New Mexico Geological Society

Downloaded from: http://nmgs.nmt.edu/publications/guidebooks/43

A stream-sediment geochemical map (from NURE data) showing bulk silica distribution within the Eocene San Jose Formation, San Juan Basin, New Mexico

Richard M. Chamberlin, James S. Harris, and Margaret I. Onimole, 1992, pp. 317-320

in:

San Juan Basin IV, Lucas, S. G.; Kues, B. S.; Williamson, T. E.; Hunt, A. P.; [eds.], New Mexico Geological Society 43rd Annual Fall Field Conference Guidebook, 411 p.

This is one of many related papers that were included in the 1992 NMGS Fall Field Conference Guidebook.

Annual NMGS Fall Field Conference Guidebooks

Every fall since 1950, the New Mexico Geological Society (NMGS) has held an annual Fall Field Conference that explores some region of New Mexico (or surrounding states). Always well attended, these conferences provide a guidebook to participants. Besides detailed road logs, the guidebooks contain many well written, edited, and peer-reviewed geoscience papers. These books have set the national standard for geologic guidebooks and are an essential geologic reference for anyone working in or around New Mexico.

Free Downloads

NMGS has decided to make peer-reviewed papers from our Fall Field Conference guidebooks available for free download. Non-members will have access to guidebook papers two years after publication. Members have access to all papers. This is in keeping with our mission of promoting interest, research, and cooperation regarding geology in New Mexico. However, guidebook sales represent a significant proportion of our operating budget. Therefore, only *research papers* are available for download. *Road logs*, *mini-papers*, *maps*, *stratigraphic charts*, and other selected content are available only in the printed guidebooks.

Copyright Information

Publications of the New Mexico Geological Society, printed and electronic, are protected by the copyright laws of the United States. No material from the NMGS website, or printed and electronic publications, may be reprinted or redistributed without NMGS permission. Contact us for permission to reprint portions of any of our publications.

One printed copy of any materials from the NMGS website or our print and electronic publications may be made for individual use without our permission. Teachers and students may make unlimited copies for educational use. Any other use of these materials requires explicit permission.

New Mexico Geological Society Guidebook, 43rd Field Conference, San Juan Basin IV, 1992

A STREAM-SEDIMENT GEOCHEMICAL MAP (FROM NURE DATA) SHOWING BULK SILICA DISTRIBUTION WITHIN THE EOCENE SAN JOSE FORMATION, SAN JUAN BASIN, NEW MEXICO

RICHARD M. CHAMBERLIN, JAMES S. HARRIS and MARGARET I. ONIMOLE
New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico 87801

Abstract—We present a geochemical map showing the estimated silica (eSiO_2) content of 496 NURE stream-sediment samples collected within the Eocene San Jose Formation. This computer-generated map essentially shows the bulk distribution of quartz within the formation. The formation is clearly divisible into a central low-silica (low quartz) domain, a western intermediate-silica domain and a southeastern high-silica domain. Our follow-up stream-sediment sampling and analysis have verified the chemical patterns seen in the NURE data. Preliminary petrographic study of follow-up stream-sediment samples indicates that quartz/feldspar ratios are relatively constant *within* each silica domain, as defined by the NURE data. Some second-order noise within silica domains apparently reflects high concentrations of mudstone grains or heavy minerals in the NURE samples. Quartz/feldspar estimates from 44 thin sections of San Jose sandstones demonstrate a good correlation of granite-derived arkose with the low-silica domain, cherty subarkose with the intermediate-silica domain, and subfeldspathic arenite with the high-silica domain. We interpret the intermediate-silica, subarkosic strata and the high-silica, subfeldspathic strata as the products of southerly flowing early Eocene river systems that entered the basin near Aztec and Llaves, respectively; these rivers appear to have joined near Cuba. Preliminary field observations and second-order geochemical patterns suggest that the low-silica, arkosic strata represent relatively thin deposits of a younger river system which overlies the main body of San Jose strata. Additional data are needed to accurately define the geometry of low-silica arkosic strata within the San Jose Formation.

INTRODUCTION

We present a reconnaissance geochemical map (Fig. 1) that shows the estimated silica (eSiO_2) content of 496 NURE stream-sediment samples collected within the Eocene San Jose Formation. This computer-generated map has been created as part of an ongoing study concerning the geochemistry, mineralogy, sedimentary petrology, fluvial architecture and provenance of the San Jose Formation within the New Mexico portion of the San Juan Basin. This study began with a relatively unconstrained interpretation of stream-sediment geochemical data (Chamberlin, 1987). The geochemical data were produced as part of the U.S. Department of Energy's National Uranium Resource Evaluation (NURE)–Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) program. Since 1987, the NURE data set (496 samples, analyzed for 32 different elements) has been examined utilizing numerous geochemical maps of individual elements, selected element ratios, scatter diagrams, histograms and cumulative frequency diagrams. This project has progressed primarily through the assistance of computer-literate, undergraduate, work-study students at the New Mexico Institute of Mining and Technology (Margaret Onimole, 1987–1990; and James Harris, 1990–present) whose tasks have been guided by the senior author. The silica distribution map (Fig. 1) represents the sustained efforts and computer skills of the junior authors. The purpose of this study is to better understand the geology of New Mexico by cautiously using a large quantitative database from the public realm.

To validate the patterns seen in the NURE data, seventeen follow-up stream-sediment samples were collected by the senior author. The follow-up samples were sieved to minus 100 mesh, and analyzed by standard XRF techniques at the New Mexico Bureau of Mines and Mineral Resources for all major components, including SiO_2, volatiles (i.e., loss on ignition, LOI), and a few definitive trace elements. We also have completed semi-quantitative XRD clay-mineral analyses of the minus two micron fraction of each follow-up sample using techniques developed at the New Mexico Bureau of Mines and Mineral Resources. Thin sections of grain mounts from follow-up samples show that they consist, almost entirely, of varying proportions of quartz, feldspar and fine-sand-sized grains of semi-opaque mudstone. The senior author has made preliminary visual estimates of quartz/feldspar/mudstone proportions for all the follow-up stream-sediment samples. Also, quartz/feldspar/lithic ratios have been estimated for thin sections of 44 San Jose sandstones collected at widespread locations across the

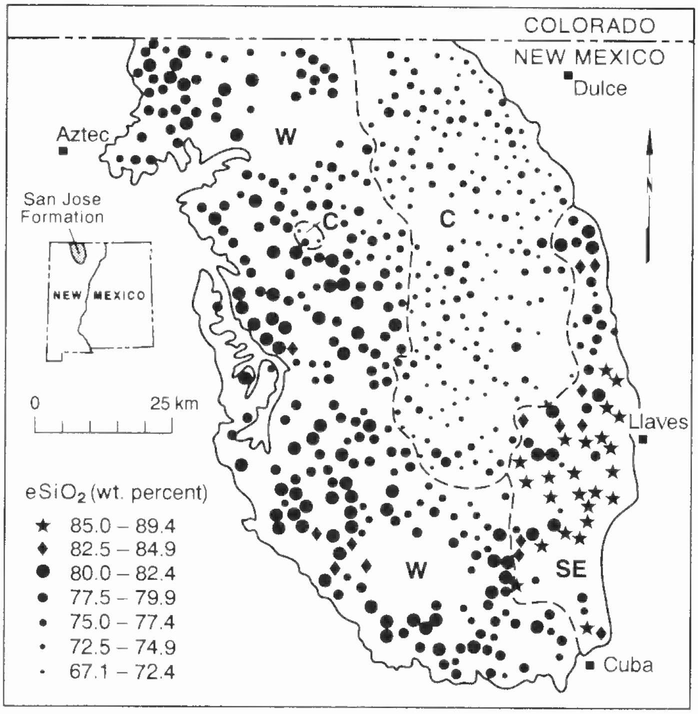

FIGURE 1. A reconnaissance geochemical map showing the estimated silica content (eSiO_2) in the fine-grained fraction (minus 100 mesh) of 496 Holocene stream-sediment samples collected from second- and third-order drainages within the Eocene San Jose Formation, New Mexico. Original sample location data and major element data (Al, Fe, Ti, Mg, Ca, K, Na) used to calculate eSiO_2 are from U.S. Department of Energy open-file reports that present NURE-HSSR data for the Aztec 1° × 2° quadrangle (U.S. Department of Energy, 1978, 1981). The map is subdivided into three broad compositional domains: a southeastern high-silica domain (SE), a western intermediate-silica domain (W), and a central low-silica domain (C); the latter apparently including a small outlier within the western domain.

basin. These new chemical and mineralogical data (Chamberlin and Harris, unpubl. data) permit a more confident empirical interpretation of the silica distribution map than was previously possible.

MAP PRODUCTION

The San Jose Formation makes an ideal target for a stream-sediment reconnaissance survey due to a well-developed dendritic drainage pattern, a great area of exposure (7300 km^2), simple structure, and an isolated topographically high position in the regional landscape (which allows for a relatively minor Pleistocene cover). As part of the NURE-HSSR program, 511 stream-sediment samples were collected from second- and third-order arroyos draining the San Jose Formation within the Aztec 1° × 2° quadrangle (U.S. Department of Energy, 1978, 1981). Ten samples, collected in the Canyon Largo area, have been deleted from the original NURE data set because they represent fourth-order Pleistocene valley fills, carried about 30 km from their source. Four anomalously boron-rich (tourmaline rich?) samples collected downstream from Pleistocene piedmont gravels near Cuba have also been deleted because they represent Quaternary detritus derived from Proterozoic rocks in the San Pedro Mountains. And finally, one strontium-rich sample collected downstream of a basaltic dike near Dulce has been deleted because it represents a middle Tertiary dike.

To maximize legibility and spatial relationships, the point value symbols representing each sample (Fig. 1) have been relocated to the approximate center of their respective catchment area. Catchment areas range from 2–40 km^2 and average about 15 km^2. Most samples are shown within 5 km of the actual point of collection. Local topographic relief, essentially equivalent to the stratigraphic range of the sample, varies between 30 and 200 m. Thus, each sample may be regarded as a composite or bulk sample representing a significant fraction of the San Jose Formation.

The fine-grained fraction (minus 100 mesh) of each NURE stream-sediment sample from the Aztec quadrangle was analyzed by plasma-source emission spectrography at the Oak Ridge Gaseous Diffusion Plant for 24 trace elements, and all major constituents (Al, Fe, Ti, Mg, Ca, K, Na) except silicon and combined water (H_2O^+). We converted major element concentrations in the NURE data set to their oxide equivalents using standard gravimetric constants, found in most geochemistry textbooks. We then calculated the estimated silica content ($eSiO_2$) of each NURE sample using the formula: $eSiO_2 + H_2O^+ + CO_2 = 100$ percent–($Al_2O_3 + Fe_2O_3 + TiO_2 + MgO + CaO + K_2O + NaO_2$). Petrographic study of follow-up samples and CaO/Al_2O_3 statistics for NURE samples indicate that nearly all of the NURE samples (488 of 496) contain negligible calcite (less than 0.7% $CaCO_3$, or 0.3% CO_2). Published data for argillaceous sandstones (Hill et al., 1967, p. 219), and our own LOI data for the 17 follow-up samples, indicate an average combined water content of 5 ± 3% H_2O^+. For the above calculation of estimated silica we have assumed a *constant* combined water content of 5% and a negligible CO_2 content.

Based on measurements control (precision) information provided in the original tabulated NURE data (U.S. Department of Energy, 1981, p. 16) and the average composition of NURE stream-sediment samples derived from the San Jose, we have calculated the maximum analytical error to be ± 1.3% $eSiO_2$. The maximum analytical error occurs when the sum of major oxides equals 28%, which is equivalent to an $eSiO_2$ concentration of 67% $eSiO_2$ ($95-28=67$). Because the calculation is based on subtraction of the measured values from a constant, the relative analytical error actually decreases to ±0.3% at 89% $eSiO_2$. The uncertainty of combined water and carbonate content, combined with analytical error, indicates that our calculated estimate of SiO_2 content is normally within 5% of the actual SiO_2 content of each sample. Better empirical corrections for combined water and CO_2 content, based on regression analysis of Al_2O_3 and CaO data, could increase the accuracy of estimated SiO_2 to ±2.5%.

A class interval of 2.5% $eSiO_2$ was chosen to represent the main body of samples (i.e., 417 of the 496 samples shown on Fig. 1), which range from 72.5 to 82.4% $eSiO_2$. This class interval was chosen following inspection of a cumulative frequency diagram (Fig. 2), which indicates a median value of 77.3% $eSiO_2$ and distinct decreases in frequency above 85% $eSiO_2$ and below 72% $eSiO_2$. A useful class interval must be larger than the maximum analytical error, yet small enough to show potential trends within the main body of data; 2.5% $eSiO_2$ seems to fit both of these constraints reasonably well. Larger class intervals at the high end (4.4%) and low end (5.3%) of the spectrum do not violate the above principles and permit the use of a smaller number of visually distinct symbols. A computer program entitled GSPOST, version 1.0, by Selner et al. (1987), was used to plot the symbols representing estimated silica content.

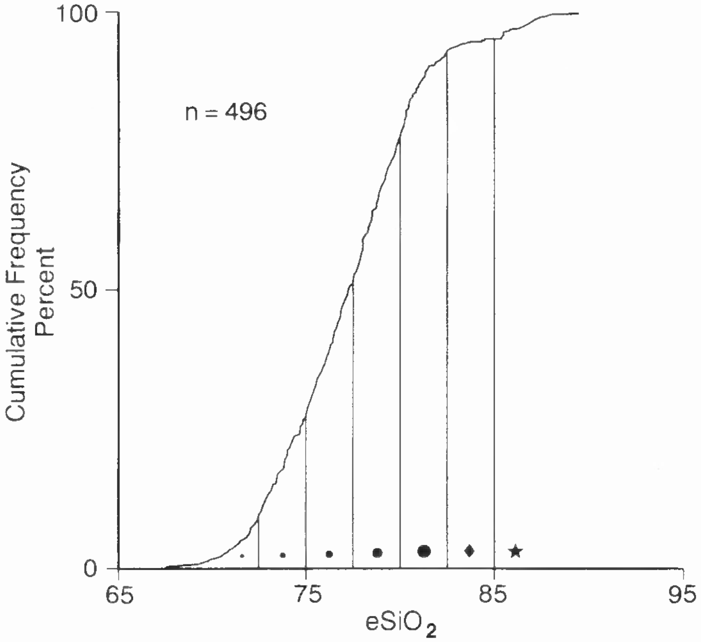

FIGURE 2. A cumulative frequency diagram depicting the estimated silica content ($eSiO_2$) of 496 NURE stream-sediment samples derived from the Eocene San Jose Formation. Class intervals and point-value symbols match those shown on Fig. 1.

MAP INTERPRETATION

The geochemical map, shown as Fig. 1, is designed to allow a rapid visual analysis of regional (first-order) trends in silica concentration. The map also allows rapid recognition of statistically significant (large) differences in silica content (e.g., southwest of Llaves) that form "noise" within the first-order trends. It is clear that the class interval could be doubled in size, to 5%, and the map would still show the same regional trends. In other words, this geochemical map appears to be statistically robust (i.e., it is hard to mask the primary signal).

It is well established (Pettijohn, 1963, table 1) that the SiO_2 concentration in siliciclastic sediments decreases with decreasing grain size. In arkosic sediments, SiO_2 decreases with increasing feldspar content (Pettijohn, 1963, table 8). Since NURE stream-sediment samples have been sieved to minus 100 mesh (lower-fine-sand-size and smaller grains), the chemical data are biased toward lower SiO_2 values. However, this grain-size bias is a consistent component of all NURE data, and has no significance in this case where NURE data is compared to itself.

The geochemical map (Fig. 1) clearly shows that the San Jose Formation is divisible into a southeastern high-silica domain (SE), a western intermediate-silica domain (W) and a central low-silica domain (C). Field observations and details within the NURE data set (e.g., distribution of heavy mineral indicators Fe and Ti) do not allow the first-order silica domains to be interpreted as a function of regional grain size distribution; a central lacustrine facies is not apparent. The only reasonable alternative remaining is that these three silica domains represent the bulk distribution of quartz in the San Jose Formation.

Other NURE data (boron and radiometric K^{40}) and our field observations indicate the presence of a fourth geochemical domain at the base of the formation west of Dulce (Carracas Canyon area). This small intermediate(?)-silica domain is not apparent on the $eSiO_2$ map, because its signature in the Holocene sediments is largely masked by low-silica (feldspar-rich) sediment derived from topographically higher strata. Additional discussion of this small domain is beyond the scope of this article.

It is important to point out that the domain boundaries of Fig. 1 may represent sharp compositional breaks in the Eocene strata that have been made to look gradational by mixing of distinctly different Eocene sediments in Holocene streams. Table 1 illustrates that the three major silica domains (Fig. 1) have other distinctive geochemical signatures that represent lower-order variations in feldspar, clay, mica and/or heavy mineral content. The ratio of heavy mineral indicator elements (Fe, Ti, Zr) to light mineral indicator elements (Al, Mg), which can be used to calculate a stream-energy index for each sample, is a subject that will not be pursued here.

A comparison of the silica distribution map with our unpublished geochemical maps showing iron, magnesium and phosphorus distribution strongly suggests that the gradational boundary of the central domain with the western domain is mostly due to sediment mixing in Holocene streams. Along this line, it is also important to note that the central low-silica domain is located on the topographically high eastern side of an escarpment that trends south from the state line at Carracas Mesa (west of Dulce) to Cañada Larga (west of Llaves).

Duval (1988) has published aerial gamma-ray contour maps (prepared from NURE aeroradiometric flight line data), which show the relative distribution of potassium, thorium and uranium in surface materials across New Mexico. Our unpublished stream-sediment map showing potassium distribution in the San Jose Formation compares very well with Duval's map of radiometric potassium. In fact, the boundary between the low-potassium, high-silica southeastern domain and the relatively high-potassium central and western domains is sharp and well defined on Duval's map of K^{40} distribution. Duval's map and our preliminary field observations strongly suggest that the low-silica (high potassium) central domain (Table 1) truncates and overlaps the high-silica (low potassium) southeastern domain about 25 km south of Dulce. Stratigraphic implications of these observations are discussed below.

TABLE 1. Summary of univariate statistical data (mean and standard deviation, s.d.) for 425 NURE stream-sediment samples representing three compositional domains (see Fig. 1) within the Eocene San Jose Formation. The principal data set of 496 samples (Fig. 1) has been edited to 425 samples in order to reduce the effects of mixing at domain boundaries. The relatively distinctive geochemical signatures of each domain are listed in bold type.

Domain:	Central (low silica)	Western (intermediate silica)	Southeastern (high silica)
No. Samples:	190	179	56
Major Constituents: (wt. percent)	mean ± s.d.	mean ± s.d.	mean ± s.d.
$eSiO_2$	**73.4 ± 2.4**	**78.8 ± 1.9**	**81.2 ± 4.9**
$eSiO_2$ (mode)	(72.8)	(79.4)	(86.0)
Al_2O_3	11.3 ± 1.7	9.3 ± 1.2	7.7 ± 3.2
TiO_2	0.6 ± 0.2	0.5 ± 0.1	0.4 ± 0.2
Fe_2O_3	**4.0 ± 0.8**	2.4 ± 0.6	2.8 ± 1.1
MgO	**1.0 ± 0.3**	0.6 ± 0.2	0.6 ± 0.3
K_2O	1.8 ± 0.3	1.6 ± 0.3	**1.2 ± 0.3**
CaO	1.0 ± 0.3	0.7 ± 0.2	0.7 ± 0.2
Na_2O	1.1 ± 0.3	1.1 ± 0.2	**0.3 ± 0.2**
Trace Constituents: (ppm)	mean ± s.d.	mean ± s.d.	mean ± s.d.
P	**538 ± 170**	266 ± 62	328 ± 99
Y	**20 ± 5**	14 ± 3	14 ± 5
Th	8 ± 5	9 ± 5	6 ± 5
Zr	84 ± 46	**61 ± 15**	83 ± 35

Our follow-up stream-sediment samples agree in all respects with the silica patterns defined by the larger NURE data set. Preliminary petrographic examination of grain mounts from the follow-up samples indicates that within the three major silica domains, quartz/feldspar ratios are relatively constant. Estimated quartz/feldspar ratios for the high-silica (SE), intermediate-silica (W), and low silica (C) domains are respectively 10/1, 4/1 and 1/1. Follow-up samples also indicate that NURE samples with a distinctly low-silica content, which create "noise" within a domain, reflect either unusually high concentrations of mudstone grains (which range from 10 to 70% by volume) or high concentrations of heavy Fe-Ti oxides (1–5% by volume). Mud-rich samples in the NURE data set are distinguished by relatively high concentrations of alumina. Heavy mineral-rich samples typically contain distinctly high concentrations of Fe, Ti, Zr, Y, Ce, Th and/or U.

Preliminary petrographic data from 44 thin sections of San Jose sandstones show a good correlation of sandstone petrology with the high-, intermediate- and low-silica domains defined by the NURE data. These thin sections were prepared at a commercial laboratory and have been stained for potassium feldspar and plagioclase using standard techniques. Staining greatly increases the accuracy of estimated quartz/feldspar ratios.

Sandstones from the low-silica central domain are classified as granite-derived arkose containing 40 to 50% feldspar. Potassium feldspar (mostly microcline) and twinned plagioclase occur in subequal proportions. Micas and heavy minerals are relatively abundant. Sandstones from the western intermediate-silica domain are classifed as cherty (10–15%) subarkose containing 20 to 25% feldspar. Potassium feldspar (orthoclase and microcline) is subequal in volume to untwinned sericitic plagioclase plus finely twinned plagioclase (albite?). Sandstones from the high-silica southeastern domain are classified as subfeldspathic arenites containing 5–10% feldspar. Microcline is about 4 times more abundant than plagioclase. Coarser-grained sandstones from the southeastern domain contain a larger volume (20–40%) of metaquartzite lithic fragments than fine-grained sandstones from the same domain. The quartz is almost entirely monocrystalline in the fine-grained sandstones. These variations in lithic content have no chemical expression.

Standard semi-quantitative clay mineral analyses of follow-up samples at the New Mexico Bureau of Mines and Mineral Resources (J. Harris, unpubl. data) indicate that kaolin is dominant (6 to 8 parts in 10) in the mudstones of both the low-silica and intermediate-silica domains. Clays derived from the central low-silica domain contain subequal concentrations of kaolin and illite, together with a minor amount of mixed layer illite-smectite.

GEOLOGIC IMPLICATIONS

The Eocene San Jose Formation is generally described as consisting of intertonguing arkosic sandstones and varicolored mudstones of fluvial origin (e.g., Smith and Lucas, 1991). The formation has been subdivided into a basal sandstone (Cuba Mesa Member), a medial mudstone-dominated Regina Member, a medial to upper sandstone-dominated Llaves Member, and an uppermost red mudstone-dominated Tapicitos Member (e.g., Manley et al., 1987). Mapping of sandstone members has been based on apparent continuity in outcrop, and the subsurface projection of outcrops using closely spaced well-log data (Smith and Lucas, 1991). Bulk sandstone composition has not been used as a mapping criteria.

With all this in mind, the silica distribution map (Fig. 1) can now be viewed as a crude geologic map showing the distribution of low-silica arkosic strata (C), intermediate-silica subarkosic strata (W), and high-silica subfeldspathic strata (SE). Comparison with the geologic map of Manley et al. (1987) shows a good correlation of the intermediate-silica subarkosic strata with the Cuba Mesa and Regina Members of the San Jose along the west flank of the basin. However, the combined Llaves-Tapicitos Members, as mapped by Manley et al. (1987) clearly includes *both* high-silica subfeldspathic strata near Llaves and low-silica arkosic strata about 40 km west of Llaves. Our experience shows that hand specimens of arkose, subarkose and subfeldspathic sandstones (identified in thin section) are indistinct to the naked eye, even when one is informed of the differences. Additional criteria (possibly the color of associated mudstones) must be established if these geochemically mappable units are to be accurately mapped in the field.

In conjunction with the paleocurrent, sandstone continuity and paleontological data presented by Smith and Lucas (1991), it now seems almost certain that the intermediate-silica subarkosic strata and the high-silica subfeldspathic strata represent early Eocene river systems that entered the basin near Aztec and Llaves, respectively. The early Eocene rivers apparently flowed southward and joined near Cuba.

The San Jose Formation fills a north-south-trending synclinal basin of Laramide ancestry. San Jose strata on the east and west flanks of the basin dip gently toward the axis of the basin. Thus, it appears that the high-silica southeastern domain and the intermediate-silica western domain represent a significant volume of the formation, from its base to near its eroded top.

Second-order geochemical patterns of titanium, magnesium and potassium distribution within the central low-silica arkosic domain indicate that these arkosic strata were also deposited by a southerly flowing river system. This interpretation is independently supported by paleocurrent data of Smith and Lucas (1991, fig. 29). If the central low-silica arkosic river system was contemporaneous with (i.e., intertongued with) the intermediate-silica subarkosic system and the high-silica subfeldspathic system, then the low-silica geochemical domain should extend down to the base of the formation in the area west of Cuba. This possibility is not supported by the silica distribution map (Fig. 1). These geochemical constraints and our preliminary field observations suggest that deposits of the central low-silica arkosic river system are relatively thin and stratigraphically overlie the main body of the San Jose Formation. Additional data are needed to accurately define the geometry of low-silica arkosic strata in the San Jose Formation.

Paleocurrent and compositional data presented by Brister (1990, p. 103) suggest that the arkosic Blanco Basin Formation (in the vicinity of the Needle Mountains, Laramide San Juan uplift) could be the proximal equivalent of the low-silica arkosic strata interpreted here as part of the upper San Jose Formation.

To our knowledge, all lower Eocene vertebrate fossils discovered in the San Jose Formation have come from intermediate-silica subarkosic strata near Gobernador (Smith and Lucas, 1991), or from high-silica, subfeldspathic strata near Regina and east of Gavilan (Lucas et al., 1981, fig. 3). The age of low-silica arkosic strata in the central part of the basin apparently may be constrained as post–early Eocene and pre–late Oligocene. Basaltic dikes southwest of Dulce, which cut the arkosic strata, have been radiometrically dated at approximately 27 Ma (Aldrich et al., 1986, stress indicator no. 307, p. 6201).

The most significant conclusions of this investigation are summarized in the abstract and will not be repeated here.

ACKNOWLEDGMENTS

The U.S. government publishes all NURE data with a comprehensive legal disclaimer which essentially says, nothing is guaranteed. Regardless of this fact, we thank all those nameless individuals who worked conscientiously within the NURE organization to provide what appears to be (at least for New Mexico) a reasonably accurate and useful database. NURE data are not a panacea and have caveats; nevertheless, it can provide valuable information, if used cautiously. A pamphlet describing NURE data pertinent to New Mexico (including 1220 geochemical maps) and its availability through the New Mexico Bureau of Mines and Mineral Resources (McLemore and Chamberlin, 1986) may be obtained at no cost from the Bureau, in Socorro (505-835-5410).

R.M.C. graciously thanks the Jicarilla Apache Tribal Council for allowing him to collect samples on their reservation. Alan Ardoin (Bureau of Indian Affairs, soil scientist) assisted in obtaining permission from the tribal council and Douglas Diekman (BIA) served as field guide within the reservation. Discussions with Larry Smith and Spencer Lucas provided important insights concerning the San Jose Formation. During an early phase of our study, Larry Smith also graciously permitted inspection of thin sections made for his dissertation research concerning the San Jose Formation.

Standard XRF analyses of follow-up sediment samples were made by Chris McKee at the NMBMMR. George Austin (NMBMMR) provided expert guidance regarding XRD analyses of clay minerals. Becky Titus skillfully redrafted our computer-made geochemical map with her computer in the Bureau drafting department. Likewise, Mickey Wooldridge redrafted our cumulative frequency diagram employing his skills on the computer. Lynne McNeil quickly and accurately typed the manuscript on her computer at the Bureau. Funding was provided by the New Mexico Bureau of Mines and Mineral Resources general operating fund. Manuscript reviews by Steve Cather, Neil Whitehead III and Virginia McLemore were quite helpful and eliminated some potential sources of misunderstanding.

REFERENCES

Aldrich, M. J. Jr., Chapin, C. E. and Laughlin, A. W., 1986, Stress history and tectonic development of the Rio Grande rift, New Mexico: Journal of Geophysical Research, v. 91, no. B6, p. 6199–6211.

Brister, B. S., 1990, Tertiary sedimentation and tectonics: San Juan sag–San Luis Basin region, Colorado and New Mexico [Ph.D. dissertation]: Socorro, New Mexico Institute of Mining and Technology, 267 p.

Chamberlin, R. M., 1987, Compositionally distinct Eocene fluvial systems in the San Juan Basin (NM-CO): a preliminary interpretation of NURE stream-sediment geochemical data: Geological Society of America, Abstracts with Programs, v. 19, p. 265.

Duval, J. S., 1988, Aerial gamma-ray contour maps of regional surface concentrations of uranium, potassium, and thorium in New Mexico: U.S. Geological Survey, Geophysical Investigations Map GP-979, scale 1:750,000, 3 maps.

Hill, T. P., Werner, M. A. and Horton, M. J., 1967, Chemical composition of sedimentary rocks in Colorado, Kansas, Montana, Nebraska, North Dakota, South Dakota and Wyoming: U.S. Geological Survey, Professional Paper 561, 248 p.

Lucas, S. G., Schoch, R. M., Manning, E. and Tsentas, C., 1981, The Eocene biostratigraphy of New Mexico: Geological Society of America Bulletin, v. 92, p. 2268–2307.

Manley, K., Scott, G. R. and Wobus, R. A., 1987, Geologic map of the Aztec 1° × 2° quadrangle, northwestern New Mexico and southern Colorado, U.S. Geological Survey, Miscellaneous Investigations Map I-1730, scale 1:250,000.

McLemore, V. T. and Chamberlin, R. M., 1986, National Uranium Resource Evaluation (NURE) data available through New Mexico Bureau of Mines and Mineral Resources: New Mexico Bureau of Mines and Mineral Resources, free pamphlet, 11 p.

Pettijohn, F. J., 1963, Chemical composition of sandstones—excluding carbonate and volcanic sands: U.S. Geological Survey, Professional Paper 440-S, 19 p.

Selner, G. I., Smith, C. L. and Taylor, R. B., 1987, GSPOST, Version 1.0: a program to plot symbols and post numerical data from ASCII tables on regional scale maps using an IBM PC (or compatible) microcomputer and plotter: U.S. Geological Survey, Open-file Report 87-87-127A, Program Disk 87-127B.

Smith, L. N. and Lucas, S. G., 1991, Stratigraphy, sedimentology, and paleontology of the lower Eocene San Jose Formation in the central portion of the San Juan Basin, northwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 126, 44 p.

U.S. Department of Energy, 1978, Uranium hydrogeochemical and stream sediment reconnaissance of the Aztec NTMS quadrangle, New Mexico: U.S. Department of Energy Open-file Report GJBX-129(78), 75 p.

U.S. Department of Energy, 1981, Hydrogeochemical and stream sediment reconnaissance, basic data for Aztec quadrangle, New Mexico: U.S. Department of Energy Open-file Report GJBX-321(81), 170 p.