the largest ground motion that can be expected at a site, regardless of the likelihood of this event occurring during the design life of the project. A probabilistic seismic analysis differs from a deterministic analysis in that it evaluates the probability for shaking of a certain intensity to occur at a particular site over a given span of time.

The intensity of seismic ground shaking can be characterized qualitatively, by its visible effects on people and structures, or quantitatively, as an instrumental measurement of the shaking intensity at a given location. The Modified Mercalli Scale (Table 4-3) is used in a qualitative way to characterize shaking intensity during an earthquake. Ground shaking intensity as determined by instrumental readings is measured in “g”, where one g is equivalent to the acceleration of the earth’s gravity.

4.3.2.1 Deterministic Seismic Shaking Analysis

Table 4-4 shows estimated magnitudes (Mw (MAX)) and expected type of fault motion for the maximum expected earthquakes on each of the above-listed fault systems (Petersen et al., 1996; Cao et al., 2003). Estimated mean peak horizontal ground acceleration (PGA) and mean peak plus one dispersion (PGA + ∂) horizontal ground acceleration values for the site are calculated using the estimated magnitudes and fault geometries shown on Table 4-4 and the fault distances shown on Table 4-2. The estimated accelerations are based on an attenuation relationship derived from the analysis of historical earthquakes (Sadigh et al., 1997) and are for sites founded on rock. It should be noted that the listed values are approximations, based on theoretical curves generated from a relatively small data set; actual measured accelerations may be larger. The PGA + ∂ value is a conservative design parameter intended to compensate for the uncertainty in the attenuation relationships.

The duration of strong seismic shaking shown in Table 4-4 is calculated from a magnitude-dependent formula proposed by Abrahamson and Silva (1996). The expected recurrence interval (RI), after Petersen et al. (1996), is the expected time between major earthquakes on each fault. The UBC Seismic Source Type (Cao et al., 2003) is also listed.

In summary, the San Gregorio fault, passing within 7.5 km of the site, is expected to generate the largest earthquake ground motion at the site. The characteristic earthquake on this fault (Mw(MAX) = 7.2) is expected to generate estimated ground motions in the range of 0.46 to 0.67g. The duration of strong seismic shaking from this event would be about 19 seconds. The recurrence interval for this design earthquake is about 400 years.

Table 4-4
Deterministic Ground Motions

Fault	**$M_{W\ (MAX)}$**	**Rupture Geometry**	**PGA (g)**	**PGA + ∂ (g)**	**Duration (sec)**	**Recurrence Interval (years)**	**Seismic Source Type**
San Gregorio	7.2	Strike-slip	0.46	0.67	17	400	B
Zayante-Vergeles	7.0	Reverse	0.41	0.62	14	8,821	B
Monterey Bay-Tularcitos	7.3	Strike-slip	0.37	0.54	19	2,841	B
San Andreas (1906 rupture)	7.9	Strike-slip	0.31	0.45	33	210	A

Source: Nolan Associates, 2007.
Notes:
$M_{W(MAX)}$: Moment magnitude of maximum credible earthquake. San Andreas 1906 rupture after Peterson et al., 1996; San Gregorio, Zayante-Vergeles, Monterey Bay-Tularcitos after Cao et al., 2003.
Rupture Geometry and Recurrence Interval after Peterson et al., 1996.
PGA: Mean peak horizontal ground acceleration. After Sadigh et al., 1997.
PGA + ∂: Mean peak horizontal ground acceleration plus one dispersion. After Sadigh et al., 1997.
Duration: Abrahamson and Silva, 1996
Recurrence Interval: Peterson et al., 1996
Seismic Source Type from CBSC, 2002

It is important to note that the ground acceleration values given in Table 4-4 are not directly equivalent to seismic or pseudo-static coefficients used in slope stability analyses (CGS, 1997). Use of these values in the development of seismic coefficients for use in stability analysis should be based on state and local jurisdictional regulations and on appropriate engineering standards of practice.

4.3.2.2 Probabilistic Seismic Shaking Analysis

The U.S. Geological Survey and the California Geological Survey together produced a probabilistic seismic hazards assessment for the state of California (Petersen et al., 1996; revised in Cao et al., 2003). The study used a model that explicitly considered faults that are capable of generating moment magnitude 6.5 or greater earthquakes. The San Francisco Bay area, Monterey Bay area and Santa Cruz Mountains are traversed by numerous minor faults and splays, many of which may be capable of generating smaller earthquakes; to account for these seismic sources, a background source magnitude of 6.5 was also applied in the probabilistic model.

Probabilistic ground motions for the proposed Boundary Expansion Area based on this joint study are listed in Table 4-5. These estimated ground motions assume a soil profile type Sc (firm rock), per the 2001 California Building Code (CBSC, 2002). The values may need to be modified for specific site conditions prior to using them in any site-specific analysis.

The ground motion intensities shown in Table 4-5 are the seismic shaking intensities that have a 10 percent probability of being exceeded in 50 years or a 2mpercent probability of being exceeded in 50 years. The ground motion with a 10 percent probability of being exceeded, 0.43g, is considered appropriate for residential and non-habitable structures. The ground motion with a 2 percent probability of being exceeded, 0.7g, is considered appropriate for critical structures such as hospitals or fire stations.

Table 4-5
Probabilistic Ground Motions

Ground Motion Measure	**10 Percent probability of being exceeded in 50 years**	**2 Percent probability of being exceeded in 50 years**
Peak Ground Acceleration (g)	0.43	0.7
Spectral Acceleration (g) at 0.2 sec.	1.01	1.68
Spectral Acceleration (g) at 1.0 sec.	0.43	0.77

Source: Nolan Associates, 2007.

4.3.2.3 Ground Shaking Amplification

The ground motion values listed in Tables 4-4 and 4-5 are merely expected values based on uniform site conditions in firm bedrock; actual ground motions during an earthquake may vary due to unique site conditions (e.g., bedrock type or topography) or the way different portions of the earth's crust transmit seismic energy to the site. Ground motions at the crest of a very steep slope can be several times as intense as in the adjacent valleys due to topographic amplification (Hartzell et al., 1994). Topographic amplification is therefore potentially important for steep, high slopes such as quarry faces. However, the influence of topography on seismic shaking is complex, sometimes leading to pronounced disagreements between theoretical predictions and observed effects (Geli, et al., 1988; Hartzell et al., 1994). Hartzell et al. (1994) found amplification factors on a steep-sided ridge crest to be as high as five times for aftershocks of the 1989 earthquake. Ashford and Sitar (2002) have developed a method for estimating seismic shaking amplification on steep slopes.

4.3.2.4 Project Seismic Shaking Impacts

Very strong seismic shaking may occur during the project lifetime. Seismic shaking could damage buildings and other structures associated with the quarry operation. Because no new structures or any increase in the scale of the quarry operation is planned, the existing level of hazard due to seismic shaking is not expected to increase due to the quarry expansion. Therefore, the seismic shaking hazard associated with the project is not significant.

4.3.3 Seismically-Induced Ground Deformation

Ground deformation associated with strong seismic shaking may manifest in several ways:

- Seismically-induced differential settlement occurs when seismic shaking compacts loose soils.
- Off-fault co-seismic ground cracks or fissures may form in response to strong shaking, particularly along the crests of ridges or at the top of very steep slopes.
- Seismic shaking can trigger landslides on slopes that are already marginally stable.
- Liquefaction occurs when generally loose, saturated, cohesionless soil (typically sand) loses strength due to seismic shaking, causing it to behave like a liquid. Ground deformations that accompany liquefaction include lurch cracking, fissuring, and lateral spreading (i.e., liquefied soils flowing laterally down very gentle slopes).

In the proposed Boundary Expansion Area, the principal hazards from seismically-induced ground failure are co-seismic ground cracking along the crests of proposed Boundary Expansion Area slopes, and seismically induced landsliding, rock falls, or topples on the quarry faces. Soil liquefaction and differential settlement are not considered to be hazards in the proposed Boundary Expansion Area. However, it is possible that liquefaction or differential settlement during a strong earthquake could impact the levees that form the settlement basins. The settlement basins would be used to detain sediment-laden runoff from the proposed Boundary Expansion Area and prevent it from flowing directly into local streams. Liquefaction and settlement hazards to the settlement basin levees are discussed below. The potential impacts of seismically-induced landsliding are discussed in the landsliding section, to follow.

4.3.3.1 Liquefaction Hazard

Golder Associates (1991) evaluated the stability of the earth embankments (levees) used to construct settlement basins for the quarry operation. Their report identified specific stability concerns with these levees and made recommendations for remedial stabilization measures. Golder Associates (1991) did not include a formal, quantitative analysis of the liquefaction hazard but did note that "liquefaction could result in localized levee instability or complete failure" (1991, p. 13). In their assessment, they considered Settlement Basin 4 to be susceptible to liquefaction. A significant liquefaction hazard would exist only while there was an impoundment of water behind the embankments.

The Golder Associates (1991) report made recommendations for increasing the stability of the levees, but they concluded that even after implementing these measures the levee at Settlement Basin 4 could still be susceptible to liquefaction-related failure. No information has been provided to indicate that the Golder Associates recommendations were satisfactorily completed. Based on conversations with County staff (David Carlson, 2007), the recommended improvements have not been documented. The Golder Associates (1991) report did not discuss liquefaction susceptibility for Settlement Basin 3. The impacts of levee failure would result in release of sediment-laden water into local stream drainages and could be significant.

In their evaluation of levees for Settlement Basins 3 and 4, Golder (1991) found that the levee for Settlement Basin 4 was built directly on native materials, without any foundation preparation. There is some possibility, therefore, that the levee rests on liquefiable materials or materials that may cause differential settlement during an earthquake. For the Basin 3 levee, they reviewed construction notes by the quarry engineer. The notes indicated that the native substrate had been prepared for supporting the levee. However, they did not verify the condition of the levee substrate nor did they evaluate the in-place density of the levee fill.

The levee analysis performed by Golder Associates (1991) used seismic accelerations based on a magnitude 7.0 earthquake on the San Gregorio fault. More recent studies suggest that a larger maximum probable earthquake, Mw 7.2, is warranted for the fault (Cao, et al., 2003), which may change the estimated seismic ground motion for use in the analysis. Similarly, the method of choosing the appropriate seismic coefficient for slope stability analysis has changed since 1991. Golder Associates (1991) used a Repeatable High Ground Acceleration (RHGA) of 0.27g. While there is currently no universally accepted means of selecting the seismic coefficient used in slope stability analysis, the RHGA is not now commonly employed. Selection of a seismic coefficient using current information on the San Gregorio fault and current seismic coefficient selection criteria could result in different estimates of levee susceptibility to liquefaction.

It is possible that liquefaction or differential settlement during an earthquake could impact the embankment dams that retain the settlement basins, damaging drainage works and releasing sediment laden water into local stream drainages. In a worst-case event, rapid failure of a levee while the settlement basin is full could result in flooding of downstream areas. To the extent that the increased runoff from the proposed Boundary Expansion Area would increase flow to the settlement basins, the proposed Boundary Expansion Area would be associated with an impact if Settlement Basins 3 and 4 to fail. This impact is considered potentially significant. Preparing an updated liquefaction analysis and implementing the analysis recommendations would ensure that basin levees function at current industry standards. This mitigation is identified as Measure GEO-1 and would reduce the liquefaction impact to a less than significant level.

4.3.3.2 Ground Surface Rupture Due to Faulting

Earthquakes are caused by slippage along faults in the earth's crust. Where the fault intersects the ground surface, this slippage causes displacement that will damage or destroy structures placed directly over the fault. The faults mapped in the area of the quarry (Geology and Hydrology Technical Appendix, Appendix F) are related to deformation accompanying metamorphism, igneous intrusion, and uplift of the basement rock, most of which took place in Late Cretaceous and early Tertiary time. These faults are not related to the current active tectonic regime of central California. Therefore, the potential for fault-related ground surface rupture within the proposed quarry Boundary Expansion Area is considered to be low.

4.3.4 Landsliding and Slope Instability

Broadly defined, landsliding includes any gravity driven movement of earth materials outward or downward on a slope. The associated hazards depend to some extent on the type of landslide that occurs. There are different means of classifying landslides, all generally based on type of movement, type of material, and, less often, rate of movement. The most generally applied classification scheme (Cruden and Varnes, 1996) divides landslides according to type of movement (fall, topple, slide, spread, or flow) and material type (rock, debris, or soil). These categories can be further subdivided based other landside characteristics.

The types of landsliding that may occur in the Boundary Expansion Area are rock falls and rock topples along the quarry faces, sliding of the overburden exposed at the top of the quarry faces, large scale sliding of the quarry face itself, or some combination of these types. These landslides may occur as a result of seismic shaking or the may occur under non-seismic conditions

Rock falls and topples are expected to involve rock masses a few feet to a few tens of feet in size. They occur as relatively intact blocks of rock fall from the quarry slopes. This type of failure appears relatively common in the quarry, owing to the blasting and ripping of the quarry face that is part of the quarrying operation. Rock falls and topples may present a hazard to quarry workers, but are not considered to present a significant environmental impact by themselves. However, abundant, continuing rock falls or topples across the quarry slopes could damage reclamation efforts. Widespread falls and topples might occur as a result of seismic shaking.

Large-scale sliding of overburden slopes or the quarry face itself would create a large mass of broken rock and soil while disrupting drainage patterns. Very large failures could extend back from the face of the quarry tens or possibly one hundred or more feet, affecting adjacent lands. Such failures could lead to erosion and sedimentation of downstream areas or increase turbidity in ground water under the quarry. The recent landslide in the quarry appears to have involved large-scale failure of both overburden and marble.

The principal factors controlling the distribution of landsliding are the underlying rock type, the steepness of the slopes, the existence of weak zones in the rock that may facilitate landsliding, and the presence of older landslide masses susceptible to reactivation. In particular, the steepness of the terrain greatly promotes slope instability, all other factors being equal.

Landslides are often triggered by ground saturation (due to rainfall or drainage), seismic shaking, or both.

The two landslides observed in the quarry area (described above) illustrate the potential impact of quarry operations on slope stability. Renewed movement of the landslide near Liddell Spring could impair operation of the Santa Cruz City water diversion and impact the water quality of the spring. Landsliding within the quarry could threaten quarry workers or increase the risk of erosion, downstream sedimentation, and turbidity. This impact is mitigated with Measure GEO-3 (See Section 4.4).

4.3.4.1 Stability Evaluation of Proposed Limestone Quarry Boundary Expansion

An evaluation of slope stability for the proposed finished quarry configuration (including the expansion) was performed by JCA (JCA, 1997; 1998; 1999). A peer review of the JCA reports was provided by a registered geotechnical engineer (Pacific Crest Engineering, Inc., 2004) and is attached as Appendix D of the Geologic, Hydrologic, and Hydrogeologic Technical Appendix. Nolan Associates performed a peer review of the geologic portion of these reports. The following comments summarize the results of both the geologic and geotechnical reviews.

Proposed Slopes

The planned development of the proposed Boundary Expansion Area calls for the final side slopes in the quarry pit to be benched with an overall inclination of 60 degrees. Individual benches are planned to be 16 feet wide and 40 feet high, with the steps between benches having an inclination of 80 degrees (Bowman and Williams, 2001a as shown in Figure 9). Working slopes are to be slightly less steep. As proposed, the finished benches would be gently sloped to the inboard side, with inboard ditches used to collect runoff from the benches and channel it to the floor of the quarry, via down-drains.

The Use Permit 3236-U Condition III.8 requires benches of minimum 30-foot width every 60 feet vertically for slopes inclined steeper than 1:1 (horizontal:vertical), an inclination of 45 degrees. The final grading plan for the Boundary Expansion Area (Figure 9) has 16-foot wide benches every 40 feet vertically, cut on an overall slope of 60 degrees. This benching is proportionally equivalent to a bench of 24 feet wide every 60 feet vertically, so the proposed final grading plan does not meet Use Permit requirements. The Use Permit condition also limits finished slopes to an inclination not exceeding the "normal angle of repose." Although the Use Permit does not define a means for determining the normal angle of repose, the COC Condition III.A.7(2) states that "all final cut slopes completed after September 12, 1996, shall have a stability factor of safety not less than 1.2 …" Therefore, all slopes with a stability factor of safety not less than 1.2 are considered to be at or below the normal angle of repose.

Overburden slopes around the proposed Boundary Expansion Area, consisting of loose soil and Santa Margarita Sandstone, are to be cut back to an inclination of 1½:1 (horizontal:vertical), an inclination of about 34 degrees. The present plan (Figure 9) shows overburden removed from the Boundary Expansion Area, along with quarry waste (i.e., off-spec rock), placed and compacted along the western wall of the existing quarry. The plan shows the fill to be finished with a 2:1 (horizontal:vertical) slope (about 26 degrees) and benched every 40 feet vertically. In response to hydrology and water quality concerns, Measure HYD-1 recommends redesigning the overburden fill and placing it across the entire quarry floor to function as filter for recharging ground water (see Hydrology, Section 5.0).

Review of Existing Stability Analysis

A geotechnical evaluation of the proposed finished grading for the quarry, including the Boundary Expansion Area (Figure 9) was performed by Jo Crosby and Associates (JCA, 1997; 1998; 1999). Jointed rock slopes within the quarry excavation were analyzed using a fracture mechanics approach, as described below. Rotational failure models were applied to soil and sandstone overburden cut slopes around the top of the quarry and to fill slopes.

A fracture mechanics approach to stability analysis recognizes that hard rock, like marble or unweathered granite, is unlikely to slide by breaking across fresh rock. Rocks like these can stand as vertical cliffs, with little risk of sliding. Therefore, the stability of rock slopes is generally evaluated by looking at the fractures or other natural planes of weakness that cut through the rocks and might induce the rocks to slide. Fracture mechanics looks specifically at fractures that are oriented so that they tilt directly downhill. When combined with measurements of the strength along the fracture surface, this type of analysis can predict likely failures in rock slopes.

A rotational failure analysis is used for soil or rocks that are soft enough to behave like soil, such as the Santa Margarita Sandstone at the quarry site. In these types of materials, the landslide breaks directly through the material along a curving surface. The curving surface is concave upward, starting out steep at the head of the landslide and gradually flattening towards the bottom of the landslide. Because of the curvature, the landslide is said to “rotate” as it moves downhill. In a rotational failure analysis, the strength of the intact soil or rock is used in the analysis, although fractures or other types of weakness can also play a role in the analysis.

The stability analysis for both the jointed quarry faces and the sandstone slopes assumed seismic accelerations of 0.2g. This value was considered appropriate by many researchers at the time the JCA reports were prepared. Recent research, however, has prompted most current practitioners to employ higher seismic design coefficients for pseudo-static slope stability analysis in areas where very strong seismic shaking is expected (Brae and Rathje, 1998). Ashford and Sitar (2002) have developed a method for estimating appropriate seismic coefficients for analyzing the stability of very steep slopes. Although their analysis was for weakly cemented rocks, the potential for topographic amplification must be taken into account in the analysis of the planned Boundary Expansion Area slopes.

JCA concluded that the planned quarry slopes would be stable. A peer review of the JCA reports was provided by a registered geotechnical engineer (Appendix D of the Geology and Hydrology Technical Appendix). A peer review of the geologic portion of these reports was performed. The following comments summarize the results of both the geologic and geotechnical reviews.

Stability of Rock Slopes

JCA performed a fracture mechanics analysis consisting of kinematic and limit equilibrium analysis of plane and wedge failures, using stereographic projection techniques, for the metamorphic and granitic rock slopes. A stereographic projection involves using a graphical tool called a stereonet for displaying fracture information (Geology and Hydrology Technical Appendix for examples of stereonets, Appendix F). Forty-five fracture attitudes and the lines of intersection of the different fractures, taken from different rock types throughout the quarry, were plotted on four equal-area stereonets (one for each of the four proposed quarry faces—east, south, west, and north sides of the quarry pit). No identifiable structural trends or groups exist in the JCA data, indicating that the sampled fractures represent multiple structural domains (that it, it mixes groups of fractures from different areas that don't belong together). The geologic mapping and fracture orientation data collected as part of this study defined at least two separate structural domains within the quarry.

A great-circle representation of the average strike and dip of each of the four proposed finished quarry faces was plotted on a stereonet with the fracture data and the fracture lines of intersection. Fracture and intersection attitudes plotted on both sides of the great circle for each of these proposed quarry faces, indicating that many of the fractures and intersections observed by JCA are kinematically potentially unstable, and that limit equilibrium analyses are needed to resolve their stability. The material strengths required for stability were then back-calculated from an assumed potential failure surface. The JCA reports concluded that the back-calculated material strengths were reasonable, given the rock and soils types observed in the field, and that the proposed slopes are therefore likely to be stable.

Nolan Associates concluded that fracture mechanics theory was employed incorrectly in JCA's analysis for the jointed quarry slopes. This opinion is based on the following findings:

- As discussed earlier, each structural domain requires a separate analysis. Individual structural domains were not identified, and the number of discontinuities sampled was too small to provide an adequate representation of fracture conditions at the site.
- JCA's structural data and slope-face orientations were plotted on equal-area stereonets. Analysis of angular relationships using stereographic techniques, such as a fracture stability analysis, should be performed using equal-angle stereonet projections.
- JCA concluded that rock slopes were probably stable if a majority of fractures or intersections did not daylight within the slopes. In fact, a slope is kinematically unstable if only one fracture or intersection is inclined out of slope.
- JCA performed a back-calculation for an assumed 70-degree failure surface and concluded that the rock slopes were stable. No documentation was provided as to why this failure surface was selected, or if this failure surface represents the critical surface.
- No field or laboratory tests were used to determine material strength properties. The material strengths required for stability were back-calculated from assumed failures, and these calculated strengths were assumed to be present in the rock. As stated in the geotechnical peer review (Pacific Crest Engineering, Inc. (PCEI), 2004), "Since there is no data presented showing the required strengths exist for stability, no conclusion can be drawn that the slopes are stable".
- JCA did not consider fracture strength independently of rock strength. Strength differences between clean joints and infilled or cemented joints were not considered. Sampling and laboratory testing of fractured rock, both with and without infill, is required to perform this analysis.
- Water pressures (i.e., open fractures filled with water during storm events) were not considered as part of JCA's analysis.

- The seismic coefficients used in the analysis do not reflect current information on seismic shaking intensities or seismic coefficient selection.

JCA considered the satisfactory past performance of the quarry slopes, as of the publication dates of their reports (1997), as evidence that the planned slopes of 80 degrees would be stable. The landslide failure observed during the winter of 2005-2006 call this conclusion into question. Quarry slopes had not been graded to the finished slope geometry at the time of the JCA analysis and none of the quarry slopes has been subjected to the peak expected seismic shaking that would be associated with a large event on the San Gregorio fault.

Stability of Overburden Cut Slopes

JCA employed Bishop's Method of Slices to analyze the potential for rotational failures in the planned 1½:1 (horizontal:vertical) soil and sandstone overburden cut slopes. No laboratory testing was performed on representative samples of soil or sandstone material to determine in-situ strength parameters. Instead, JCA back-calculated strength parameters from an assumed failure surface to obtain a factor of safety of 1.2 under seismic loading, using a seismic coefficient of 0.2g. Because the back-calculated strength parameters were considered to be representative of the sandstone, JCA concluded that the cut slopes were stable.

The JCA rotational stability analysis for the proposed overburden and sandstone cut slopes was found to be in general conformance with the local engineering standard of practice at the time of publication, but it was recommended that the strength parameters of the sandstone be documented to validate JCA's conclusions (PCEI, 2004). Revisions to the stability analysis are required to meet the current standard of care, specifically:

- Field and/or laboratory testing should be used to determine overburden and sandstone strength parameters, and a forward stability analysis should be performed using those strengths.
- Updated seismic coefficients should be employed based on current information and procedures for seismic coefficient selection.

Stability of Engineered Fill Slopes

JCA employed laboratory triaxial test results on remolded, laboratory-compacted, screened rock fines from the quarry to represent the material that is to be used as fill on the west side of the quarry. Strength parameters from these tests were applied to double-wedge and rotational failure models.

The stability analysis for the fill slopes was found to be in general conformance with the local engineering standard of practice at the time of publication (PCEI, 2004; see Appendix C). However, PCEI (2004) noted that no strength data was presented in the report for the tests performed on compacted, screened rock fines, and no strength testing was performed on remolded sandstone overburden material or on a mixture of rock fines and sandstone material, which is also to be placed as part of the fill. The following revisions to the slope stability analysis would be required to meet the current standard of practice:

- Laboratory testing should be used to determine remolded sandstone or mixed sandstone and rock fines strength parameters. The resulting laboratory strength data should be used in an updated stability analysis.
- Updated seismic coefficients should be employed in the stability model based on current information and procedures for seismic coefficient selection.

Stability of Settlement Basin Levees

Under the Final Drainage Plan (Bowman and Williams, 2001b as shown in Figure 10), Settlement Basins 3 and 4 would be serving the proposed Boundary Expansion Area. The stability analysis performed for the levee associated with Settlement Basins 3 and 4 indicated that the levees are not stable under expected seismic shaking conditions (based on a limit equilibrium approach). Golder (1991) calculated permanent seismically induced deformations of up to 9 inches (23 centimeters) for Settlement Basin 3 if the predicted peak seismic loading (0.27g) occurred while the levee was saturated. They did not state what form the deformation would take or what the consequences of that deformation would be.

It is possible for an earthen embankment to deform without failing. However, at some point, deformation can give way to structural failure, particularly with seepage forces present in the levee and where the possibility of piping exists (piping occurs where water seeping through an earth embankment progressively washes out soil particles, eventually eroding large pipes through the embankment). Piping can be a potential hazard under any conditions, but the hazard is increased if the embankment is subject to deformation due to seismic shaking.

As discussed in the liquefaction hazard discussion, above, the levee analysis was performed based on older seismic stability methods and information. A re-analysis using current methodology and information may produce different results.

4.3.4.2 Summary of Quarry Slope Stability Impacts

Landsliding in the quarry Boundary Expansion Area could occur under seismic or static (non-seismic) conditions, as indicated by the recent landslide within the quarry. The hazards associated with non-seismic landsliding are comparable to those associated with seismically induced landsliding. The types of landsliding that may occur are rock falls and rock topples along the quarry faces or large scale sliding of the overburden or marble exposed in the quarry faces.

Until updated stability analyses are completed as recommended, the stability of proposed Boundary Expansion Area slopes and the levees for settlement basins serving the proposed Boundary Expansion Area cannot be validated. The recent landsliding near Liddell Spring and within the quarry highlight the potential hazards. Depending on the results of the updated slope stability analysis, there may be a potential for large, seismically induced landslides to impact the landscape adjacent to the Boundary Expansion Area rim thereby elevating erosion and sedimentation hazards. Landsliding could damage the land in the 25-foot set back zone between the quarry rim and northern property line and could encroach upon the adjacent residential parcels to the north owned by CEMEX. Widespread rock falls or topples could also damage reclamation efforts after the mine is closed. These impacts are considered to be potentially significant. Ensuring stable slope gradients through updated stability analysis as required in mitigation Measure GEO-2 would reduce these impacts to a less than significant level.

Mining in the Boundary Expansion Area is a continuation of the existing mining operation. Worker safety at the Bonny Doon Quarries is regulated by Cal OSHA and the Mine Safety and Health Administration. As project Lead Agency, the County of Santa Cruz relies on the technical safety regulation by these federal and state agencies charged with worker safety at the quarry. The project does not put the risk to quarry workers beyond the reach of existing regulation. Therefore, the potential safety impacts of the project are less than significant.

The quarry wall length for the existing mining area and the Boundary Expansion Area combined is about 12 percent longer than that of the existing mining area by itself (measured as the circumference of the existing mining area compared to the circumference of the combined existing and proposed mining areas), with only a very little increase in length of the north wall of the quarry. Therefore, the net increase in steep quarry slopes due to the proposed expansion is not large. In addition, the amended grading plan for the quarry (Figure 9) calls for placing spoils from the Boundary Expansion Area along the western side of the quarry. The placement of these soils in compacted form would buttress the steeper quarry walls and reduce the landslide hazard in that portion of the quarry. These two factors together suggest that the proposed Boundary Expansion Area mining would result in a modest increase in exposure to slope stability hazards even if the updated stability analysis indicates that the quarry walls are likely to be unstable.

An updated slope stability analysis using current information and analysis techniques is necessary for validation of previous slope stability evaluations as they affect the proposed Boundary Expansion Area slopes. The updated slope stability analysis should also help determine if the factors that caused the 2006 landslide pertain to other areas in the quarry. Should the updated analysis indicate that the proposed finished slopes in the Boundary Expansion Area (Figure 9) are unstable with respect to significant landsliding, the proposed finished slope design may have to be altered to provide a more stable profile. “Significant” landsliding would include:

- landslides of substantial size, such that they may encroach on adjacent properties (on the north side of the proposed Boundary Expansion Area) or have the potential to result in serious erosion and sedimentation; or
- a determination that the proposed Boundary Expansion Area slopes are so unstable with respect to smaller scale landsliding that the occurrence of numerous landslides could interfere with the quarry reclamation plan.

The occurrence of “significant” landsliding is considered to be a significant impact. Mitigation measures for reducing potential impacts to a less than significant level are summarized under Measure GEO-2.

4.3.4.3 Liddell Spring Landslide

The Liddell Spring landslide complex has been extensively characterized by PGE (2001) (Geology and Hydrology Technical Appendix, Appendix F). Potential impacts on the Liddell Spring landslide due to quarry expansion include the following:

- Additional instability could be induced by blasting.
- Placement of additional spoils from the quarry near the head of the landslide complex could further destabilize the area.
- Changes in runoff patterns could result in increased saturation of the landslide mass.

The landslide complex includes an earthflow that PGE (2001) interprets as having occurred under natural conditions, prior to quarrying, and more recent debris flows exacerbated (if not triggered) by quarry spoils placed on the slopes above. The landslide abuts the City's spring box at Liddell Spring. The PGE (2001) geotechnical report presents their stability analysis and makes recommendations for stabilizing the landslide mass, should that become necessary. They concluded that there was a high potential for portions of the landslide to reactivate. In their opinion, however, there is a lower potential for renewed landsliding to impact the City of Santa Cruz's facilities at Liddell Spring. The landslide complex appears to have been stable since monitoring began in 2000 (Reid Fisher, personal communication, 2006).

The PGE (2001) report provides recommendations for reducing the landslide hazard at Liddell Spring, including drainage control, continued monitoring, and dewatering of the landslide mass. They concluded that blasting conducted for the quarry operation would be unlikely to induce new landslide movement at the spring site.

Renewed movement of the Liddell Spring landslide could damage the City's water diversion facility and degrade water quality at the spring. The proposed quarry expansion is unlikely to have an impact on the stability of this landslide provided that:

- no more quarry waste (e.g., overburden and off-spec rock) is placed on the slopes above Liddell Spring; and
- all concentrated runoff from the quarry or roads crossing the slope above the spring is carefully controlled and is not permitted to flow across the landslide area or across older quarry spoils above Liddell Spring.

These provisions are identified in Measure GEO-3.

4.3.5 Erosion

4.3.5.1 Erosion Process

Erosion results in the gradual lowering of the ground surface due to the action of wind and water. Erosion by water begins with the loosening of individual soil particles by rain drop impact and mechanical transport of soil particles by surface runoff. Runoff starts as sheet flow that collects into tiny rills guided by small irregularities in the ground surface. Rills merge into streams and streams into rivers. The larger streams and rivers have more erosive power so they cut down more rapidly, leading to ridge and valley terrain.

In areas where the slope aspect and rock type promote redwood forests, the redwood canopy intercepts rainfall and helps protect the soil from raindrop impact. At the same time, the buildup of tree litter under the canopy creates a thick layer of duff that absorbs water and protects the ground surface from erosion. Erosion rates in these areas can be relatively low. In contrast, in areas of sparse vegetation soils are exposed to direct impact by raindrops and have little protection from erosion caused by runoff. Wind erosion tends to be a more important erosion factor in arid climates, where surface runoff is minimal and sparse vegetation leaves soils exposed to the action of wind.

Cultural activities such as road building, logging, and (in some instances) wildfires can result in an increase in erosion rates, usually referred to as “accelerated” erosion. The degree to which cultural activities impact erosion rates depends on the nature of the activity, the manner in which the activity is conducted, and the natural susceptibility of the local earth materials to erosion. The creation of impermeable surfaces, such as paved roads, or the compaction of natural soils (rendering them less permeable) reduces infiltration into the soil and therefore increases runoff volumes.

Erosion can and does occur in natural settings undisturbed by human activity. However, human activities such as agriculture, timber harvesting, road building, and quarrying have the potential to increase erosion impacts by orders of magnitude over natural conditions. Removal of vegetative cover, grading, and changes in drainage courses or redirection of surface waters can cause accelerated erosion. This accelerated erosion results in loss of soil cover, which limits opportunities for the plant growth upon which natural ecosystems depend. Downstream transport and redeposition of the eroded material can destroy aquatic habitats in downstream areas.

4.3.5.2 Limestone Quarry Boundary Expansion

The proposed Boundary Expansion Area is partially overlain by as much as 150 feet of Santa Margarita Sandstone, a weakly cemented sandstone. The mechanical removal of this material would create loose sand and silt that may infiltrate buried karst sinks and open fractures, thus gaining entry to the karst aquifer system. This sediment would also be entrained in runoff from the proposed Boundary Expansion Area.

Removal of the overburden and quarrying in the proposed Boundary Expansion Area would increase the amount of runoff from the quarry as a whole by creating steep slopes and a larger area of exposed rock. The proposed quarry expansion therefore has the potential to cause erosion by exposing loose sediment to erosion and by increasing runoff volumes and velocities, which lead to erosion. These effects may result in sedimentation of downstream areas and increased turbidity at Liddell Spring if sediment-laden water percolates into the karst ground water system.

The removal of overburden from the original quarry area in 1969-70 is closely linked to instances of sedimentation and turbidity in Liddell Spring, as indicated by anecdotal accounts and turbidity data from Liddell Spring (Geology and Hydrology Technical Appendix, Appendix F). Erosion and sedimentation due to earth moving and road building during initial quarry development directed surface water flow toward Liddell Spring and other drainages. The initial erosion control problems resulted in the mine operator failing to meet the requirements of the RWQCB permit. The result of this development was that the RWQCB eventually required a three-year soil control/erosion control plan. Additional removal of overburden has reportedly occurred since then, presumably on a smaller scale. Evidence of major sedimentation or turbidity as a direct result of more recent clearing has not been reported.

Clearing of overburden from the existing quarry ultimately involved approximately 80 acres and included development of roads and other quarry facilities. Spoils were placed at several newly prepared locations around the quarry property. In contrast, the proposed expansion would involve clearing of 17.1 acres and would use existing roads and facilities. Boundary Expansion Area spoils would be placed at disposal area "C" and/or within the quarry pit. Disposal area "C" is already developed as a disposal area and is fitted with a developed drainage system and settlement basin. Runoff from the quarry pit is also contained and routed through settlement basins. For these reasons, the scale of the erosion and sedimentation associated with the proposed expansion is expected to be smaller than from the initial land clearing.

The Final Drainage Plan for the quarry, including the proposed Boundary Expansion Area, (Figure 9) shows all runoff being captured and conducted to the quarry floor, where it would concentrate and flow to Settlement Basin 3. This drainage scheme is to be implemented at some point during mining of the Boundary Expansion Area. Prior to that time, runoff would be impounded within the quarry, as is presently the case. Potential impacts due to the expansion of mining would be different during the period that runoff is being impounded within the quarry and when the quarry outlet is graded to drain to Settlement Basin 3. Potential impacts are expected to diminish gradually over time with implementation of planned reclamation measures at the end of mining.

Under the present drainage scheme, mining of the Boundary Expansion Area would result in increased runoff and sediment volumes being impounded on the quarry floor. During this time period, soil erosion due to the quarry expansion may impact ground water quality due to infiltration of sediment-laden water into the quarry floor. To the extent that the sediment-laden water flows to Liddell Spring, soil erosion in the Boundary Expansion Area could impact turbidity and sedimentation at Liddell Spring or in areas downstream from the spring. These issues are analyzed in the hydrology section, Section 5.0.

Under the Final Drainage Plan (Figure 10), runoff in the quarry, including the Boundary Expansion Area, would be collected on inboard-sloped benches and would then flow to down-drains leading to the quarry floor. From the quarry floor, the runoff would flow to Settlement Basin 3. No provision is shown on the plan to slope the benches toward the down-drains. Sediment-laden runoff flowing along the benches may enter the subsurface where the bench drains cross open fractures or conduits, possibly contributing to turbidity and sedimentation at Liddell Spring, but this impact should be less than that related to the impounding of runoff within the quarry. However, the Final Drainage Plan (Figure 10) would greatly increase flow to the settlement basins. As discussed in the slope stability and liquefaction sections, above, updated stability and liquefaction potential evaluations for the settlement basin levees are warranted. Should any of the levees be unstable, the increased runoff due to the proposed Boundary Expansion Area would increase the potential for sedimentation of downstream areas.

At the end of active mining, the reclamation plan would result in revegetation of the quarry and other remedial measures that would reduce the supply of loose sediment over time. Provided the reclamation plan is successfully implemented, the potential hazard due to erosion and sedimentation would diminish over time.

Under any drainage condition, the principal erosion and sedimentation impacts due to mining of the Boundary Expansion Area would be related to removal and disposal of overburden. No drainage plan for controlling runoff and erosion during the actual process of removing overburden from the Boundary Expansion Area has been provided. The removal of this overburden may have significant impacts on erosion and sedimentation, unless appropriate mitigation measures are implemented over the short term. Where runoff from the quarrying operation is detained within the quarry, the increased erosion and sedimentation could impact turbidity and sedimentation at Liddell Spring or in waters downstream from the spring. The development of a drainage plan to address the potential water quality impacts of increased sedimentation in quarry runoff is required in Measure HYD-1. The impact of increased sediment loads on water quality is further addressed in Hydrology (Section 5.0).

4.3.6 Cumulative Impacts

The geologic impacts of the project include slope stability of the new cut and fill slopes, stability of settlement basin levees serving the Boundary Expansion Area, and erosion. These impacts are confined to the project site. Future mining may occur in the 9.4 acres remaining within the Legal Mining Limit. Mining in this area would have similar geological impacts as the proposed project. Mitigation measures applied to the Boundary Expansion Area would also be applicable to mining the remaining 9.4-acre area. The combined geologic impacts of the proposed project and mining in the remaining area on slope stability, levee stability, and erosion can be controlled through mitigation. There are no significant cumulative impacts associated with the project.

4.4 MITIGATION MEASURES

The following measures would reduce significant geology impacts to a less than significant level.

IMPACT: *A liquefaction assessment of the quarry settlement basin levees has not been performed. A displacement analysis for seismic shaking shows basin levees would move under seismic shaking. Mining the Boundary Expansion Area would result in increased runoff volumes and sediment loads entering quarry settlement basins. The project may result in sedimentation of downstream areas if settlement basin levees receiving runoff from the quarry Boundary Expansion Area fail during a major seismic event.*

Measure GEO-1: The Applicant shall update seismic stability evaluations and prepare liquefaction hazard evaluations for settlement basins that would be receiving runoff from the proposed Boundary Expansion Area, based on the current state of knowledge and standards of practice. The seismic stability and liquefaction hazard evaluations shall be completed and submitted to the County Planning Department as a condition of approval. The evaluations shall examine levee stability whether due to embankment deformation or liquefaction within or under the levee and shall consider the potential for piping to accompany deformation. Methodologies discussed in Blake, et al. (2002) for seismic slope stability evaluation and Seed et al. (2003) for liquefaction analysis are currently employed in Santa Cruz County, but more current analytical methods may be used. Given the proximity and 400-year recurrence interval on the San Gregorio fault, a deterministically derived maximum earthquake acceleration, magnitude, and distance based on the expected event on the San Gregorio fault may be more appropriate for analysis at this site than the probabilistic acceleration and de-aggregated magnitude and distance.

The stability and liquefaction susceptibility evaluations shall include sufficient field investigation to document the foundation condition and relative density of both levees. If the analysis predicts permanent seismically induced deformation of the levee, the consequences of that deformation with respect to the overall stability of the levee shall be clearly stated. In general, permanent deformations greater than 6 inches (15 cm) shall be considered unacceptable, but any predicted deformation shall be evaluated within the context of the levee material properties and design.
A completed liquefaction and stability analysis for the levees shall be provided to the County of Santa Cruz Planning Department for review. If the results of the stability evaluation indicate that there is a potential for failure of the levees and release of impounded runoff to downstream areas, the levees shall be modified by the quarry operator to satisfy stability concerns. Any modifications of the levee shall be based on sound engineering design. All design documents and evidence of satisfactory completion of the levee modifications must be provided for approval to the County of Santa Cruz Planning Department.

Implementation:	by CEMEX
Effectiveness:	Measure would ensure that the levee of the quarry basin receiving additional runoff and sediment from the project meets current seismic standards reducing the risk of seismic failure and the potential for release of sediment downstream.
Feasibility:	Feasible. Any required modifications would be based on industry design standards.
Monitoring:	Updated seismic stability evaluations for settlement basin shall be submitted to County for review and approval prior to commencement of project.

IMPACT: *The project may result in landsliding of proposed Boundary Expansion Area slopes, either during quarrying or after closure of the quarry, potentially resulting in accelerated erosion, water quality impacts, or encroachment of landsliding onto lands adjacent to the proposed Boundary Expansion Area.*

Measure GEO-2: The Applicant shall prepare an updated slope stability evaluation for proposed slopes in the Boundary Expansion Area. Quarry walls shall be evaluated based on methodology appropriate for jointed rock slopes. Slopes in overburden materials, such as the Santa Margarita Sandstone and overlying soils shall be evaluated based on translational or rotational slope stability models.

Recommended Procedures for Stability Analysis of Jointed Rock Slopes

A stability analysis for hard rock slopes (such as granite or marble), where failure is controlled by joints, fractures, or other discontinuities, requires that the nature of these discontinuities be adequately characterized. A preliminary rock slope reconnaissance must be performed to identify structural domains with statistically homogeneous joint or fracture characteristics, including average orientation, spacing, length, continuity, and infill or cementation characteristics. The boundaries between adjacent structural domains are usually represented by lithologic contacts, faults, or some other prominent change in the rock mass. During the quarry geologic reconnaissance, three structural domains within the quarry were identified, defined by faulted boundaries (Geology and Hydrology Technical Appendix). Where relevant to the proposed Boundary Expansion Area, these domains shall be confirmed and refined, as necessary, as part of the slope reconnaissance. Discontinuities within each domain shall be characterized in detail, using orthogonal scanline or window surveys.

Once structural domains are correctly identified and information on discontinuities has been collected, statistical methods (using stereographic density contouring or specialized software) must be applied to the measured discontinuities in each structural domain to determine averages or ranges for each set of spatially grouped discontinuities. These discontinuity averages or ranges are plotted on an equal-angle stereonet as point representations (dip and dip direction) for the plane analysis of single sets of fractures, and as intersection lineations (plunge and trend) for the wedge analysis of intersecting sets of fractures.
A kinematic fracture stability analysis must then performed comparing these discontinuities with a great circle representation of a proposed slope face, plotted on an equal-angle stereonet. Fractures and intersections that plot within the great circle are kinematically stable, meaning that these features dip steeper than -- and do not “daylight” within -- the proposed slope face. Conversely, fractures and intersections that plot outside the great circle are potentially destabilizing.

A limit equilibrium analysis, comparing driving and resisting forces, is required to resolve each potential failure scenario identified by a kinematic analysis. Forces acting on plane- or wedge-bounded failure blocks, including rock friction, infill cohesion and friction angle, hydrostatic forces, normal forces, and seismic forces, can be analyzed stereographically as part of a limit equilibrium analysis. Certain rock, fracture-infill, and fracture-cement properties required for a limit equilibrium analysis, such as cohesion and friction angles, would require laboratory testing to resolve. Seismic shaking coefficient input values shall be adjusted to account for topographic effects associated with steep slopes (see Ashford and Sitar, 1994; 2002).

The results of the limit equilibrium analysis are used to characterize expected failure modes. Given the height and steepness of the proposed quarry walls, an evaluation of sliding due to rupture through intact marble shall also be evaluated to see whether it should be included as a possible failure mode.

Recommended Procedures for Stability Analysis of Soft Rock or Soil Slopes

Overburden, sandstone, and fill slopes associated with Boundary Expansion Area mining are adequately treated as classic soil slope stability problems, without specific reference to discontinuities. Typical rotational slope failure models, such as the Bishops, Janbu, or other commonly used analytical method may be employed. Rock or soil densities and strengths used in the analysis shall be based on laboratory testing of field samples of each material constituting the slope model.

The seismic coefficient used in the analysis shall be based on current methods for coefficient selection (Blake et al. (2002) or more current) and shall account for topographic amplification. Soil strengths used in the analysis shall be selected to take into account potential dynamic and strain (displacement) related reductions in strength. If a displacement rather than limit equilibrium approach is taken to evaluating slope stability in this context, displacements of 4 to

12 inches (10 to 30 cm) shall be considered potentially significant. Displacements greater than 12 inches (30cm) shall be considered unacceptable.

The results of both the jointed rock slope and soft rock or soil slope stability evaluations shall be used to define the type of slope failures expected in the proposed Boundary Expansion Area, whether deep seated or shallow, and the degree of instability associated with the potential failures. "Significant" landsliding has been defined above as:

- landslides of substantial size, such that they may encroach on adjacent properties (on the north side of the proposed Boundary Expansion Area) or have the potential to result in serious erosion and sedimentation; or
- a determination that the proposed Boundary Expansion Area slopes are so unstable with respect to smaller scale landsliding that the occurrence of numerous landslides could interfere with the quarry reclamation plan.

Evidence for significant landslide hazard would include stability analysis results that predict large block or deep-seated circular failures with factors of safety less than 1.2 or widespread smaller failures with factors of safety less than 1.0. A factor of safety against large-scale failures of 1.2 is indicated in the 1997 Conditions of Approval. The 1997 Conditions of Approval, Part 1, III.A.7.(2) (Santa Cruz County, 1997) state that "all final cut slopes completed after September 12, 1996, shall have a stability factor of safety not less than 1.2 …"

The completed stability evaluation shall be provided to County of Santa Cruz Planning Department for review. If the stability analysis indicates a potential for significant landsliding, the configuration of the working or finished Boundary Expansion Area slopes shall be redesigned by the quarry operator to mitigate the landsliding hazard. All documentation related to slope redesign shall be provided to the County of Santa Cruz Planning Department.

The validity of the slope stability model shall be evaluated as mining progresses based on periodic surveys of rock types, fracture orientations, and faulting. These surveys shall be documented and provided to the County of Santa Cruz at least once annually. If any changes in earth material lithology or structure occur that might affect the conclusions of the slope stability analysis, the analysis shall be revised. Any indication of significant landslide hazard based on the revised stability analysis shall be mitigated by design.

Implementation:	by CEMEX
Effectiveness:	Proper analysis of quarry slope stability would allow identification and mitigation of potential slope stability hazards.
Feasibility:	Feasible. These studies can be completed and proper design measures instituted based on current industry standards.
Monitoring:	Updated stability evaluations shall be submitted to County for review and approval prior to commencement of project. All mitigating designs shall be submitted to the County for review and approval.

***IMPACT:** Renewed movement of the Liddell Spring landslide could be caused if drainage is diverted towards the landslide or dumping of overburden, off-spec rock or other waste occurs on the slopes above the spring.*

Measure GEO-3: No quarry waste (e.g., overburden and off-spec rock) or other soil or rock shall be placed on the slopes above Liddell Spring. All concentrated runoff from the quarry or roads crossing the slope above the spring shall be carefully controlled and shall not be permitted to flow across the landslide area or across older quarry spoils above Liddell Spring.

Implementation: by CEMEX
Effectiveness: Avoidance of uncontrolled surface drainage and placement additional quarry material on slopes above Liddell Spring would protect against de-stabilizing the landslide mass and triggering renewed movement.
Feasibility: Feasible. Drainage can be controlled through implementation of additional controls. No dumping of quarry material is proposed in landslide area.
Monitoring: Routine inspections by County.

***IMPACT:** The project may result in accelerated erosion within the Boundary Expansion Area, potentially impacting water quality or quantity flowing to Liddell Spring.*

Measure HYD-1: (See Section 5.4 in Hydrology and Water Quality for a complete description).

Implementation: by CEMEX
Effectiveness: Implementation of the drainage plan provisions would control runoff in the expanded mining area, reduce runoff exposure to sediment sources, reduce exposure of rock fissures and voids to runoff containing sediment, and remove sediment from runoff entering the ground water through the quarry floor. These measures would reduce the turbidity impacts on Liddell Spring and sedimentation of downstream drainages. Impacts would be reduced to a less than significant level.
Feasibility: Feasible. Movable plastic membranes can be used to line benches and collect runoff in areas not being actively mined. The runoff so collected can be conveyed to the quarry floor by temporary down-drains. The efficacy of placing a compacted fine-grained cover on the quarry floor was previously disputed (SECOR, December 1998; EMKO, August 1999). However, given proper engineering consideration, a suitable sediment filter could be designed and installed as a basal layer of the planned fill placement in the base of the quarry. The filter would have to prevent migration or collapse of fill into solution channels or voids, but should maintain some permeability to allow ponded runoff to percolate.
Monitoring: Drainage plan shall be submitted to County for review and approval prior to commencement of project.