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STRATIGRAPHY, ENVIRONMENTAL DEPOSITION AND POST-DEPOSITIONAL HISTORY OF THE MADERA LIMESTONE IN THE VC-1 AND AET-4 DRILLHOLES, VALLES CALDERA AREA, NEW MEXICO

by
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ABSTRACT

The Madera Limestone in the VC-1 and AET-4 drillholes was deposited in a basin located in the middle or outer shelf area. The limestone was transported to the basin floor by turbidites, and contains large amounts of detrital material. Mudstones and wackestones are interbedded with packstones, and represent periods in which the amounts of sediment supply were lower.

Three periods of recrystallization are recognized in the limestone. The first took place in what are believed to be burrows, resulting in a lack of compaction in these areas. The second period of recrystallization occurred after compaction of the limestone, and is associated with pressure-solution and concentration of insoluble residue, forming secondary lamination in the limestone. The last period of recrystallization took place long after deposition, and is believed related to hydrothermal solution migration along secondary porosity which formed along cracks and joints in the rocks.

Based on this study, it is believed that existing porosity in the limestone can only be found now along joint openings and karstic phenomena associated with them.

The Madera Limestone in the Valles Caldera area is much different than any of the three formations described by Myers (1982) in the

Madera Group of the Manzano Mountains to the southwest. The main difference is in the environment of deposition. It is suggested that a local formation name be given to the limestone in the Jemez Moutain area.

INTRODUCTION

The Madera Limestone was first described by Keyes (1903) who studied exposures near the village of La Madera in the Sandia Mountains. In 1907, Gordon proposed the name Magdalena Group for Pennsylvanian sedimentary units in the Magdalena Mountains, dividing the group into two units: the Sandia and the Madera Formations. The Madera Formation in the Sierra Nacimiento Mountains was further divided by Wood and Northrop (1946) into a lower limestone member and an upper arkosic member. However, according to Martinez (1974), this subdivision "has proven to be useless in light of rapid changes in facies and thickness in the southern Naciemiento Mountains." The term "Madera Group" was used by Myers (1982) for the Pennsylvanian and Lower Permian marine and terriginous rocks in the Manzano Mountains. He subdivides the Madera Group into three units: the Los Moyes Limestone, the Wild Cow Formation, and the Bursum Formation.

DuChene (1973) describes the Madera Limestone in the Guadalupe Box and vicinity (Sandoval County) which is the nearest location to the VC-1 core yet studied. However, his description does not contain a detailed petrographic picture of the rocks. According to DuChene, in this area "the Madera Limestone consists of 0 to 760 feet of intercalated limestones, shales and sandstone. It rests conformably on the Sandia Formation and is conformably overlain by the Abo Formation."

The VC-1 core and the cuttings from the AET-4 drill hole (Fig. 1) offer a unique opportunity to study the Madera Limestone in detail. The recovery in VC-1 was 95%, total length of the Madera Limestone being 1,275 feet.

In this paper, the contact between the Sandia Formation and the Madera Limestone is defined as the first appearance of a continuous limestone unit. At the top of the Madera Limestone, its contact with the Abo Formation is defined as the end of a continuous limestone sequence, immediately below the dark red shale and sandstone of the Abo Formation. Approximately 100 thin sections were studied from this interval and were used to enhance the preliminary core description.

At the AET-4 drillhole, which is located three miles to the southwest of VC-1, the Madera Limestone is only 820 feet thick. Cuttings for the preparation of thin sections were collected from approximately every 30 feet. A description of the two sections and a possible correlation is given in Fig. 2.

STRATIGRAPHIC DESCRIPTION OF THE MADERA LIMESTONE IN VC-1 AND AET-4

A detailed stratigraphic description of the limestone is given in Fig. 2. The contact between the Sandia Formation and the Madera Limestone is marked by the introduction of bioclastic material to the orthoquartzitic sandstone and siltstone of the Sandia Formation. In both the VC-1 core and the AET-4 cuttings, the lower part of the Madera Limestone contains bioclastic limestones interbedded with orthoquartzitic sandstone and siltstones. Orthoquartzites dominate the Madera lower section at VC-1, but not at AET-4. This difference between the two sites continues throughout the length of the section, with higher amounts of quartz grains and detrital material in the VC-1 core. Above the lower detrital zone, the Madera section becomes primarily carbonate. However, with the exception of a few zones, quartz and orthoquartzitic sandstones and siltstones continue to exist throughout the section. The Madera Limestone in VC-1 is thicker than that in AET-4 due to thicker carbonate layers which contain greater amounts of detrital material and bioclastic grains. The highly recrystallized zone near the top of the VC-1 was not found in AET-4 and is believed to represent a fault zone.

ENVIRONMENT OF DEPOSITION

In VC-1, most of the Madera section is composed of detrital limestone, containing various amounts of bioclastic material, detrital quartz, feldspar, mica and chert fragments. The section also contains mudstones composed of clay and silica and sandstones with graded bedding and cross-bedding. In many of the bioclastic limestones containing small amounts of detrital quartz grains, the matrix is composed of mudsize quartz grains. The bioclastic fragments are relatively well-preserved, and the fossils have been broken into relatively few fragments. The quartz grains are angular to sub-angular. The texture is both grain-supported and mud-supported (Fig. 3). Calcitic wackestone shows no evidence that shell fossil fragments caused an umbrella effect. This suggests that the fine material was transported with the detrital grains.

In the rock cuttings from AET-4 it would be difficult to recognize textures such as graded bedding and cross-bedding. The lower part of the section in AET-4, mainly detrital, is similar to that in VC-1, both in composition and thickness. However, in contrast to VC-1, above the detrital zone in AET-4, the dominant rock is limestone with little or no detrital quartz grains. Calcitic mudstones in AET-4 are as common as bioclastic limestones, which are mud-supported. In general, there is much less detrital material here, and the limestone units containing detrital quartz grains are much thinner than in VC-1.

The greater thickness of the limestone at VC-1 and the more detrital nature of its sediments suggest that here was a channel or lower area into which detrital material was transported and accumulated.

The observations mentioned above also seem to indicate that the sediments of VC-1 were transported by turbidites carrying larger amounts of material than those at the AET-4 site. The angular to sub-angular shape of the quartz grains and the barely broken fossil fragments indicate that they were transported only a short distance from their source (Fig. 4). The mix of mud-size matrix with larger grains both in mud-supported and grain-supported textures suggest turbidites as the mode of transportation (Figs. 5, 6). Periods of lower energy are indicated by mudstones interbedded with the bioclastic units (Figs. 7,8). Organic-rich mudstone represents periods of low energy in the environment between turbidites (Fig. 9).

In the AET-4 site, in what seem to be the same turbidite periods as those of VC-1, smaller amounts of material were carried and mudstones are a greater constituent than bioclastic limestones with or without detrital quartz. The site of AET-4 was probably higher, receiving less transported sediment.

The breccia found in VC-1 is interpreted as intrabasin sedimentary breccia and probably originated from a higher area.

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Based on the discussion above, it is suggested that a basin located in the middle or outer shelf area was the environment of deposition of the Madera Limestone in these sites. The AET-4 site was probably on the margins of the basin, while VC-1 represents the lower area of the basin where more sediments accumulated. Lack of shallow-water sediments and high energy textures eliminates the possibility of shallower environments such as the inner shelf.

POST DEPOSTIONAL HISTORY

The limestone was originally deposited as packstones, wackestones and mudstones. Because all the limestone contained either calcitic mud or fine silica matrix, porosity was very low. The porosity which did exist was intraparticle, in fossil fragments which were either broken or filled with micrite (Fig. 10). Therefore, the intraparticle porosity was also very low. At the AET-4 site, portions of the limestone were silicified, and chert is commonly found. In contrast, the limestone at VC-1 was silicified in only a few places, except in the highly recrystallized zone previously mentioned. In general, the micritic and coarser matrix was only slightly recrystallized. The matrix was recrystallized in what appear to be burrows, these areas appearing as spots of different colors in hand specimens.

The most noticeable post-depositional event in the VC-1 Madera Limestone was compaction and pressure-solution. The burrows in which the micritic matrix was already recrystallized are the only ones in which compaction did not take place, indicating that recrystallization and lithification occurred in them near the time of deposition (Figs. 11, 12).

A second stage of recrystallization took place after the compaction of the limestone, recrystallizing some of the compacted limestone. Pressure solution of the limestone also resulted in recrystallization, and areas which were not subjected to pressure were not recrystallized (Fig. 13). As a result of pressure solution and limestone dissolution, the insoluble residue, mainly quartz grains and echinoderm fragments, were concentrated, forming areas rich in grains (Fig. 14). These areas are mainly found along the borders of the burrows (Fig. 15). Early recrystallization of the matrix in burrows prevented disolution of the micrite and concentration of the insoluble residue.

Calcite veins, and the coarse sparry calcite associated with them, represent the last stage of recrystallization of the limestone. They are vertical, or near vertical and are not displaced by stylolites. Parallel to the fractures in the limestone, they probably were formed by solution migration along the joints. The highly recrystallized zone in the Madera Limestone of VC-1 (1600 feet) contains large crystals of quartz and calcite, and was probably formed by hydrothermal solutions.

Silicification of the limestone is noticed mainly at the AET-4 site, where chert is commonly found. At the VC-1 site, there is almost no silicification of the limestones, and chert is not found. The limestone with quartzitic matrix at VC-1 is cemented by both silica and calcite. The silica-cemented quartzitic matrix can be easily mistaken for chert, especially in hand specimens. It is difficult to explain the lack of chert at VC-1 as compared to its abundance at AET-4. Possibly, the silicification at the AET-4 site is a result of prolonged contact with seawater, due to the slower rate of deposition.

Opal is found in some of the limestones, near the highly recrystallized zone of VC-1. This occurence is also believed to be the result of hydrothermal solution migration through the rock.

As mentioned above, the primary porosity of the limestone was very low. Secondary porosity existed in the open cracks prior to being filled in by the calcite, which formed calcite veins.

As a result of the processes described above, no porosity is evident in the Madera Limestone at the sites studied, except in the highly recrystallized zone (1560 - 1660 ft.).

DISCUSSION AND CONCLUSIONS

Comparison of the Madera Limestone at the VC-1 and AET-4 sites, located three miles apart, reveals a difference between them in the amount of clastic material present. At VC-1, the Madera Limestone contains higher amounts of bioclastic and quartzitic grains, and the section is 1.5 times thicker. The Madera Limestone at VC-1 is composed mainly of wackestones and packstones, in contrast to AET-4 where mudstones predominate.

The most likely environment of deposition seems to be a basin in a middle or outer shelf, with the VC-1 site located more towards its center. The sediments of the Madera Limestone were probably transported by turbidites and debris flows from the inner shelf into the basin. Great amounts of quartzitic detrital material, and the angularity of the fragments indicates that the distance of transportation was short, from nearby land. Periods in which the supply of detrital material was low resulted in the deposition of mudstones rich in clay and organic material. The few limestones containing algacoated grains, mudclasts and breccia were transported by debris flow from the inner shelf. The lack of grainstones indicates that the basin floor was not subjected to high energy currents. The few cross-bedded sandstones found in VC-1 were formed by the turbidite currents.

In 1977, DuChene described the Madera Limestone from outcrops in the Guadalupe Box vicinity, which is located ten miles to the southwest of the VC-1 and AET-4 sites. He reported that the Madera Limestone is composed of limestone shales and sandstone, and that its maximum thickness is 760 feet. He describes the lower part as dense, fossiliferous, cherty limestone, and the upper part as arkosic limestone intercalaed with highly fossiliferous calcareous shales. Arkose, he says, becomes predominant near the top of the unit.

This field description differs from that indicated by the drillholes, primarily in that the Madera section does not become predominantly arkosic toward the top. This difference might be due to a different definition of the contact between the Madera Limestone and the arkosic Abo Formation.

According to Martinez (1974), who studied the Pajarito Peak area located 15 miles southwest of the VC-1 and the AET-4 sites, "the lithology and thickness of the Madera vary markedly within short distances." He describes the Madera Formation as mainly coarse arkosic sandstone, containing ten inch boulders of gneiss, and arkosic mudstone, with much less limestone. The thickness is reported as at least 745 feet. The extremely arkosic nature of the Madera indicates a nearby source, he says.

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Both of the above descriptions of the Madera Limestone are based on field observations only and lack the information concerning composition and texture of the interbedded limestones which is necessary for suggesting the environment of deposition.

Myers (1982) gives a more detailed description of the Madera Group from study of the Manzano Mountains. According to his description, the Madera Group contains calcarenite, arkosic sandstone, sandstone, siltstone, shale and conglomerate. Silicified logs as long as 2.5 m, petrified logs, "fossil-tree stumps in position of growth" and algal colonies are all found within these rocks. The Madera Group, described by Myers in contrast to the Madera Limestone of the Jemez Mountains (80 miles to the northwest), indicates a much shallower environment of deposition.

It is the authors' opinion that the limestone section found between the Sandia Formation and the Abo Formation in the Valles Caldera area cannot be genetically related to one of the three formations described by Myers (1982). We therefore suggest that the limestone section described in this paper be given a formation name.

Fig. 1 Location Map

Fig. 2 Stratigraphic Description of the Madera Limestone in VC-1 and AET-4.

Fig. 3 Bioclastic packstone abundant in angular quartz grains. Matrix composed of calcitic and quartzitic silt-size particles. Scale 0.5 mm.

Fig. 4 Quartzitic sandstone containing well-preserved foraminifera bioclastic grains and mud clasts. Matrix composed mainly of quartizitic grains. Scale 0.5 mm.

Fig. 5 Bioclastic packstone. The lower half is compacted; the upper half shows very little compaction. This difference is believed to be depositional, as in both parts the micrite is only slightly recrystallized. Two different stages of turbidites are probably responsible for this difference. Scale 0.5 mm.

Fig. 6 Orthoquartizitic sandstone containing feldspar grains. Poorly sorted, containing angular grains in a grain-supported texture. Matrix composed of silt-size quartz grains. Scale 0.5 mm.

Fig. 7 Contact between orthoquartzitic bioclastic sandstone and quartzitic siltstone. Scale 0.5 mm.

Fig. 8 Contact between sandstone and siltstone, both composed of angular quartz and chert grains. Scale 0.5 mm.

Fig. 9 Quartzitic sandstone showing graded bedding. Matrix composed mainly of quartz grains. Scale 0.5 mm.

Fig. 10 A laminated limestone. The lower part is composed of mudstone containing small quartz grains; upper part is composed of packstone with recrystallized micrite and well-preserved fossil fragments. The upper part is believed to have formed during a period of slow accumulation of material (between turbidites) in which longer contact with seawater resulted in early recrystallization of the micrite, and lithification of the limestone. In this photograph is evidence of a rare primary porosity as can be seen in the development of a droozy calcite under the upper fossil fragment and inside the lower fragment. Scale 0.5 mm.

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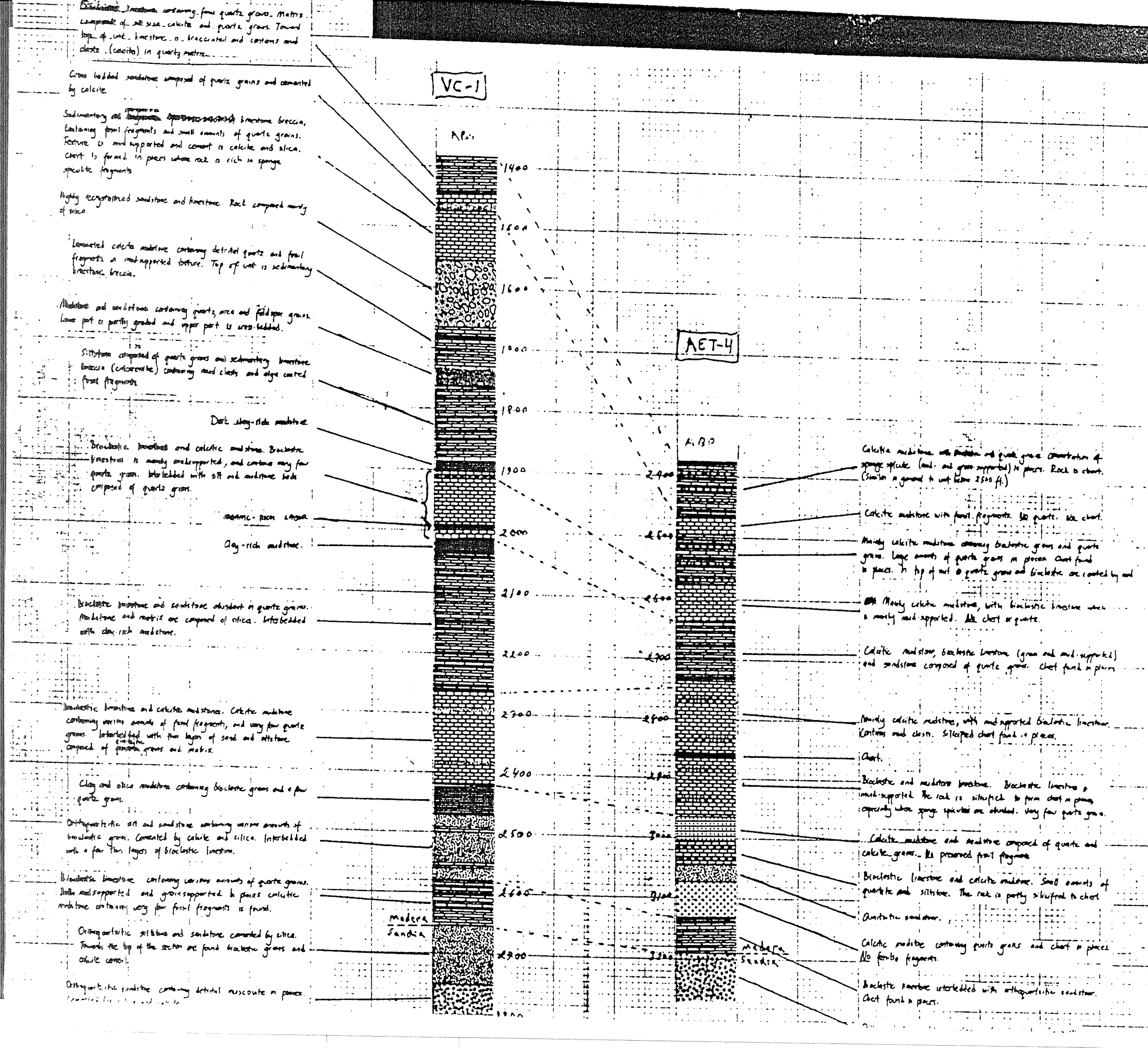

VC-1
AET-4
ft.
Bioclastic limestone containing fine quartz grains. Matrix composed of silt size calcite and quartz grains. Toward top of unit limestone is brecciated and contains mud clasts (calcite) in quartz matrix.
Cross bedded sandstone composed of quartz grains and cemented by calcite
Sedimentary and limestone breccia, containing fossil fragments and small amounts of quartz grains. Texture is mud supported and cement is calcite and silica. Chert is formed in places where rock is rich in sponge spicule fragments
Highly recrystallized sandstone and limestone. Rock composed mainly of silica.
Laminated calcite mudstone containing detrital quartz and fossil fragments in mud-supported texture. Top of unit is sedimentary limestone breccia.
Mudstone and sandstone containing quartz, mica and feldspar grains. Lower part is partly graded and upper part is cross-bedded.
Siltstone composed of quartz grains and sedimentary limestone breccia (calcarenite) containing mud clasts and algae coated fossil fragments
Dark clay-rich mudstone
Bioclastic limestone and calcitic mudstone. Bioclastic limestone is mainly mud-supported, and contains very few quartz grains. Interbedded with silt and mudstone beds composed of quartz grains.
organic-rich layer
Clay-rich mudstone.
Bioclastic limestone and sandstone abundant in quartz grains. Mudstone and matrix are composed of silica. Interbedded with clay rich mudstone.
Bioclastic limestone and calcitic mudstones. Calcite mudstone containing various amounts of fossil fragments, and very few quartz grains. Interbedded with thin layers of sand and siltstone composed of carbonate grains and matrix.
Clay and silica mudstone containing bioclastic grains and a few quartz grains.
Orthoquartzitic silt and sandstone containing various amounts of bioclastic grains. Cemented by calcite and silica. Interbedded with a few thin layers of bioclastic limestone.
Bioclastic limestone containing various amounts of quartz grains. Both mud-supported and grain-supported. In places calcitic mudstone containing very few fossil fragments is found.
Orthoquartzitic siltstone and sandstone cemented by silica. Towards the top of the section are found bioclastic grains and calcite cement.
Orthoquartzitic sandstone containing detrital muscovite in places.
Madera
Sandia
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
ABO
2400
2500
2600
2700
2800
2900
3000
3100
3200
Calcite mudstone with quartz grains. Concentration of sponge spicule (mud- and grain-supported) in places. Rock is chert. (Similar in general to unit below 2500 ft.)
Calcite mudstone with fossil fragments. No quartz. No chert.
Mainly calcite mudstone containing bioclastic grains and quartz grains. Large amounts of quartz grains in places. Chert found in places. In top of unit quartz grains and bioclastic are coated by mud
Mainly calcite mudstone, with bioclastic limestone which is mostly mud-supported. No chert or quartz.
Calcitic mudstone, bioclastic limestone (grain and mud-supported) and sandstone composed of quartz grains. Chert found in places
Mainly calcite mudstone, with mud-supported bioclastic limestone. Contains mud clasts. Silicified chert found in places.
Chert.
Bioclastic and mudstone limestone. Bioclastic limestone is mud-supported. The rock is silicified to form chert in places, especially where sponge spicules are abundant. Very few quartz grains.
Calcite mudstone and mudstone composed of quartz and calcite grains. No preserved fossil fragments
Bioclastic limestone and calcite mudstone. Small amounts of quartzite and siltstone. The rock is partly silicified to chert
Quartzitic sandstone.
Calcitic mudstone containing quartz grains and chert in places. No fossil fragments.
Bioclastic limestone interbedded with orthoquartzitic sandstone. Chert found in places.
Madera
Sandia

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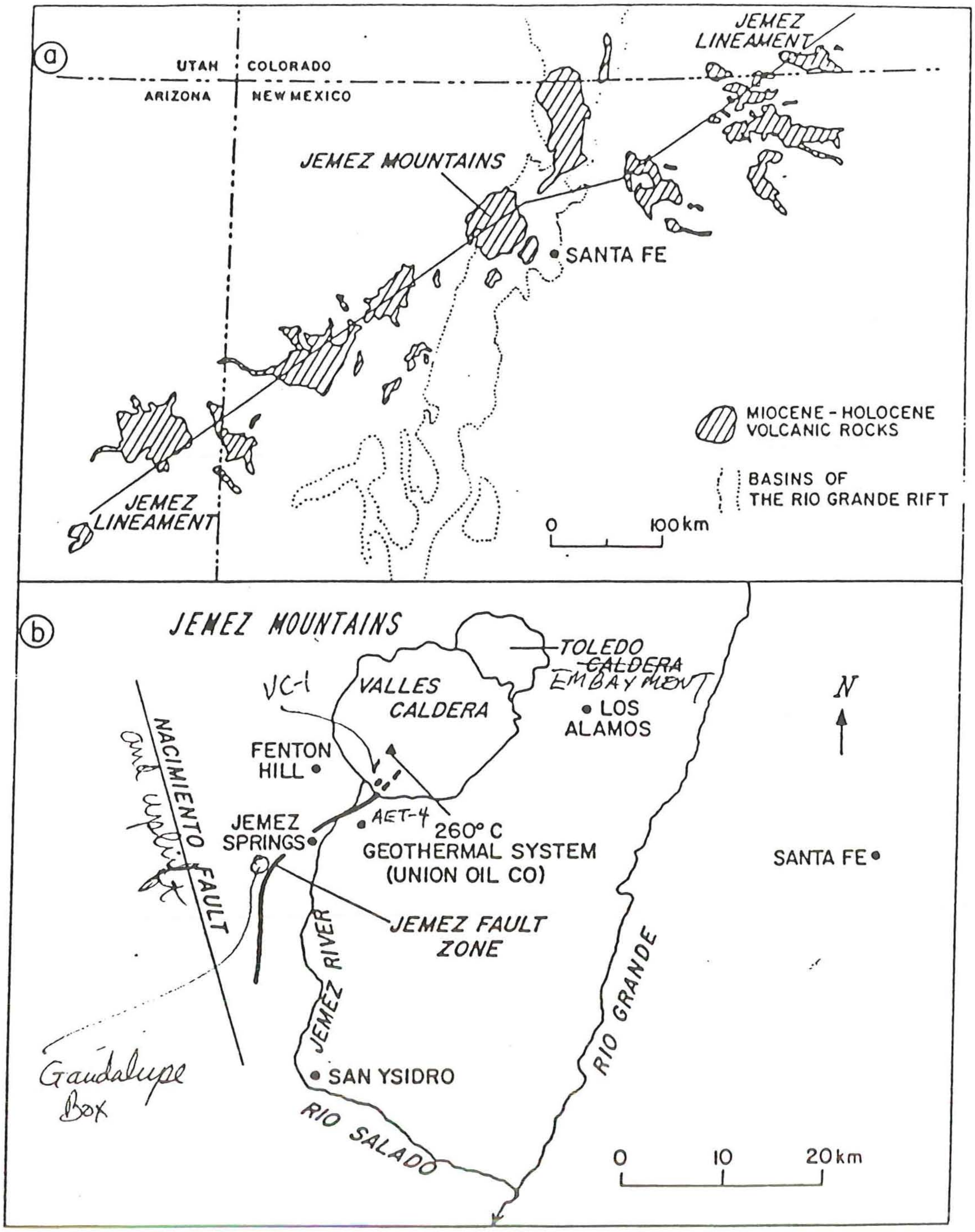

Figure 1.

a. Location of the Jemez Mountains volcanic field, at the intersection of the Rio Grande rift and Jemez volcanic lineament.

b. Sketch map of the Jemez Mountains volcanic field, showing relation of the exposed portion of the Toledo caldera to Valles caldera. Also shown are the main geothermal developments. The hydrothermal system within the Valles caldera is being developed by Union Geothermal Company of New Mexico. Los Alamos' hot dry rock geothermal project is located at Fenton Hill, on the western rim of the Valles caldera.