INTERIM GEOLOGICAL REPORT

ON THE

STANFORD TWO-MILE LINEAR ELECTRON ACCELERATOR SITE

SAN MATEO COUNTY, CALIFORNIA

REPORT TO STANFORD LINEAR ACCELERATOR CENTER

STANFORD UNIVERSITY SUBCONTRACT NO. 8-128

UNDER AEC CONTRACT AT(04-3)-363

Submitted by [Signature]

Approved by [Signature]

AETRON-BLUM-ATKINSON
A Joint Venture
ARCHITECT-ENGINEER-MANAGER
580 College Avenue
Palo Alto, California

November, 1962

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## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>2</td>
</tr>
<tr>
<td>SUMMARY</td>
<td>4</td>
</tr>
<tr>
<td>GENERAL GEOLOGY</td>
<td>5</td>
</tr>
<tr>
<td>STRATIGRAPHY</td>
<td>5</td>
</tr>
<tr>
<td>General Observations</td>
<td>5</td>
</tr>
<tr>
<td>Mesozoic Rocks</td>
<td>7</td>
</tr>
<tr>
<td>Jurassic</td>
<td>7</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>9</td>
</tr>
<tr>
<td>Cenozoic Rocks</td>
<td>10</td>
</tr>
<tr>
<td>Eocene</td>
<td>10</td>
</tr>
<tr>
<td>Miocene</td>
<td>17</td>
</tr>
<tr>
<td>Pleistocene and Recent</td>
<td>27</td>
</tr>
<tr>
<td>STRUCTURE</td>
<td>28</td>
</tr>
<tr>
<td>ENGINEERING GEOLOGY</td>
<td>36</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>37</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>38</td>
</tr>
<tr>
<td>APPENDIX 1</td>
<td></td>
</tr>
</tbody>
</table>
INTRODUCTION

The present report is the third in a series of reports on the geology of the Sand Hill area, the site of Stanford University's linear electron accelerator. The first preliminary report (8) submitted in December 1961, was based largely on the results of a rapid survey of the geologic structure and stratigraphy exposed in San Francisquito and Bear Creeks and along Sand Hill and Alpine Roads. These features form the periphery of the Sand Hill area. Relevant information contained in previous reports on the general geology and the engineering geology of the area (particularly those of F. W. Atchley) also was included in the preliminary report. These sources of information are listed in the bibliography of the present report (1), (2), (3), (4), (5), (6), (7), (10), (11) and (12).

The second report (9) on the accelerator site was submitted in October 1962. This report and its map, included in the present report as Appendix 1, are devoted principally to those aspects of structure and stratigraphy that bear on the engineering geology of the site. Slight differences in corresponding areas of the two maps arise as the result of the incorporation of information either not available for the October issue or not fully developed at that time.

The present report represents a reconciliation of the opinions expressed in the preliminary report with those developed as the result of additional detailed work in San Francisquito Creek, a review of the information afforded by the exploratory trenching and drilling operations in late 1961 and the forepart of 1962, and the study of paleontologic information developed by E. E. Brabb (13) of the United States Geological Survey and K. L. Edwards (14), consultant in paleontology.
Additional information on the geology of the Sand Hill area also has become available as the result of discussions with Erabb, T. W. Dibblee, Jr., and E. Pampeyan of the United States Geological Survey; with R. M. Page of Stanford University; and with R. R. Skjel, F. R. Conwell, and E. A. Dunchy of the engineering geology group of Astron-Blume-Atkinson.

The geological map evolved from all of the above-mentioned sources of information does not differ significantly from that submitted with the preliminary report in December 1961. The principal changes are: (a) the provisional assigning of a synclinal rather than a fault origin to the long northerly-trending topographic depression passing through Alignment Station 60+00, and (b) the mapping of what now appears to be a relatively narrow band of steeply-dipping sandstones and claystones of probable Upper Eocene age passing northerly across the accelerator alignment between Stations 76+20 and 32+10. These changes, and others of lesser importance, are described in subsequent pages of this report. Alignment Stations are shown on the accelerator centerline on the accompanying map.
SUMMARY

The geological features of the Sand Hill area, the site of the Stanford Linear Electron Accelerator, are largely concealed by a soil mantle and vegetation. Reconnaissance geological field work was done in 1960 (4). In order to more fully investigate the geologic structure and stratigraphy of the area, additional field work and extensive exploratory trenching and drilling operations were carried out in late 1961 and early 1962. The present report and its maps present current conclusions on the geology of the area based on all information thus far accumulated.

The Sand Hill area is underlain by rocks of Jurassic, Eocene and Miocene age and, possibly, by rocks of Cretaceous ages. The later Quaternary deposits along the accelerator alignment consist of sporadically distributed dark-colored gravels lying in sheet-form on slopes and on hilltops. The Eocene section consists of interbedded sandstones and claystones. The Miocene rocks consist predominantly of sandstone. Minor amounts of claystone occur near the top and, possibly, at or near the base of the Miocene section.

The Eocene rocks of the Sand Hill area have a complex geologic structure, with faulting the predominant structural feature, particularly in the southwestern part of the area. Early folding may have occurred, but if so it has been all but obliterated by subsequent faulting. The age of the faulting is not known; most of the Miocene rocks are relatively undeformed except near their western boundary where they may be in fault contact with rocks of Eocene age. So far as now known there are no known active faults in the accelerator area.

The San Andreas fault passes one mile west of the western end of the accelerator alignment. The potential threat it poses to the stability of
the accelerator is accepted as a calculated risk.

In the report of Appendix I the advantages and disadvantages from an engineering standpoint of the differing rock formations present in the accelerator area are evaluated. The conclusion is that there is no presently known defect to prevent the safe construction and operation of the accelerator.
GENERAL GEOLOGY

STRATIGRAPHY

General Observations

The cumulative effects of several periods of severe deformation combined with the nearly complete concealment of the country rocks of the accelerator site by alluvium and regolithic deposits make it impossible to present a complete account of the stratigraphy of the site and its peripheral area. Exploratory trenching and drilling operations yielded results of such caliber than an adequate lithologic sequence could be established along the accelerator alignment, but from the standpoint of structural information, results of these operations were inadequate. The reasons for this lie in the inherent massiveness of the sandstones of the Tertiary rocks and, with regard to the trenching operations, the highly weathered condition of most of the rocks encountered within the limits of excavation.

The acquisition of paleontologic information in recent months has provided helpful additional data. However, there are still critical gaps in the information necessary for the accurate delineation of formational contacts, notably in separating rocks of Eocene age from those of Miocene age. It is anticipated that examination of fossil-bearing samples recovered in deep excavations will assist in these distinctions.*

The two most important rock boundaries in the Sand Hill area are those separating the Jurassic metamorphic rocks (serpentine) of Jasper Ridge and

* Excavation of the westernmost 3000 feet of the accelerator alignment is scheduled to begin in November or December of 1962.
lower Bear Creek from the Eocene rocks to the north and northeast, and the Eocene from those of Miocene age. Regardless of the possibility that only slight differential movement may have occurred along the plane, or in the zone, of each of the two boundaries, the opinion is that both are more in the nature of faults rather than normal deposition. One reservation to this opinion, expressed in the preliminary report, is that the contact of the Eocene rocks with the serpentine in and west of the locality of Rattlesnake Rock may be one of normal deposition. The Eocene-Miocene boundary that crosses the accelerator alignment between Stations 49+00 and 50+00 may in its northwesterly trend out of the Sand Hill area be of depositional nature.

In the following discussion the stratigraphy of each time-rock sequence from later Mesozoic to late Cenozoic is briefly described. The lithology of the respective rocks is outlined; the lithologic descriptions appearing in the preliminary report generally are valid and may be reviewed to augment the descriptions of the present report.

**Mesozoic Rocks**

**Jurassic**

The Jurassic rocks of the Sand Hill area are represented by serpentine, the altered equivalent of ultrabasic igneous rocks. The serpentine occupies much of the top and western end of Jasper Ridge along which it is in contact with sandstones of Eocene age. It occurs in a form typical of its occurrence in other areas of the San Francisco Bay region, namely in pale grayish-green, structureless masses.
Landsliding may have occurred in the serpentine area immediately southeast of Rattlesnake Rock. If sliding has occurred there, the accuracy of the presently shown boundary between the serpentine and the Eocene sedimentary rocks may thereby have been prejudiced. The relationship as now interpreted is discussed in the present report in the section devoted to the description of the Eocene rocks.

A small isolated mass of serpentine in part flanked by silicate-carbonate rock crops out near the northeastern corner of the Sharon Heights golf course. So far as now known the outcrop occurs in an area largely, if not wholly, made up of rocks of Upper Eocene age. A possible exception to this arises from the fact that Cretaceous fauna have been found in rocks in a locality approximately 500 feet SSE of the serpentine, but there is the possibility that the fauna may be of the redeposited type. The problem is discussed in a subsequent paragraph.

Hard, bluish-gray, schistose rock crops out intermittently over a distance of 170 feet in the lower part of Bear Creek, beginning upstream approximately 100 feet southeast of Station 470. The age of the schist is unknown but is presumed to have formed in pre-serpentine time.

There is a noteworthy occurrence, also in the lower part of Bear Creek, of a massive, detrital, fine to pebbly sandstone of shattered aspect. The outcrop is on the south side of the creek, approximately 275 feet upstream from the juncture with San Francisquito Creek. The rock contains debris resembling serpentine. The age of the rock may be Franciscan. A similar type of sediment containing granules and small pebbles of serpentine
is noted by Pampeyan in the locality of the schist described above.

Cretaceous

Rocks of this age now are believed to crop out in at least one, and possibly two localities in the Sand Hill area. The known locality, outside the map area, is in San Francisquito Creek about 200 feet downstream from the Willow Road bridge. According to Graham (Geol. Soc. Amer., Abstracts, 1959, V. 70, p. 1610) the rocks at that locality are of Campanian age. The outcrop consists of irregularly-bedded, concretionary, light gray and olive brown claystone and siltstone. The attitude of the beds cannot be accurately determined but is estimated to be about 75 degrees southerly, the inclination of a tabular concretion in the beds. Beds of probable Upper Eocene age, dipping 65 degrees southerly, crop out at sample locality 68 approximately 500 feet upstream from the bridge. The relationship of these to the above described Campanian beds is unknown; the contact, assumed as a faulted one prior to the determination of the Eocene age of the rocks at locality 68, may equally well be one of normal deposition.

Rocks of Upper Cretaceous age may be present in sample locality 95, in the northernmost part of the map area. The sample, collected for later lithologic study, was taken over a distance of 100 feet in a trench excavated during the construction of the Sharon Heights golf course. The Upper Cretaceous age of the rocks at the locality is not certainly established because of the finding during paleontologic examination of admixed fauna of Eocene age. The paleontologist concluded that either an Eocene-Upper Cretaceous boundary had been crossed during sample collection, or that

* Oral communication, November 2, 1962.
contamination had occurred in the laboratory. A replotting of the traverse indicates that the paleontologist probably selected for study a sample from only one of the claystone bands encountered in the traverse, and an alternative conjecture is that the claystone is of Eocene age but contains reworked Upper Cretaceous fossils, although so far as now known no other rocks determined as of Eocene age were found to contain Cretaceous fossils. The beds from which the above-described sample probably was taken lie about 500 feet S 30°E of the serpentine of sample locality 96 and near Fault XV, as shown on the maps of both the 1961 preliminary and the present report.

The subsurface extent of the Cretaceous rocks is unknown. So far as known, rocks of that age were not encountered during either the trenching or drilling operations. Rocks of Cretaceous age thus far have not been reported along the serpentine contact in the southwestern part of the Sand Hill area. However, they may be present but concealed either by faulting or, if the contact is assumed as a depositional one, by onlap of sediments now designated as of Eocene age. A third possibility is that the detrital, serpentine-bearing sandstones in the lower part of Bear Creek may be of Cretaceous age.

**Cenozoic Rocks**

**Eocene**

Rocks of this age are best exposed in the southwestern part of the map area, principally in the upper part of San Francisquito Creek and the lower part of Bear Creek. As exposed there the Eocene sequence consists of beds of hard, erosion-resistant, light to dark gray, bluish-gray, and greenish-gray sandstones with which are interbedded notably softer, medium
to very dark gray, silty to fine sandy claystone and siltstone. No mappable bodies of conglomerate have been found in the Eocene section to date, although in a few places thin lenses of fine pebbles do occur in the sandstones. One such locality is on the bank of San Francisquito Creek, 200 feet northwest of Station 805. A second locality of pebble-bearing sandstone crops out near Fault I, on the northerly slope of Jasper Ridge and approximately 130 feet southeasterly of Station 1031. The sandstones of neither locality contain pebbles of serpentine.

All of the Eocene rocks are believed to be of marine origin. Foraminifera are fairly prevalent and have been used principally to more closely establish the boundary with the Miocene rocks between Alignment Stations 49+00 and 50+30, and near 82+00.

Assuming it to be in a locality unaffected by faulting, the thickest sandstone member in the Eocene section, dipping steeply to the north, appears to be that of Rattlesnake Rock where the thickness is estimated to be 450 to 500 feet. The thickest single sandstone encountered along the accelerator alignment lies between Stations 42+50 and 47+50 where the thickness is estimated at about 400-500 feet; this particular member includes a few thin beds of claystone. A contiguous, yet greater thickness of Eocene sandstone may be present in the northerly slope of Jasper Ridge, farther to the southeast, but exposures there are so few that a value cannot be assigned.

Most sandstones of Eocene age are of detrital nature, frequently containing, besides quartz, angular to subangular grains and fragments up to granule size of what appear to be crystalline rocks, chert, and feldspar.
This type of assemblage and the fact that characteristically they are poorly sorted serve as empirical evidence in distinguishing them from the "cleaner" sandstones of Miocene age.

The Eocene sandstones generally are hard, of medium grain size, but may be found in both finer and coarser grade sizes. They weather to tan or greyish-tan colors and in so doing assume rounded or blocky form, as at Battlesnake Rock. The sandstones are not notably concretionary and are almost always so poorly bedded that the obtaining of reliable bedding-plane attitudes is impossible. Cross bedding rarely is discernible and when present is but faintly developed. The sandstones are not excessively jointed except in and near shear zones. The joint pattern has not been systematically surveyed but from study to date the more prominent joints appear to strike NW or NE and dip steeply NE or NW. Cementation of the sandstone is effected in some cases by a hardened admixture of kaolin and limonite but more generally by calcite or silica, the latter probably being the more prevalent.

The claystone and siltstone with which the sandstone is interbedded, frequently in rhythmic succession, are best exposed in San Franciaquito and Bear Creeks. They rarely possess definite bedding and appear to be closely jointed. In those localities where the claystone and siltstone long have been subjected to the drying action of the sun they characteristically fracture into innumerable small angular fragments, probably the result of intersecting bedding- and joint-patterns. Weathered colors range from pale gray through bluish-gray to olive brown and green. Narrow sandstone dikes occur in claystones in San Franciaquito Creek near Fault VI, and downstream near the contact of the Eocene rocks with those of Miocene age.
In the southwestern part of the Sand Hill area the single thickest sequence of the finer-grained Eocene sediments may be that along the accelerator alignment between Stations 12+50 and 19+00. Disregarding the thin sandstone interbeds there, the thickness appears to be about 250-300 feet. The determination of an accurate ratio of sandstone to claystone and siltstone is made virtually impossible by the presence of complex structure; it is estimated that the gross ratio is about 60:40.

As encountered in trenching and drilling operations many claystones and siltstones were found to be slickensided, polished, and seemingly brecciated. In most, but not all such cases, associated sandstones were not so affected. The present opinion is that in some instances these phenomena are their origin to surface and near-surface agencies, probably creep, swelling, and heaving. In other cases features of the type here described may be the result of shearing attendant on the up-ending of sequences of alternating competent and incompetent strata. Similar phenomena also are noted in Miocene claystones and siltstones.

Complex structure and concealment by Quaternary deposits precludes accurate determination of the stratigraphic succession in the Eocene section of the Sand Hill area. Assuming that the thick sandstone sequence at Rattlesnake Rock is in normal contact with the serpentine or, if faulted not to the extent of great displacement, it appears that the deposition of the Eocene sediments was of such nature that the bulk of the sandstone tends to underlie claystone and siltstone. There is considerable substantiation of this order of succession as shown in the eastern part of structure section A-B of the preliminary report. In the syncline shown in that part of the profile the
Sedimentary rocks, formerly thought to be of Miocene age but subsequently found to be of Upper Eocene age, are so disposed that claystone and siltstone do overlie a relatively thick section of sandstone. The thickness there is about 1500 feet. For the present the succession here outlined is assumed to hold true. It may have been of the transgressive type.

Because of the severe deformation of the Eocene rocks accurate determination of their thickness is difficult. Atchley and Dobbs (1) estimate a thickness of 4000 feet. The writer's estimate, as given in the preliminary report, is 3000-3500 feet. The thickest section seemingly uncomplicated by faulting has a thickness of about 1100 feet. This section is on the accelerator alignment, between Faults VIII and IV.

Worthy of note in the description of the lithology of the Eocene rocks is the presence in their midst, in the northeastern part of the map area, of a small body of igneous rock. The igneous rock crops out on the southwest slope of a ridge in a locality approximately 2,500 feet N 73°W from the intersection of Sharon Heights Drive and Sand Hill Road. The outcrop, oriented northeast, is about 100 feet long by 20 feet wide, has a brecciated aspect, and consists of light putty-gray, pale lavender gray, and cream-color silicified rock some of which bears a resemblance to similar colored siliceous sediments in the Miocene sequence of the area. According to Panayotov*, however, the rock is rhyolite. A hand-lens examination verifies the igneous origin of the rock, some fragments showing the presence in a dense fine-grained matrix of phenocrysts of dark ferromagnesian minerals, including euhedral crystals of biotite. Sandstones of Eocene age occur on

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* Oral communication, October 29, 1962.

- 14 -
line to the northeast and at a distance of about 50 feet. No alteration
effects are noted in the sandstone. The latter is feldspathic and contains
occasional small fragments which may have been derived from the igneous
rock.

The distribution of the Eocene rocks in the southwestern part of
the Sand Hill area remains essentially as shown on the map of the preliminary
report. The distribution in the rest of the area is shown in somewhat changed
form, as illustrated on the maps of the present report. The rearrangement in
substantial part has been affected on the basis of recent paleontological
studies, and to a lesser extent by the adopting of information shown on other
geological maps, (15), (16), of the area, where such data have been found
consistent with those assembled during the field work of the past year.

From paleontological studies it is believed that a considerable part
of Sand Hill area is underlain by Eocene and possibly older rocks, and that
a trend of exposed Upper Eocene rocks 700 feet or more wide passes northerly
through the eastern part of the accelerator alignment. The lithology of the
Eocene rocks there differs in no essential respect from that of rocks of the
same age in the southwestern part of the Sand Hill area.

Throughout most of its extension the boundary of the Eocene sedi-
mentary rocks with the serpentine is believed to be that of a fault rather
than one of normal deposition. The evidence to prove this is indirect but
of such nature that it cannot be wholly disregarded. The principal evidence
consists, along some segments of the boundary, of known and probable trunc-
ation of the sedimentary rocks by the serpentine, and the dip of the former
into the serpentine, particularly when the angle of inclination is relatively low. The presence of detrital serpentine in the sedimentary rocks near serpentine in place is considered firm but not conclusive evidence that the contact is of depositional nature; the absence of such detritus does not necessarily strengthen the case for faulting.

There is no assurance that the above-described serpentine-bearing sandstones in lower Bear Creek are not of pre-Eocene age; so far as now known no sandstones now accepted as Eocene age, and near the contact along the latter's trend in the western part of Jasper Ridge carry detrital serpentine, although Pempeyan^ is does report serpentine pebbles in sandstone near the contact farther southeast.

At Station 417, the junction of Bear Creek with San Francisquito Creek, the contact of the Eocene sedimentary rocks with the serpentine is present within a concealed interval 10 to 15 feet wide. There the lowermost observable beds, devoid of serpentine detritus, consist of tan siltstones and sandstones. This unit directly underlies a massive brown sandstone, the plane of the contact of the two units dipping 60 degrees in a NNW direction. Several feet northerly there is a faint indication of near-vertical dip, not shown on the accompanying map because of uncertainty that it is actually present.

From Station 417 the contact, determinable within limits of 50-100 feet, trends ENE up the slope of Jasper Ridge to an intersection with Vault XIX.

^ Oral communication, October 1962.
The Eocene strata of Rattlesnake Rock appear truncated against this fault. Similar conditions, including possible truncation of Eocene beds, appear along the contact in San Franciscquito Creek from whence the contact passes upslope to the top of Jasper Ridge. There, between Stations 1049 and 1055, sandstone probably of Eocene age and within a few feet of serpentine in place, dips steeply toward the older rock. So far as now known detrital serpentine is not present in the sediments of that locality. The beds there appear to be truncated westerly by Fault I.

The angle of dip decreases as the contact zone is traced southeasterly beyond the limits of the map area; at Station 725 the dip is 55 degrees southwesterly into the serpentine, in well-bedded, highly glauconitic sandstone. According to Pompeyan the dip becomes less to the southeast outside the limits of the map area.

The descriptive material of the foregoing paragraphs represents a brief recapitulation of presently available field evidence. The present interpretation is that although part of the boundary between the Eocene rocks with the serpentine—possibly that part at and west of Rattlesnake Rock—may be of the depositional type; the balance of the boundary is a faulted one. This conclusion does not necessarily demand that the plane of the contact itself be a fault; the actual fault could be nearby and wholly confined to serpentine.

Miocene

Rocks of Miocene age are well developed in the Sand Hill area, occurring principally along the eastern part of the accelerator alignment, from whence they extend northerly beyond Sand Hill Road and southerly to and
beyond San Francisquito Creek. All of the Miocene rocks are believed to be of marine origin.

The Miocene rocks in the upper part of the section, as exposed by trenching and drilling operations along the alignment east of Station 82+30, consist of fine- to medium-grained sandstones and are believed to be over- and underlain by claystone, which includes indefinite zones of siltstone and thin sandstone beds. The ratio of the sandstone to the finer-grained sediments is estimated at about 60:40. This value is a rough approximation because of the absence of adequate structural control.

The sandstones of the alignment area east of Station 82+30 are relatively soft, of subangular grain, and generally well sorted. They are noticeably quartzose, with a well-washed, "clean" aspect. Cementation, by limonite, is poor. Some are silty, but there is little interstitial clayey material, a disadvantage in the use of the sandstone as compacted fill material.

The unweathered sandstone is of light gray color, the weathered equivalent of light tan color. It was found during the drilling operations that the tan hue, that characterizing the zone of oxidation, abruptly changes to darker gray at depths of 25 to 35 feet. The sandstone with rare exceptions is massive to poorly-beded, and when bedding is present it is generally of vague orientation. Cross bedding probably is present in some zones but is difficult to accurately determine within the limits of exposure afforded by trenching or drilling operations. Conglomerates are absent but, in the easternmost part of the alignment, thin lenses of granules and pebbles of quartz, chert, and crystalline rocks embedded in a dark brown sandstone occasionally are found. Concretions infrequently occur in the sandstone.
along the alignment but are fairly numerous in the Miocene sandstone of nearby San Francisquito Creek, immediately upstream from the Alpine Road bridge.

Jointing is well developed, the more prominent sets being oriented NW to NE and dipping steeply either easterly or westerly. Worthy of note for future reference is the fact that color banding, probably induced by the ingress of surface water along joints that have undergone slight movement, is notably well developed in sandstone near Alignment Station 105+00. The bands strike northerly and stand in near-vertical position. The original assumption was that the bands are those of bona fide strata; however, if such is the case they are all of the same texture. More conclusive evidence of pseudo-stratification lies in the fact that in the same locality one set of color bands may intersect a second set at large angles with or without offsetting.

Much of the sandstone of Miocene age in other parts of the Sand Hill area, including that in the locality of the Test Laboratory and other buildings now being erected, and along Sand Hill Road, is of the type described above. However, variations do occur as, for example, along Alpine Road north of the bridge over San Francisquito Creek.

A composite section along Alpine Road indicates the presence of about 330 feet of tan and light gray, indifferently bedded sandstone becoming pebbly toward its base, at the level of the road. An intercalated basalt flow 15-25 feet thick occurs in the lower part, and two or more beds of shell sandstone toward the upper part of the section. The lower sandstones generally are of a less well sorted, more detrital aspect than that of the sandstone.
along the eastern part of the accelerator alignment. With one possible exception, none of the rocks in the Alpine Road assemblage are identifiable in the alignment area. The exception is that of sandstone containing finely comminuted shell fragments and encountered at a depth of 32 to 33 feet in Borehole 53, located 230 feet northerly of Alignment Station 104+22.

Sandstone of Miocene age in the more westerly part of the alignment area, between Stations 76+00 and 50+00, generally resembles that farther east. In some of the drill holes, however, the sandstone appears to be somewhat less homogeneous, with a greater admixture of unidentified dark grains. It also appears to contain a greater amount of interstitial clayey material, and tends to be more micaceous.

The Miocene sandstones are much better sorted than their Eocene counterparts, a field criterion of considerable importance in distinguishing between the two. Other criteria of use in distinguishing Miocene rocks from those of Eocene age are the tendencies of the former to be less deformed, more easily eroded, and to contain zones of highly siliceous shale, siltstone, or fine sandstone.

The sandstones along the alignment are, within themselves, generally free of interbedded claystone. However, rock of this type does occur in independent bodies immediately east of the boundary with the Eocene rocks at Station 82+10, in Broad Valley (Station 60+00), and at the contact with the Eocene rocks in the vicinity of Station 50+00.

As encountered at depth in many of the drill holes, the claystones are dark grey to dull black but assume lighter grey, olive brown, and olive
green colors nearer the surface. The rock is extensively jointed, tending to fracture to tabular chunks, and frequently is highly micaceous.

Other types of finer-grained rocks encountered in the Miocene section of the Sand Hill area are those of highly siliceous shale and siltstone which are generally associated with sandstone. Most such rocks crop out as isolated small bodies, not traceable over any appreciable distance. Two members, however, are of more continuous nature and warrant brief description.

The first member, interbedded with sandstone, consists of hard, light gray, siliceous shale. Near the accelerator alignment it has a thickness of about 30 feet. The trace of the member, shown on the maps of the present report, begins north of Sand Hill Road and terminates approximately 200 feet north of Alignment Station 75+50. The termination occurs either by faulting or by change of facies, more likely the former.

Surface manifestations of the second member disappear at the prominent hill 700 feet WNW of the intersection of Sand Hill Road and the former Walsh Road. As exposed there the member consists of light-colored, well-bedded siliceous siltstone and fine sandstone with an estimated thickness of 500 feet or more. The member forms the backbone of the prominent ridge trending southeasterly through Station 52+00. The ridge ends about 1500 feet farther southeasterly; its component rocks do not appear as such in San Francisquito Creek farther to the southeast.

The deciphering of the stratigraphy of the Miocene rocks should be relatively simple for, unlike the Eocene rocks, the younger ones have been subjected to the complicating effects of fewer periods of structural deformation. However, this advantage is offset in large degree by the generally
poor exposure of the younger rocks and the fact that even when exposed, as by trenching, they yield little information on their structural orientation. The one exception to this is that of the partial section along Alpine Road where, although bedding-plane attitudes are scarce, a reasonably accurate stratigraphic sequence can be established.

As established by paleontologic determinations to date the Miocene rocks along the eastern part of the accelerator alignment range in age from upper Eocene to and including probable upper Lusitan. Foraminifera of probable upper Eocene age occur in a sequence of sandstone and minor interbedded siltstone in a borehole at Station 93+60; a probable upper Lusitan age is indicated for fauna occurring in the sandstone of a borehole 300 feet south of Station 113+00. Unfortunately, fauna recovered from the sandstone-siltstone sequence of Borehole 36, between Stations 49+00 and 50+00, and therefore near the contact with the Eocene rocks of the locality, proved of no diagnostic value other than to indicate a general Miocene age. The claystones of Borehole 13, in Broad Valley (Station 60+00), contain foraminifera assigned an age of probable late Lower Miocene by Brabb (13).

Edwards (14) determines an age intermediate between upper Eocene and upper Lusitan for claystones in nearby Borehole 6. The sandstones cropping out along the more northerly part of Alpine Road are assigned a Vaqueros age. An undifferentiated Vaqueros-Monterey age is assigned the rest of the Miocene rocks of the San Hill area (15).

The proper stratigraphic sequence and correlation of the Miocene rocks, the ages of which are listed above, is not closely established. This is because of the absence of accurate structural control, adequate exposure, and the lack
of additional paleontologic determinations. On the basis of presently available field evidence it is reasonably certain that the Miocene rocks along Alpine Road underlie the large syncline the axis of which lies between 1500 and 1800 feet west of the road. These rocks are not recognized as such at the surface or in the subsurface farther west either because of rapid change in facies, structural complication, or both. The only clue to their westward extension is in the above-mentioned occurrence of a shell sandstone in Borehole 53, 290 feet north of Alignment Station 109+22. There is no assurance that this sandstone correlates with one of those of similar type that crop out in the cut along Alpine Road.

The eastward extension of the upper Zemorrian sandstones exposed near Alignment Station 93+00 is unknown but presumably would normally underlie or tie in with some part of the Alpine Road section. Yet less is known of the eastward extension of the claystone beds shown on the geological progress map (9) and on the map of the present report as occurring in fault contact with Upper Eocene rocks near Station 82+00. If the member is of lower Miocene age and does continue eastward, it should underlie the Alpine Road sequence. An alternative possibility is that the claystone member is of Eocene age. So far as now known no correlation exists between this member and the one of known Miocene age in fault contact with probable upper Eocene beds in the locality of Station 46+00.

The claystone beds of Broad Valley (near Sta. 60+00) are not determinable as such in the more eastern part of the accelerator alignment, nor do they appear in recognizable form in San Francisquito Creek, on line to the southeast. The beds have an estimated thickness of 150 feet. As shown on the accompanying
The stratigraphic position of the claystone member in Broad Valley is such that its presence might be explained by downfolding between faults to the east and the west. On the map of the preliminary report (8) the topographic depression of the locality was accounted for by faulting.* The total thickness of the Miocene rocks in the Broad Valley block is estimated at 800 to 1,000 feet, the latter probably representing most of the total thickness of the Miocene section in the Sand Hill area. The thickness east of Fault XIIA (82410) probably does not exceed 700 feet, part of which may be repeated in the Broad Valley locality. On the basis of current mapping and age determinations the claystones and siltstones of Broad Valley should be present in the general synclinal area east of Fault XIIA. Assuming present information correct, the most likely reasons for the nonappearance of the member as such would be thinning or rapid facies change, or faulting.

The boundary of the Miocene rocks with those of Eocene age near Alignment Station 49+00, and to the southeast where it crosses San Franciscoquito Creek, is shown as a fault on all maps thus far submitted, including those of the present report. The alternative explanation, given in the preliminary report, is that the boundary is a depositional one but overturned.

At its intersection with the alignment the boundary cannot be accurately delineated because it occurs in a zone predominantly of claystone the differing ages of which are not determined within limits closer than 100-150 feet. Late upper Eocene fauna occur in the sediments of Borehole 12, 100 feet west of the contact as now shown on the geological progress map (9). Sediments of Miocene

* As of November 14, 1962, deep excavation in Broad Valley has exposed, near the eastern side, a 12-inch gouge zone and steep dips possibly indicative of large-scale faulting.
Age are found in Borehole 36, 50 feet to the east. Dips in the claystone zone are vertical or steeply inclined to the WSW. A noticeable amount of brecciation is present in the zone. Evidence to either prove or disprove overturning was not observed during the trenching operations. Strata of Miocene age are not recognized along the alignment to the west. With these conditions the present opinion is that while either type of contact could be present, that of faulting is the more likely. The evidence for faulting is clearer where the boundary crosses San Franciscuito Creek.

The contact between the Eocene and Miocene rocks is believed to cross San Franciscuito Creek less than 100 feet west of sample locality 83. The fauna of nearby samples 293 and 305A indicate as upper Eocene the age of the containing claystones; that of sample 82, more closely determined and also occurring in claystone, is of late upper Eocene age. The age of the cherty siltstone from which sample 83 was taken could not be positively determined, but was tentatively designated as possible lower Miocene. The siltstone dips 85 degrees southwesterly to vertical; in nearby rocks of similar type the dip is 70 degrees northeasterly. The dips of the adjacent upper Eocene rocks range from 70 to nearly 80 degrees southwesterly. Beds of probable upper Eocene age crop out on the south side of the creek, 200 feet west of sample locality 82. These beds, dipping 77 degrees southwesterly, clearly are in their original depositional sequence, are not overturned. This particular outcrop occurs approximately 70 feet SSE of the point at which a well-marked trail crosses the creek. The present opinion is that the foregoing field evidence more nearly indicates the Eocene-Miocene boundary of the locality to be that of a fault rather than one of normal deposition, and it is thus shown on the map of the present report.
On the accompanying maps a band of upper Eocene strata is shown as crossing the alignment between Stations 76+20 and 82+10. The age designation is based on but one determination, that of the fauna of Borehole 17. Beds of this age are believed to extend westward to Station 76+20, as judged by their steep dip; their rhythmic alternation of claystone and sandstone, a characteristic of Eocene stratigraphy in the western part of the alignment, and by the fact that most of the interval is spanned by a surface cover of black clayey soil, accepted as a surface indication of Eocene claystones to the west. Similar criteria are found at the intersection with Sand Hill Road of the above-described beds projected along strike. The black soil extends unbrokenly between the two localities.

The nature of each of the boundaries of the older rocks with the Miocene rocks to the east and west is not known but provisionally is depicted as that of a fault. The alternative explanation is that upper Eocene beds occur in this part of the alignment by reason of uplift on an anticlinal fold. Less tenable is the possibility that older strata appear in the locality as the result of deposition of Miocene sediments around a topographic high in rocks of upper Eocene age.

In the northeastern part of the Sand Hill area the upper Eocene and serpentine of the ridges of Sharon Heights are believed separated from upper Eocene and Miocene rocks to the southwest by Fault XIV, further discussed in the section devoted to geologic structure.

The normal contacts on either side of Sand Hill Road, and in the northwestern part of the area, are in substantial part those shown on other maps (15) (16), but adjusted on the basis of presently available field data. The
presumption is that the normal relationship of the Miocene rocks to those of Eocene age is that of angular unconformity.

So far as now known rocks of neither later Miocene or Pliocene age are present in the Sand Hill area proper.

Pleistocene and Recent

Sediments of these ages have no great importance in the construction of the accelerator. The more important occurrences of the sediments along the alignment are shown on the large scale geological progress map as an item of general interest, but are not shown on the map that accompanies the present report except in a few instances, and then only on the structure sections where they conceal localities critical in the interpretation of structure.

During the trenching operations it was found that dark-colored gravels, sands, and clays may be present in relatively thin, discontinuous sheets, generally in depressions or on ridge slopes. It was found that the absence of gravels at the surface does not necessarily indicate their absence in the subsurface of the locality, and that the reverse conditions might also hold. The thickest gravels—"25 feet or more"—occur in the western part of the alignment, in the area of most severe faulting. There is no apparent relation between the faulting and the presence of the gravels.

The age of the gravels, sands, and clays encountered along the alignment is not known; they are tentatively regarded as of post-Santa Clara (Pleistocene) age, but older than the Recent gravels and sands in San Francisquito Creek and its flanking terraces.

- 27 -
STRUCTURE

Southwestern Part of Sand Hill Area

The structure of that part of the Sand Hill area occupied by Eocene and older rocks--principally the southwestern part--is characterized by faulting. The more prominent faults, including I, II and IV*, trend northwesterly and generally parallel the present structural grain of the surrounding region. The Eocene rocks are in form of a wide band that appears to conform to the trend of the northerly edge of Jasper Ridge. Folding, if formerly present, is all but obliterated by the distorting effects of faulting. Later folding on a minor scale occasionally is encountered in the upper part of San Francisquito Creek, principally in the finer grained, less competent rocks where these occur in and near shear zones; sets of reverse dips do appear in the sandstones but probably owe their origin to tilting on faults, although in a few cases, as near Fault VIII, actual flexuring seems to have occurred.

Although the field evidence is inconclusive, there nevertheless remain some clues to show that the pattern of northwesterly-striking faults has had imposed on it a set of secondary faults striking northerly and northeasterly. Examples are Faults X, XI, and XIX. The fault pattern on the top of Jasper Ridge reflects with considerable clarity the offset of Fault I by XI, and recent aerial photographs show, on Fault X, a small apparent left-lateral displacement of a band of black clay which presumably is the weathered equivalent of an Eocene claystone zone.

* The structural characteristics of Faults I and IV are described in the section on stratigraphy and are not here discussed in detail.
Fault XIX offsets the Eocene-serpentine contact and in such manner that the Eocene strata of the Rattlesnake Rock locality appear to be truncated by the fault.

Fault II probably is present as shown on the accompanying maps. Evidence of the offsetting by it of the older fault between the Eocene beds and the serpentine is largely concealed by the presence of soil and stream gravels; however, it does appear that at least 20 feet or more of westerly-striking Eocene beds in the creek bottom are cut off by the fault.

There are probably many more minor faults in the upper part of San Franciscquito Creek than shown on the maps. Of those shown, Faults V, VI, VII and VIII seem to be the more important. Fault VIII is marked by an outcrop of steeply dipping, shattered sandstone exposed on the northerly bank of the creek and by a zone of severely deformed claystones and interbedded sandstone extending upstream about 200 feet. Fault VIII occurs either in the sandstone itself or else between the sandstone and an adjoining band of claystone and minor sandstone to the northeast. The fault is believed to extend northwesterly to and possibly beyond the accelerator alignment. The locality of the intersection is marked by the presence of brecciated, gougy claystone and sandstone, and anomalous bedding-plane attitudes. The relationship of Fault VIII to X is unknown; for the present it is shown as offset by Fault X and extending yet farther northwesterly.

Most of the faults in the upper part of San Franciscquito Creek are mapped on the basis of secondary evidence, generally on the abrupt appearance of a zone of unusually severe deformation and erratic bedding-plane attitudes, or on the occurrence of locally truncated strata. The faults probably stand at
near-vertical angles, and on the accompanying maps their dips arbitrarily are shown as westerly or southwesterly. The estimating of the strikes of the faults and the degree of deformation generated on them generally is a matter of spot inspection because they are rarely exposed over any appreciable length. Faults I and VIII may with some degree of certainty be projected northwesterly to an intersection with the accelerator alignment; most of the intervening faults may cross the alignment, die out in a shorter distance, or end against nearby faults of the longitudinal or transverse types. Such termination might in part explain the difficulty experienced in attempting to project beds of distinct lithology from the creek to the alignment.

According to Bibble, most if not all of the southwesterly-dipping Eocene beds and those of the adjacent Miocene section in the southwestern part of the Sand Hill area are overturned. Overturning of the older beds undoubtedly has occurred along larger faults of the type of I and IV, but not necessarily continuously for, as previously mentioned, southwesterly-dipping Eocene beds in San Francisquito Creek near Fault IV appear to be in normal depositional sequence.

Further, unequivocal criteria of overturning of Eocene strata in the creek, other than those few instances where actual inversion can be observed in a resistant sandstone bed unaffected by hillside creep, are infrequent. Inspection of structure section A-B of each of the accompanying maps, indicates that most of the Eocene strata along the westernmost part of the accelerator alignment dip northeasterly, as far east as Fault VIII. There

* Written communication, December 29, 1961.
southwesterly dip abruptly begins, steepening to near-vertical angles in the locality of Faults IV and XVIII, involving a stratigraphic thickness of 1000 feet or more. The presence of 450–500 feet of northerly-dipping beds in the Rattlesnake Rock locality is noted in an earlier part of the present report. The basal beds of this sequence are in contact with serpentine.

An alternative explanation for at least part of the southwesterly-dipping Focene sequences is that instead of extensive overturning, some may be normally southwesterly-dipping elements of now relict folds developed during an early period of deformation. Subsequent deformation, possibly of relay nature, then produced parallel faults of generally lesser magnitude such as those of V, VI, VII, VIII, and more northerly trending faults of the type of IX and X, and in so doing destroyed the identity of the older folds.

Inspection of structure section A–B also indicates, even if only in faint profile, the possible earlier presence of an anticlinal axis in the locality of Station 10+00, on the projection of Fault I, and a synclinal axis near Station 38+00 (Fault VIII). These may afford some clue to the presence of the "relict folds" described above. In view of the faulted nature of the terrain, lithologic continuity scarcely could be expected over the entire distance from west to east.

From the standpoint of engineering geology an important consideration, assuming extensive overturning is present, is the causal mechanism, whether this is in the nature of a few or many faults and their locations, if not now properly shown, and whether or not zones of undue weakness have been
created. It is hoped that deep excavation soon to be initiated in the
westernmost part of the alignment will serve to clear up these and allied
problems.

Of passing interest is the indication, however indefinite, that the
more northerly-trending faults—the later ones mentioned above—occur in
a rude radial-like pattern near the "elbow" of Jasper Ridge, where it
changes direction from northwest to west.

In summary, present evidence also indicates that the Eocene rocks of
the Sand Hill area probably have undergone several periods of deformation.
The greater degree of deformation of rocks of that age as compared to that
of the Miocene rocks shows that throughout later geologic time, subsequent
to faults of the type of IV and those near Stations 76+00 and 82+00, the
area has remained in a quiescent state.

Central and Northern Parts of Sand Hill Area

The structure of the balance of the Sand Hill area is comparatively
simple, the chief complicating effects being those of concealment of contacts
by Quaternary deposits, and the absence in the Miocene section of bedding
planes to permit the accurate determination of structure.

Inspection of the eastern part of structure section A-B and the San Fran-
cisco sheet of the geologic map of California gives rise to the opinion that
within the limits of the Sand Hill area and the adjoining area to the north
the Miocene sediments may have been deposited in a relatively shallow trough
narrowing to the north and disappearing in that direction at about the lati-
tude of Woodside.
In the westward extension at the latitude of section A-B, the Miocene strata became progressively more folded, finally terminating at Fault IV, although originally they must have extended an appreciable distance yet farther west. East of Alpine Road the Miocene beds are reported to be in normal contact with rocks of Eocene age. North of Sand Hill Road, in the Sharon Heights district, the Miocene strata, as shown on the map of the present report, are interpreted as terminating at a normal contact with sediments of Eocene age. The relation of the Miocene beds of the locality to the Eocene beds immediately northeast of inferred Fault IV is unknown. If the fault actually is present and does extend yet farther southeast, it clearly does not disrupt strata of Miocene age, from which it may be concluded that the fault is of pre-Miocene age. The weight of present evidence indicates that east of the map area the boundary between the rocks of the two ages is a depositional one.

Folding in the Miocene section is of the open, gentle type except near the three larger faults shown on the structure profile. The largest single fold appears to be that of the syncline the axis of which is near Alpine Road. As to whether or not the syncline represents the original axis of deposition is not known, but it may be presumed that such is the case. The axis of the syncline pursues a somewhat sinuous northerly course and either terminates abruptly in a faulted Eocene sequence near Sand Hill Road or else gradually fades out in a depositional contact. The syncline appears to be topographically reflected, a possible indication of comparatively late folding.

There is no assurance that the smaller Miocene structures shown on section A-B are in reality present. Their mapping is based for most part on vague, indefinite bedding. Their axes, length unknown, appear to trend generally north.
Faulting within geographic limits in the Miocene rocks themselves appears to have occurred, if at all, on a small scale. The alternative explanation is that a greater amount of faulting is present but has not been detected during the investigations of the accelerator site.

Faulting may occur in Broad Valley (Station 60+00). This unusual depression is shown on the map of the preliminary report (4) as the site of a long fault (III), and as a syncline on the maps of the present report, the change being made on the basis of the interpretation of trench and borehole data. However, deep excavation now in progress indicates the possible presence of two northerly-trending faults along the easterly side of the valley, one of the faults having a well-defined gouge zone 12 inches or more in width. A variation of the idea of the fault origin of the valley is that it is the result of simple synclinal downwarping between confining faults on the east (Stations 76+00 - 82+00) and on the west (Stations 49+00 - 50+00).

The structure of the Eocene rocks in the northeastern part of the map area is shown with but slight variation in the same form as that appearing on the map of the preliminary report. Fault XV is retained as an inferred fault. At the northern edge of the map area the fault is drawn to separate, on the west, beds of probable early late Eocene age striking east into the faults from the serpentine mass and nearby beds of possible late Cretaceous age on the east. The older beds strike northerly and stand at near-vertical angles. Structural trends in Eocene rocks of the ridge to the northeast of the fault are approximately WNW; those to the southwest are more northwesterly.

Fault XV is projected southeasterly to and slightly beyond the zone of near-vertical beds cropping out on both sides of Sand Hill Road, near the intersection with Sharon Heights Drive.
There is no surface evidence of Fault XV yet farther southeast; it may either be cut off on a cross fault as shown on the map of the preliminary report or else, if it does extend to the southeast, is concealed beneath Quaternary deposits and gently-dipping sediments of Miocene age present in that direction.

On the San Francisco sheet of the geologic map of California (15) a fault which may be the continuation of Fault XV is shown as beginning in the locality of sample 92 and extending northwesterly through an area of Eocene sediments to pass along the west side of Bear Gulch reservoir, thence to and beyond Woodside Road. The projection southeast, to Sand Hill Road, is indicated as a normal contact between Eocene and lower Miocene rocks.

The alternative explanation is that rather than having been exposed by faulting, the serpentine of sample locality 96 and, if actually present, the upper Cretaceous of locality 95, are exposed in the crest of an anticlinal fold.

The structural nature of the Eocene-Miocene boundaries intersecting the accelerator alignment at Stations 76+20 and 82+10 is discussed in an earlier part of this report.
Those aspects of geologic structure and stratigraphy bearing on the engineering geology of the accelerator site are discussed in detail in the report (9) of Appendix 1 of the present report, hence further discussion here is unnecessary, except to add that as a result of precise horizontal surveys carried out over the past six months, there is some evidence, as yet unconfirmed, that slight movement, tectonic or superficial, may be present in the western part of the accelerator alignment between Stations 0+00 and 37+00.

A point 300 feet north of Station 18+00 shows an apparent movement of 0.37 inches northerly, and a second point, near Station 37+00, a movement 0.26 inches in the same direction. Each point falls near an inferred fault on the smaller-scale (1:6000) map that accompanies the present report. The balance of the alignment has remained essentially straight. Investigations currently are being carried out to determine the validity of the early results and whether tectonically or only superficially induced. There is no topographic evidence of tectonic movement in the accelerator area; an undrained depression is present at a locality toward the northwesterly end of Fault X, but the present opinion is that it is of artificial origin. It is anticipated that information of value will become available during the course of deep excavation in the western part of the accelerator alignment.
CONCLUSIONS

In light of investigations in the Sand Hill area to date, there is no geologic reason, structural or stratigraphic, why the linear electron accelerator cannot be safely built and maintained.

[Signature]

L. L. TABOR
Field Geologist
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APPENDIX 1

GEOLOGICAL PROGRESS REPORT

ENGINEERING GEOLOGY ASPECTS
OF THE ACCELERATOR CONSTRUCTION

L. L. Tabor

Actron-Blume-Atkinson
Inter-Office Memorandum
October 15, 1962
INTRODUCTION

The accompanying map and profile section illustrate the present interpretation of the type of rock and geological structure that will be encountered in cut and fill operations for the Stanford Linear Accelerator along the accelerator alignment at the Sand Hill site. This interpretation is based on a study of the results of trenching and borehole exploration in the period September, 1961 - July, 1962.

Regional geology of the Sand Hill area and a more general coverage of the same area are contained in a preliminary geological report, ARA-31, submitted in December, 1961.

GEOLOGICAL ASPECTS OF CONSTRUCTION

In the following pages the several geological features particularly related to construction in the alignment area are discussed in some detail. Such features include the types of rock that will be encountered during the construction and the nature of their geological structure, the latter including the attitudes of the strata and the degree and prevalence of rock deformation caused by folding and faulting.

For the prevention of differential settlement, it is important to distinguish those areas along the alignment underlain by relatively strong rocks such as sandstones from those occupied by weak rocks of the shale type. Knowledge of the attitude of each stratum or group of strata, that is, its direction in a horizontal plane (strike) and its inclination to the vertical (dip), and the angular relationship of the strike and dip to the direction of the alignment, is of importance in the prevention of slides. Equally important, and for the same reason, is the study of the relationship of the strike and dips of faults and joints to the alignment's direction.
MAJOR ROCK TYPES AND PROPERTIES

On the map and profile section rock units are shown in simplified form as (a) sandstone and, (b) shale. From an engineering standpoint both these rock units are important in that generally their respective bearing strengths and cohesiveness stand in marked contrast. Where exposed along the alignment, the sandstone units are identified by their coarser texture, light grey or tan colors and, generally, by their greater degree of hardness. The sandstones of the alignment area, in contrast to the shales, are of relatively high structural competence, capable of sustaining heavier loads.

The shales of the area occur as alternating layers in the sandstones, this being notably the case in the westernmost 4800 feet of the alignment. They are distinguished by their dark gray to ashy-black colors, softness, and their tendency to fracture into small angular fragments. This type of fracture is believed due in part to the presence of a system of closely-spaced intersecting joint planes. The load-carrying capacity of the shales is less than that of the sandstones, a condition which raises the problem of differential settlement in any locality in which both types of rocks form part of the foundation of the accelerator. The shales of the area also are less resistant to weathering and erosion and, therefore, would be more prone to sliding on steep slopes, particularly in those localities in which closely spaced jointing is present.

In the following discussion only the older sedimentary rocks, sandstones and shales of early to middle Tertiary age, are considered in detail.\(^1\) The youngest sediments along the alignment are of Quaternary age and consist of gravels, sands, and clays either singly or admixed. Although rocks of this age, particularly gravels, are prevalent between stations 20+00 and 30+00, they nevertheless are of surficial occurrence and therefore can be removed where necessary.

\(^1\) For the subdivisions of later geologic time, refer to the legend of the accompanying map.
The oldest rock in the general area of the proposed accelerator installation is serpentine. This rock, believed to be of Jurassic age, is an alteration product of igneous rocks of high ferromagnesian mineral content. It crops out on the top and northern flank of Jasper Ridge, which lies south of the western end of the accelerator (see map). In that locality the serpentine is believed to be in faulted contact with the older of the Tertiary sandstones and shales mentioned above. So far as now known, the presence of the serpentine in the area bears no significant relationship to the problem of the construction and later stability of the accelerator.

**GEOLOGICAL AGES AND STRUCTURES**

For purposes of further discussion, the sandstones and shales of Tertiary age may be subdivided into two geologic ages. Rocks of those types between stations 0+00 and 48+20 are of Eocene age (55 to 60 million years, as determined by radioactive means) while those yet farther east, with the exception of an included locality between stations 76+30 and 82+10, are of Miocene age (17 million years). The rocks between stations 76+30 and 82+10 are of Eocene age, similar in lithology and geological structure to those of the same age west of station 48+20. They are bounded both to the east and the west by rocks of Miocene age and owe their presence to uplift along faults or the axis of an upfold, the top of which has been removed to reveal the older rocks.

On the accompanying map and profile section, a fault interpretation is illustrated.

For the engineer's purpose, the designation of the geologic age of the rocks in the alignment area possesses some merit in that once in mind it serves to set aside that part (Eocene) of the accelerator alignment in which potential mishaps of construction exist from that part (Miocene) in which the rocks, mostly sandstones, are more adaptable to the purposes of construction. Miocene
terrain presents fewer engineering problems not only because it consists in
large part of relatively stable sandstone but also because of being much
younger, it has not been subjected to the severe deformation by faulting and
folding with the resultant fracturing and shearing that now characterize the
older rocks. The contrast in deformation of the rocks of the ages is readily
discerned in the field, and is clearly illustrated on the map and profile
section. It will be noted that the main area of Eocene rocks (stations 0+00
to 48+20) is crossed by numerous faults and occasional anticlinal and syn-
clinal folds. Most of the folds owe their origin to shearing action along
faults. In contrast, the Miocene rocks are relatively free of faulting, and
the folding is of the open gentle type. A possible exception occurs in the
locality of station 105+00 where, during trenching operations, it appeared there
might be a narrow shear zone of near-vertical strata striking in a northerly
direction. However, the present opinion, based on the results of additional
trenching, is that a shear zone is not present and that simulation of the
same is effected by weathering discoloration along nearly vertical joint
planes. The occurrence is mentioned here as a possible point of future dis-
cussion.

FAULTS

Knowledge of the type and trend of faults is as yet incomplete, particular-
ly for those now believed to intersect the western part of the alignment area.
This uncertainty arises principally because although trenching and exploratory
drilling yielded adequate information on the types of rock present, the geo-
logical structure of the site can only be generally indicated by these tech-
niques because of the extreme complexity of the geology in detail. This dif-
ficulty is compounded by the fact that reliable bedding-plane attitudes are
only rarely developed in the sandstones along the accelerator alignment.
Those larger faults now believed to be present appear to trend NNW to NW, crossing the alignment at the corresponding angles. In the few localities in which faults are exposed in San Francisquito Creek, they appear to stand in near-vertical attitudes and are thus shown on the accompanying profile section. There, however, as in the trench along the accelerator alignment, neither the direction nor the magnitude of the faults can be ascertained with any degree of accuracy.

A brief study of the accompanying map and profile section shows that most of the faults believed to cut the area of construction are concentrated in the westernmost 5000 feet of the alignment and, further, as judged by the disruption of adjacent strata, that these are the faults along and between which the most intense rock fracture has occurred. From this it follows that in that part of the alignment area will be concentrated the greatest potential risks of construction mishaps and alignment instability.

In their relation to engineering geology the faults thus located may be considered in two aspects: (1) whether active or inactive and, (2) the amount and degree to which the rocks have been weakened by shearing along the faults. An active line or zone of fracture crossing the alignment would pose a threat to the stability of the accelerator during the latter's life. Zones of shattered or gougy rock extensively developed laterally and vertically would make more difficult the problems of construction and maintenance, as well as prejudice accelerator stability.

Other than the actual witnessing by man of the disastrous consequences of appreciable movement on a fault in any given locality, there are no certain criteria for determining whether a fault is active or inactive. Field evidence currently used is wholly of topographic nature, including the presence of scarps in geologically young gravels, sag ponds, and offset drainage.
The presence of these features along the trend of the nearby San Andreas fault attests the currently active status of that line of fracture. Within the limits of the accelerator area itself, however, there is no presently known evidence to indicate that any of the mapped faults are now active.

The short fault which crosses San Francisquito Creek approximately 200 feet west of Fault I does separate geologically young sandstone debris from serpentine debris, but no scarp is present. The fault now is considered as inactive.

Of the several faults crossing the accelerator alignment, the most important from the standpoint of their relation to construction problems appear to be those designated I, VIII, and XVIII in that order, as shown on the accompanying map and section. Faults I and XVIII may be multiple, that is, in form of a zone of fracture rather than a single plane of separation. There are now believed to be at least three localities in which by reason of the intersection of the alignment by faults, potential construction difficulties may be anticipated. The first such locality lies between stations 46+50 and 50+00. Fault XVIII is believed to pass through the western edge of this locality. Easterly for a distance of 200 feet interbedded sandstones and shales, some of which are slickensided, stand in near-vertical attitudes, possibly the result of differential movement on a subsidiary fault or faults. Whether or not faults are present, it is clear that in attaining their near vertical dips, the shales, over and underlain as they are by more competent sandstones, must have been subjected to a shearing action and therefore weakened. This condition may be expected to become yet further aggravated in a locality of intersecting faults, such as the second of those described above.
Presently available information on the thickness of gouge zones and their role in channeling subsurface water is scanty. In those rare instances where faults are exposed in the upper part of San Francisquito Creek, little if any gouge seems present, the reaction to shearing having been, instead, that of the twisting and contorting of the shale beds and some shattering of more competent sandstones. As far as now known, no springs are present on or near the faults. However, as noted on the accompanying map, zones of gouge-like material, shattered rock, and flows of subsurface water, either separately or in company, have been encountered in some of the drill holes on and near suspected faults, particularly in the western part of the alignment area. In formulating plans for either excavation or filling in that part of the area, it should be assumed that similar unfavorable conditions will be encountered at the intersection of the corresponding faults with the alignment.

JOINTING AND FRACTURING

The rocks of both Eocene and Miocene ages are extensively jointed. This is particularly true of the Eocene shales in which jointing frequently is of such intensity that a rude type of fissility (fracture cleavage) is induced. Shales of this age commonly fracture along intersecting joint sets to produce small angular fragments, particularly where exposed to the drying action of the sun.

Shales of Miocene age generally are less intensely jointed this probably being due to the fact that they have been subjected to crustal stresses over a much shorter period of time. Sandstones of both ages also are jointed but the joint planes tend to be more widely spaced and the intervening spaces between opposite joint walls more prone to healing by the deposition of calcareous or siliceous cement than is the case of the shales.
The seemingly more prominent joints in the rocks of both ages trend NNW or NNE in contrast to those of more northwesterly direction.

Whatever the origin or nature of the jointing in the rocks of the accelerator alignment, it is clear that its presence creates an unsatisfactory condition with regard to construction not only because the rocks thus are weakened but also because openings are present for the ingress of surface water and the freer circulation of ground water.

The following table is submitted as a summary of the geological factors described in the foregoing pages. Under the heading "Approximate Angle of Intersection with Alignment", the values therein entered represent a "best guess", in face of present vaguely portrayed structural data (strikes, dips, faults) along the accelerator alignment.
### Natural Text

The accelerometers are used to approximate the number of feet of each rock type, measured along the sedimentary sequence. The accelerometers are used to approximate the number of feet of each rock type, measured along the sedimentary sequence.

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Eocene (40 Million Years)</th>
<th>Oligocene (37 Million Years)</th>
<th>Miocene (17 Million Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30%</td>
<td>10%</td>
<td>20%</td>
<td>30%</td>
</tr>
<tr>
<td>30-60%</td>
<td>20%</td>
<td>30%</td>
<td>40%</td>
</tr>
<tr>
<td>60-90%</td>
<td>30%</td>
<td>40%</td>
<td>50%</td>
</tr>
<tr>
<td>90-120%</td>
<td>40%</td>
<td>50%</td>
<td>60%</td>
</tr>
</tbody>
</table>

**Eocene**:
- Sand and gravel
- Limestone
- shale
- **Oligocene**:
- Sand and gravel
- Limestone
- shale
- **Miocene**:
- Sand and gravel
- Limestone
- shale

The percentages are based on the approximate number of feet of each rock type, measured along the sedimentary sequence.

**Eocene-Fossil Fossils**

- *Eogoneus*
- *Gonionus*
- *En.functionis*
- *Eogoneus*
- *Gonionus*
- *En.functionis*

**Oligocene-Fossil Fossils**

- *Eogoneus*
- *Gonionus*
- *En.functionis*
- *Eogoneus*
- *Gonionus*
- *En.functionis*

**Miocene-Fossil Fossils**

- *Eogoneus*
- *Gonionus*
- *En.functionis*
- *Eogoneus*
- *Gonionus*
- *En.functionis*