Spatial distribution of calcite cement in the Sante Fe Group, Albuquerque Basin, New Mexico: Implications for groundwater resources

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Spatial distribution of calcite cement in the Santa Fe Group, Albuquerque Basin, NM: implications for ground-water resources

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Abstract

Calcite is the most abundant cement in the Santa Fe Group. Calcite-cemented zones occur as concretions and as laterally extensive cemented beds (>2 km lateral extent in some cases). Calcite cementation in the Santa Fe Group appears to be controlled by two main factors: depositional facies and primary depositional texture. Calcite is most abundant in tributaries to the ancestral Rio Grande, closed-basin fluvial facies, and piedmont facies. It is least abundant in the ancestral Rio Grande facies. The differences in the degree of cementation of the different facies may result from differences in their pore-water chemistry. This is supported by present-day chemical data that show undersaturation for calcite in aquifers adjacent to the modern Rio Grande, and oversaturation away from it. Regardless of depositional environment, coarser grained and better sorted sediments tend to be preferentially cemented. This suggests that cementation was in part controlled by pre-cementation permeability, perhaps from a greater flux of calcium and/or bicarbonate in permeable horizons.

Introduction

An understanding of the spatial distribution of porosity and permeability in aquifers, and the development of models predicting the distribution of these hydraulic properties in the subsurface, are of critical importance to ground-water studies. The hydrologic properties of sedimentary rocks are controlled by primary depositional features such as grain size and sorting, as well as diagenetic alterations that affect the pore structure (i.e., precipitation, dissolution, and compaction). Studies have addressed the question of primary depositional controls on the spatial distribution of hydraulic properties of aquifer units (e.g., Anderson, 1989; Hawley and Haase, 1992; Davis et al., 1993; Neton et al., 1994; Detmer, 1995; Hawley et al., 1995; Haneberg, in press). However, the effect of diagenesis on these properties has been largely ignored.

This paper presents field data on the spatial distribution of calcite cements from an ongoing investigation of calcite cementation in the Santa Fe Group in the Albuquerque Basin (Fig. 1). The Santa Fe Group (Oligocene to Pleistocene) is the synrift sedimentary basin fill of the Rio Grande rift (Chapin, 1988), and is the principal aquifer unit in the Albuquerque Basin and other basins along the rift in New Mexico (Hawley et al., 1995; Thorn et al, 1993). Calcite is the most volumetrically important cement in the unit. In places it completely cements sandstone and conglomerate beds, forming aquicludes and aquitards several meters thick and thousands of meters wide.

Methods

The spatial distribution of calcite cementation was examined in outcrops of the Santa Fe Group throughout the Albuquerque Basin. Representative stratigraphic sections were measured using a Jacob's staff. The lateral extent of cemented beds was determined by measuring the longest straight-line segment of continuous cementation exposed in the outcrop. In many cases the full lateral extent of the bed could not be determined because of limited exposure, so in some cases lateral continuity may be considerably greater than the reported values. Grain size and sorting were estimated in the field using visual comparitors.

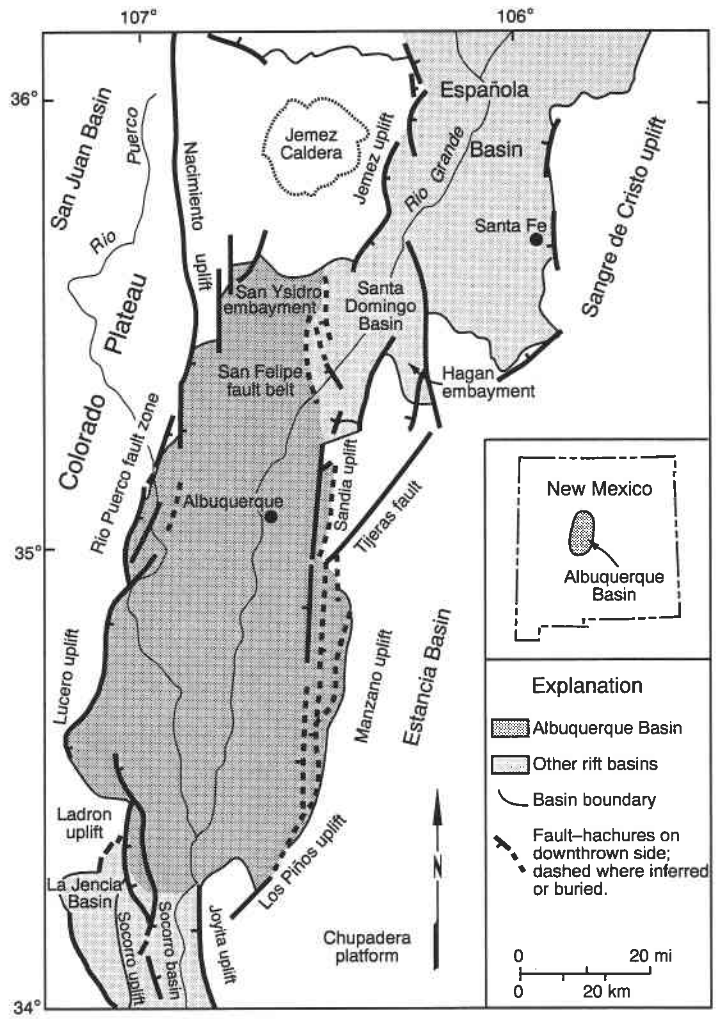


Figure 1—Albuquerque Basin index map (after Hawley and Haase, 1992).

Calcite saturation indices were calculated using data from Anderholm (1988) and the aqueous geochemical computer model PHREEQE (Parkhurst et al., 1980). Although analytical uncertainties for the analyses tabulated in Anderholm (1988) were not presented, it appears that bicarbonate analyses were most frequently reported to the nearest 10 mg/l and calcium analyses were most frequently reported to the nearest mg/l. A sensitivity analysis based on these apparent uncertainties suggests that the uncertainty in the calculated calcite saturation indices should be ± 0.037. No indications were given in Anderholm (1988) whether alkalinities were measured in the field or in the laboratory. If alkalinities were measured in the laboratory, the uncertainty in the calculated calcite saturation indices may be significantly larger than ± 0.037. However, the regularity of the calcite saturation pattern suggests that the data is reasonably accurate.

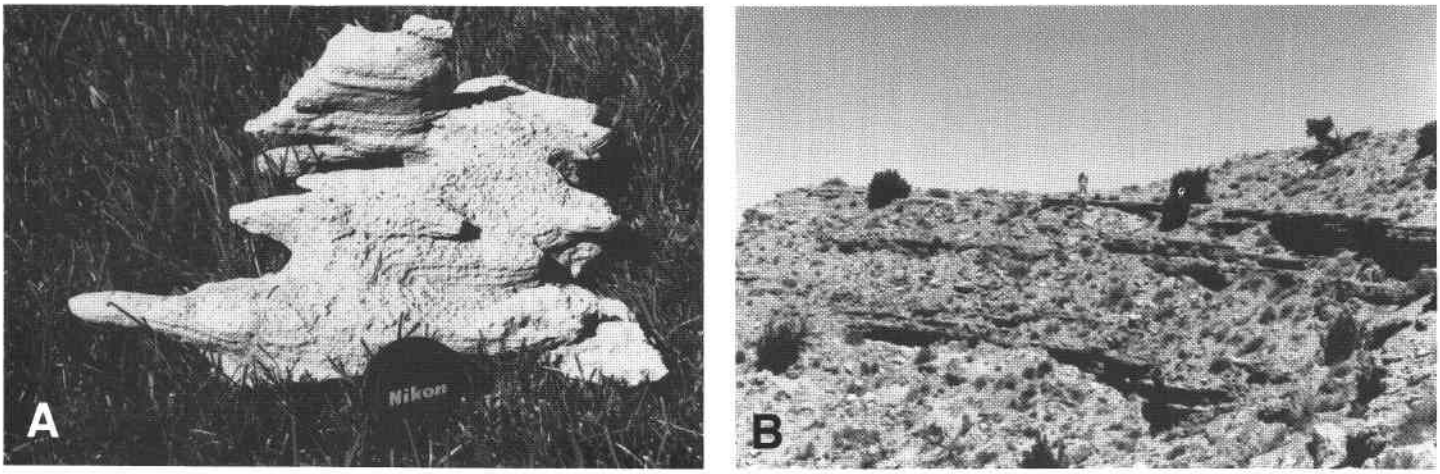


Figure 2—**A**, Complex elongate concretion from the ancestral Rio Puerco facies of the Sierra Ladrones Formation; lens cap is 5 cm in diameter. **B**, Laterally extensive cemented layers (resistant zones) in the unnamed member of the Zia Formation.

Types of calcite cementation

Calcite-cemented zones in the Santa Fe Group occur in two principal forms, isolated concretions and laterally extensive cemented beds (Fig. 2). The concretions are highly variable in size, geometry and surface texture. Cemented beds are more laterally continuous than the concretions, commonly extending for many tens of meters or more along a particular stratigraphic horizon.

A striking feature of some concretions is a pattern of elongation parallel to bedding, with the long axes of the elongate concretions subparallel to other elongate concretions in the same portion of the outcrop (Fig. 2A). Mozley and Davis (in press) examined elongate concretions in the Sierra Ladrones Formation (upper Santa Fe Group) and concluded that they formed from ground-water flow in the saturated zone, with the orientation of the elongation reflecting the orientation of ground-water flow at the time of concretion precipitation. Similar elongate cemented zones have been observed in calcite-cemented fault zones in the Santa Fe Group (Mozley and Goodwin, 1995).

Although most authigenic calcite in the Santa Fe Group occurs as a pore-filling cement, the playa lake facies of the Zia Formation contains several horizons of synsedimentary carbonate. These layers are characterized by highly irregular shapes and are interpreted to be lacustrine tufa deposits (Lozinsky, 1988). In addition, minor amounts of pedogenic calcite are locally present in both the upper and lower Santa Fe Group.

Spacial distribution of calcite cements

Relationship to facies and depositional texture

The distribution of calcite cement in the Santa Fe Group is strongly controlled by facies and depositional texture (Table 1; Figs. 3 through 8). Carbonate cements are most abundant in tributaries to the ancestral Rio Grande (i.e., ancestral Rio Puerco), in closed-basin fluvial facies, and in piedmont facies. Calcite cement is least abundant in the ancestral Rio Grande facies. Within a particular facies, coarser grained and better sorted units tend to contain the most cement (Figs. 3 through 8). Lateral continuity of cemented horizons varies considerably among the different facies examined (Table 1). The most laterally continuous horizons were observed in the closed-basin fluvial, eolian, and playa-lake facies (>1 km). The least laterally continuous horizons were observed in the ancestral Rio Grande deposits (maximum observed = 9 m).

Some strongly cemented beds in the eolian facies of the Zia Formation contain abundant rhizocretions (concretions formed around roots) and a variety of other textures and structures characteristic of pedogenic carbonate (e.g., tepee structures, laminar cemented zones; Esteban and Klappa, 1983; Goudie, 1983; Wright and Tucker, 1991). Cementation in these beds does not follow primary textural differences in the host lithology (e.g., laterally extensive horizons in Fig. 8).

Controls on cement distribution

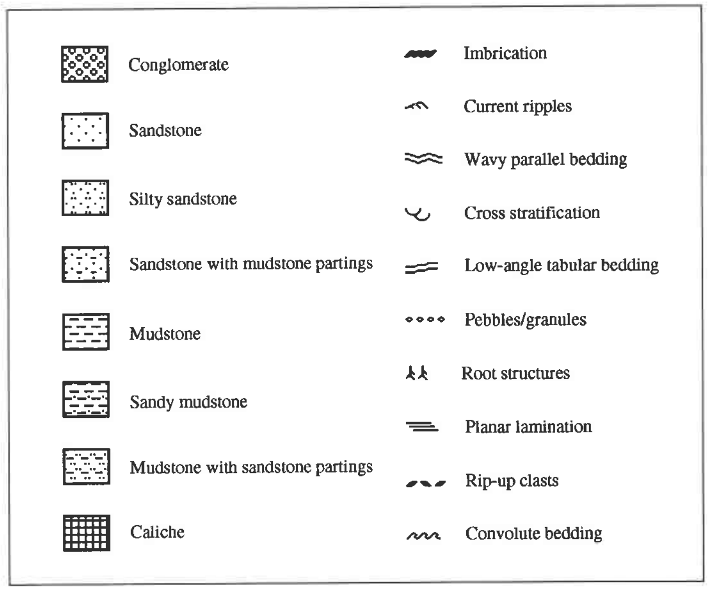
The preferential cementation of coarser grained and better sorted horizons in most outcrops of the Santa Fe Group indicates that a fundamental control on calcite distribution was pre-cementation permeability (saturated permeability increases with increasing grain size and sorting). This suggests that sediments that originally had the greatest permeability and connectivity of permeable packages became preferentially cemented by calcite. One possible explanation is that cementation was limited by the availability of dissolved calcium and/or bicarbonate, and greater amounts of these dissolved components were available in the best portions of the aquifer (i.e., areas that experienced the greatest flux of aqueous species). As previously noted, some strongly cemented beds in the Zia Formation do not appear to follow textural differences in the host sediment. The presence of many pedogenic features in these beds suggests that calcite cementation in the beds may be in part the result of pedogenesis. The pedogenic carbonate may have been augmented by later carbonate that formed preferentially on the preexisting carbonate substrate.

Although the relationship between pre-cementation permeability and cementation can be used to explain the overall distribution of calcite cement in a given facies, it does not adequately explain variations in cementation among facies. Specifically, the highly permeable ancestral Rio Grande facies should be heavily cemented by calcite if pre-cementation permeability was the principal control on cementation, yet it is the least cemented of the facies. The smaller amounts of calcite in the ancestral Rio Grande facies probably result from differences in the pore-water chemistry of the different facies at the time of cement precipitation. The ancestral Rio Grande facies pore waters may have been largely undersaturated for calcite, whereas tributary, closed-basin fluvial, and piedmont facies were supersaturated. This hypothesis is supported by the present-day ground-water chemistry of the Albuquerque Basin. Calcite saturation in Santa Fe Group pore waters shows a strong axial trend of undersaturated conditions roughly centered on the modern day Rio Grande (Fig. 9). Ground water becomes progressively more saturated away from this axial trend.

TABLE 1—Summary of calcite cement relationships in the Santa Fe Group, Albuquerque Basin. Hydrostratigraphic units noted are described in Hawley and Haase (1992).

Facies/units	Lithologic associations	Cement abundance	Lateral continuity	Controls on cementation	Outcrops examined
Piedmont slope (Hydrostrat. unit: USF-1)	Cement occurs mainly in grain-supported conglomerates and medium- to very coarse grained sandstones.	Abundant to absent	Proximal: often minimal (<5 m) because of lateral termination of coarse-grained rock types. Distal: continuous cemented zones (>500 m) common.	Cementation controlled by pre-cementation permeability. Some cementation may have occurred in perched aquifers.	Upper Santa Fe Gp: Tijeras Arroyo & W of Placitas; Sierra Ladrones Fm: Arroyo de la Parida.
Ancestral Rio Puerco (Hydrostrat. unit: USF)	Coarser grained sandstones and to a lesser extent conglomerates preferentially cemented. Very poorly sorted conglomerates not well cemented.	Abundant	Highly variable (<1 m to >200 m).	Cementation controlled by pre-cementation permeability.	Upper Santa Fe Gp, Sierra Ladrones Fm: W, NW, & SW of Belen.
Ancestral Rio Grande (Hydrostrat unit: (USF-2)	Coarser grained sandstones and conglomerates preferentially cemented, but relationship is not very strong.	Rare	Minimal (maximum observed = 9 m).	Cementation controlled by pre-cementation permeability.	Upper Santa Fe Gp, Sierra Ladrones Fm: S Alb., Black Mesa, Isleta Pueblo, I–25 between Belen & Socorro, Johnson Hill area
Closed-basin fluvial (Hydrostrat. unit: (LSF)	Coarser grained sandstones and soil horizons preferentially cemented	Abundant	Highly variable (<1 m to 2 km).	Cementation controlled by pre-cementation permeability and pedogenesis.	Lower Santa Fe Gp, Zia Fm: W of Rio Rancho; Popotosa Fm: W of Lemitar.
Eolian (Hydrostrat. unit: LSF)	Coarser grained, sandstones, and soil horizons preferentially cemented	Abundant to absent	Highly variable (<1 m to 1 km)	Cementation controlled by pre-cementation permeability and pedogenesis.	Lower Santa Fe Gp, Zia Fm: W of Rio Rancho.
Playa (Hydrostrat. unit: LSF)	Coarser grained sandstones preferentially cemented. Syndepositional carbonates locally important.	Rare to abundant	Highly variable (<1 m to 2 km).	Cementation controlled by pre-cementation permeability and depositional environment.	Lower Santa Fe Gp, Zia Fm: W of Rio Rancho; Popotosa Fm: Gabaldon Badlands

Figure 3—Key to lithologic and structural symbols used in Figs. 4 through 8.



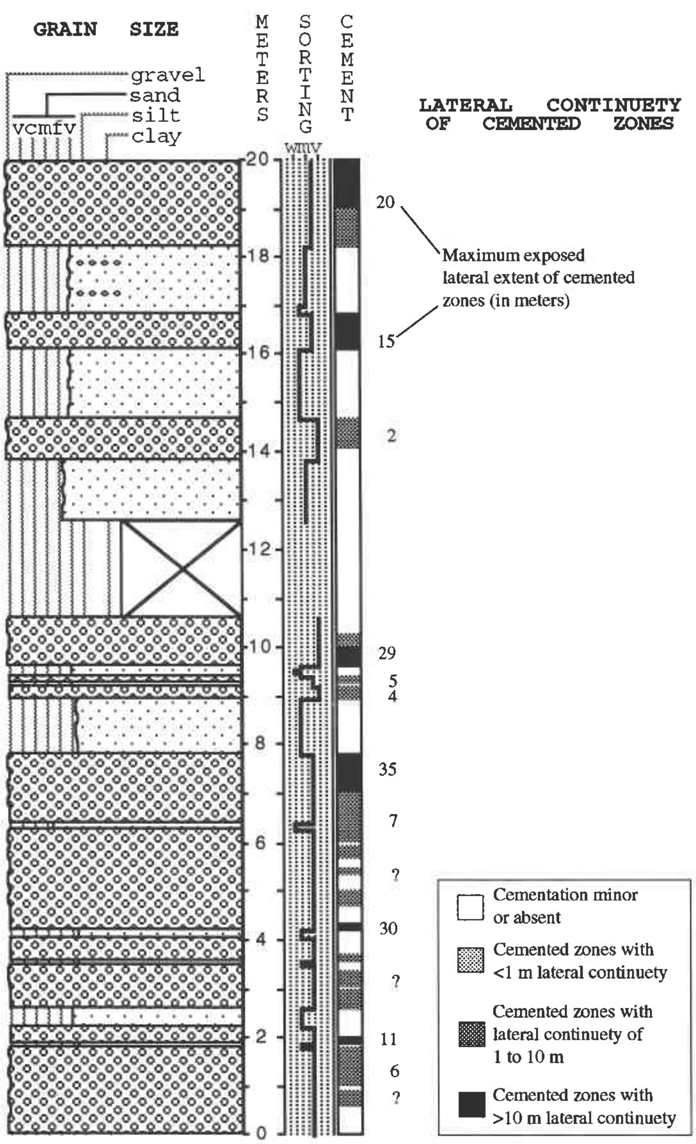


Figure 4—Stratigraphic column of upper Santa Fe Group piedmont-slope deposits near Placitas, N. M.

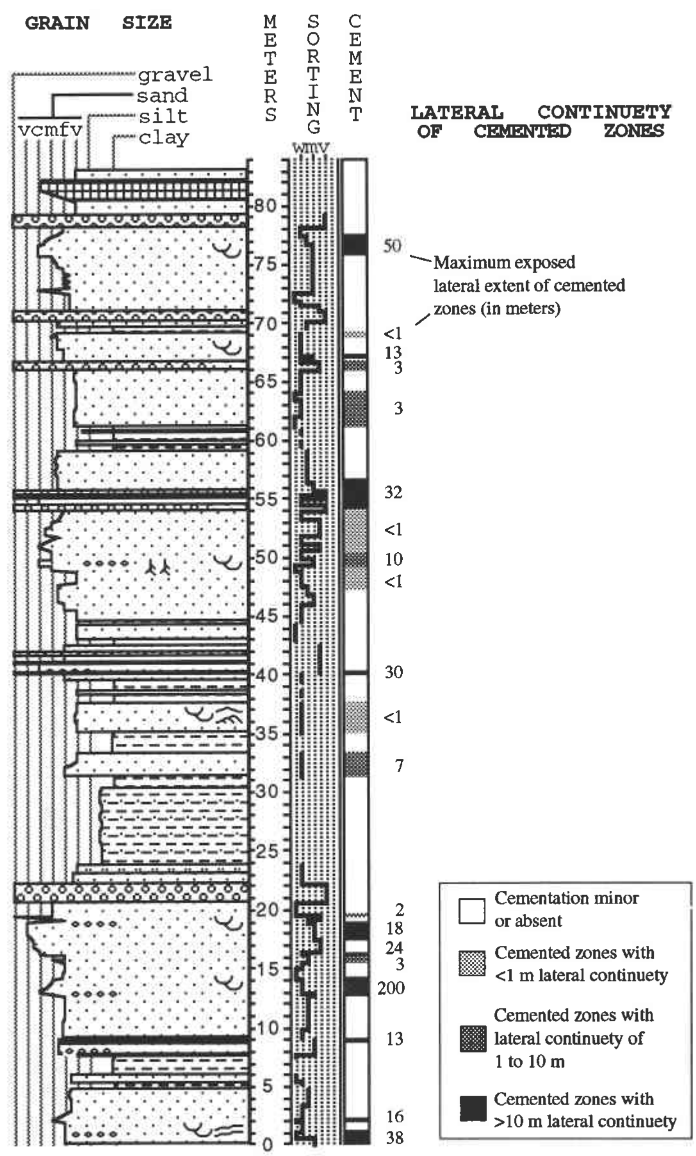


Figure 5—Stratigraphic column of ancestral Rio Puerco deposits near Bosque, N. M.

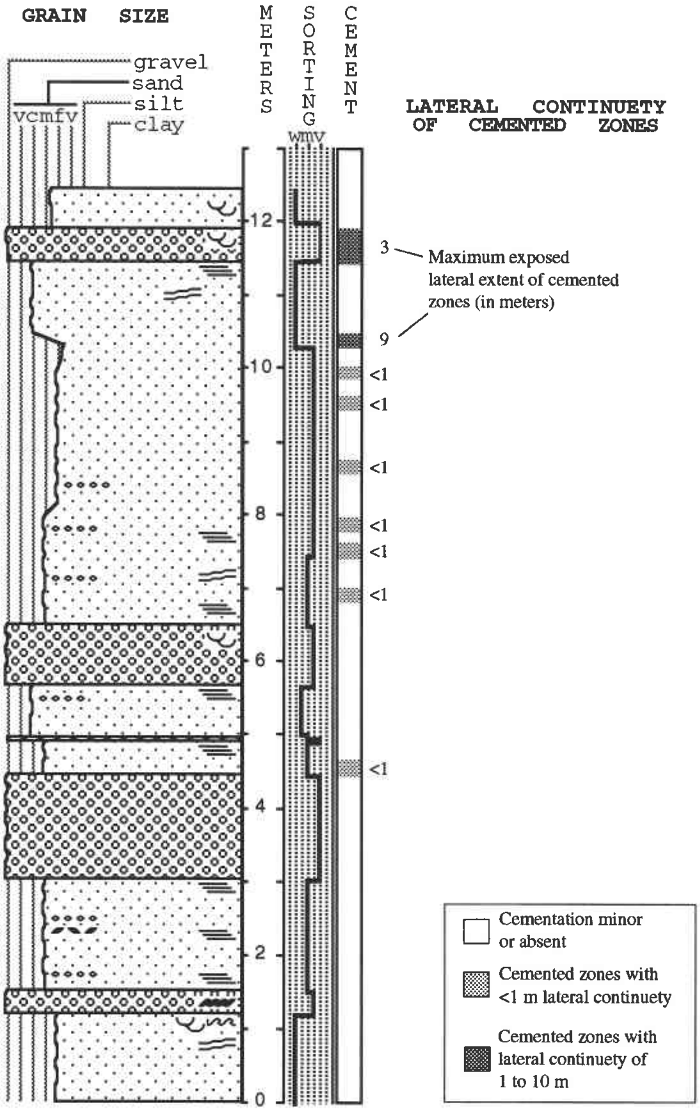


Figure 6—Stratigraphic column of ancestral Rio Grande deposits near the Rio Bravo exit on I–25. Many ancestral Rio Grande outcrops contain no significant calcite cementation. This relatively carbonate rich section was selected to show the relationship between cementation and sedimentary textures.

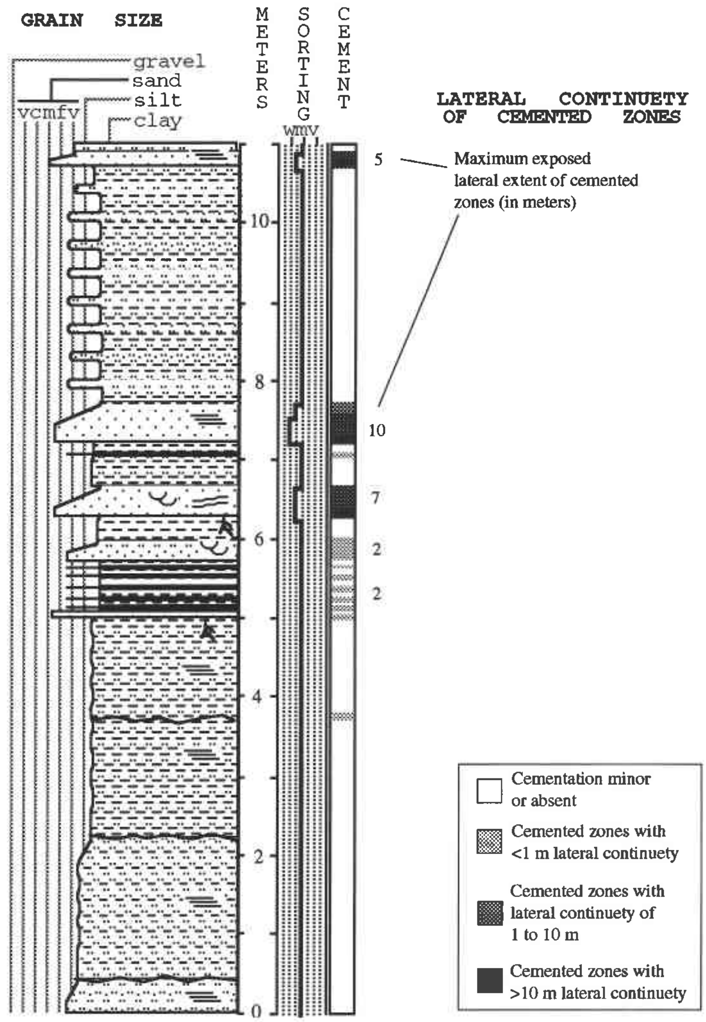


Figure 7—Stratigraphic column of closed-basin fluvial deposits in the Zia Formation west of Rio Rancho.

Effect of cementation on ground-water resources

Calcite cementation in the Santa Fe Group greatly reduces permeability and porosity forming both local and regional aquitards and aquicludes. The impact of cementation on aquifer quality is invariably negative, particularly because it disproportionately affects the best portions of the aquifer (i.e., beds with initial high permeability and porosity). In extreme cases this has led to a wholesale inversion of aquifer quality, in which beds that were initially the best portions of the aquifer are now the worst. In addition to reducing overall aquifer quality, laterally continuous zones of cementation can have a major effect on vertical fluid flow, perhaps resulting in compartmentalization of the aquifer in some cases. Such compartmentalization could result in significant production loss in water wells that are only screened above or below a laterally extensive cemented horizon.

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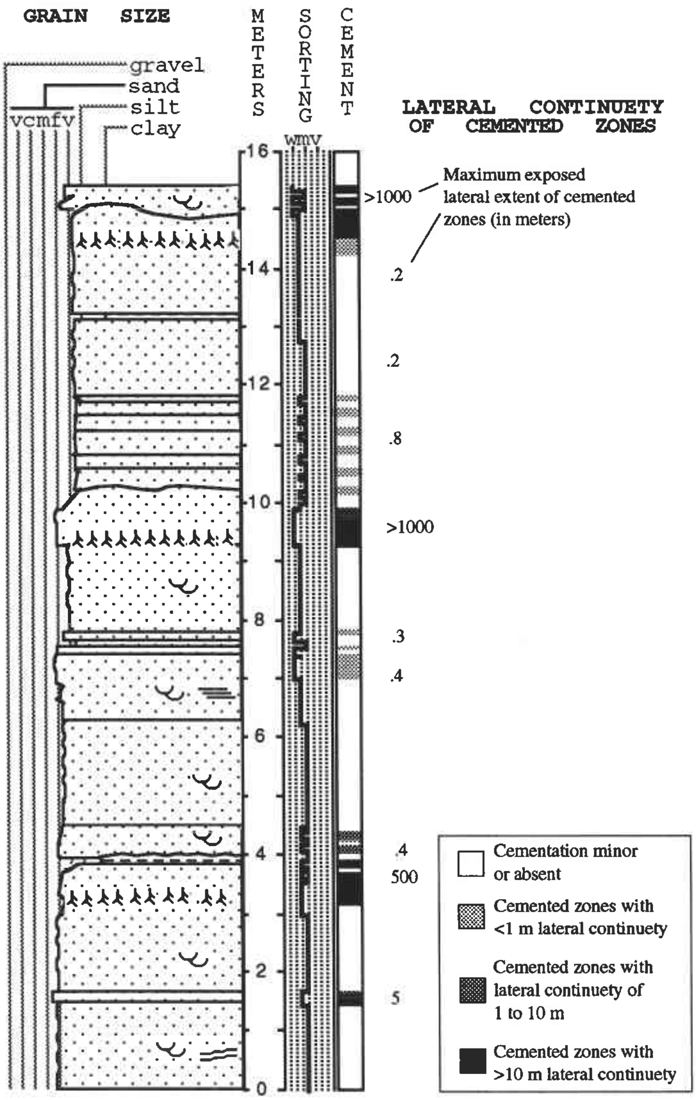

Figure 8—Stratigraphic column of eolian deposits in the Zia Formation west of Rio Rancho.

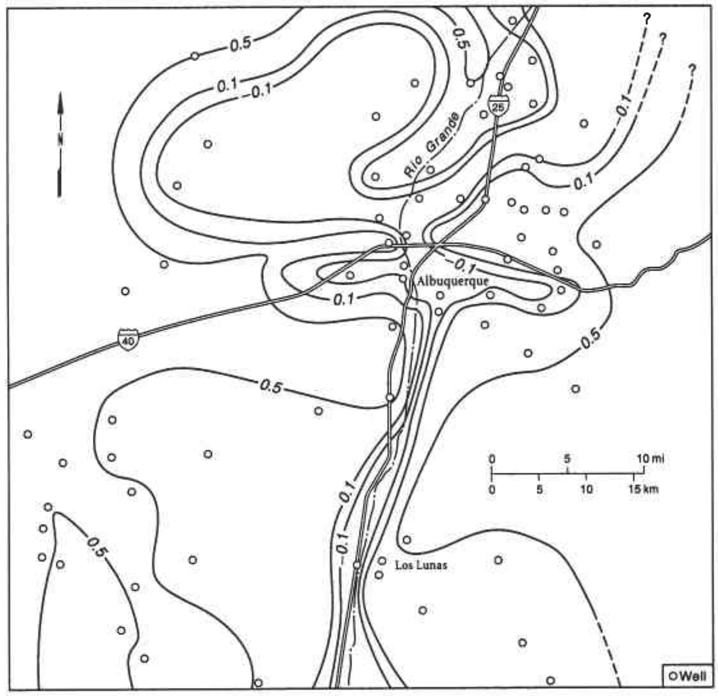

Figure 9—Calcite saturation of groundwater in the central Albuquerque Basin. Saturation occurs when the saturation index falls between 0.1 and –0.1. Waters with a calcite saturation index greater than 0.1 are supersaturated, whereas waters with a saturation index less than –0.1 are undersaturated.

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