Jour. Research U.S. Geol. Survey
Vol. 6, No. 2, Mar.–Apr. 1978, p. 221–229

STABLE ISOTOPE STUDIES OF BEDDED BARITE AT EAST NORTHUMBERLAND CANYON IN TOQUIMA RANGE, CENTRAL NEVADA

By R. O. RYE, D. R. SHAWE, and F. G. POOLE, Denver, Colo.

Abstract.—Several beds of barite occur in the Slaven Chert at East Northumberland Canyon in the Toquima Range of central Nevada. Most of the barite is internally laminated but shows massive weathering. However, rosette, disseminated, conglomeratic, and concretionary varieties also occur. New fossil evidence from conodonts and brachiopods indicates a Late Devonian age for the Slaven Chert at East Northumberland Canyon. Preliminary $\delta^{34}S$ values of most disseminated and massive-laminated barite within the Slaven Chert average about 25 permil; these are within the range of values that is typical of sulfate from Late Devonian seawater and are distinctly different from $\delta^{34}S$ values of most crosscutting hydrothermal barite veins in the area. Primary $\delta^{34}S$ values of the bedded barite appear to be retained during recrystallization and hydrothermal alteration, suggesting that $\delta^{34}S$ data of bedded barites could be developed into a useful stratigraphic tool. The $\delta^{34}S$ values of rosette and concrectionary barites range from 29.1 to 56.3 permil and indicate that these varieties of barite formed in restricted microenvironments where extensive bacterial reduction of seawater sulfate occurred. The $\delta^{18}O$ data on cherts associated with the barite beds and $\delta^{13}C$ and $\delta^{18}O$ data on carbonate beds within the Slaven Chert indicate that the depositional environment at times had restricted communication with normal seawater of the open ocean.

Bedded barite deposits at East Northumberland Canyon, Nye County, Nev., have produced about 500 000 tons of drilling-grade barite since their discovery by a U.S. Geological Survey field party in 1967. Preliminary geologic, geochemical, and mineralogic studies of the deposits were made by Shawe and others (1967, 1969), who concluded from field evidence that the bedded barite deposits were of syngenetic-diagenetic origin.

The purpose of this paper is to present preliminary stable isotope data and other data that pertain to the age and origin of the East Northumberland Canyon deposits. These deposits occur in a bedded barite province that forms a wide belt through central Nevada (fig. 1) and is associated with transitional and eugeosynclinal rocks of Cambrian, Ordovician, and Devonian age. This study is part of a larger project to investigate the origin of barite at East Northumberland Canyon and elsewhere in Nevada and to evaluate the resource potential of the bedded barite province.

GEOLOGIC SETTING

A geologic map of part of the Toquima Range is presented in figure 2. The bedded deposits at East Northumberland Canyon lie in the northern part of the Toquima Range and consist of a dark-gray barite

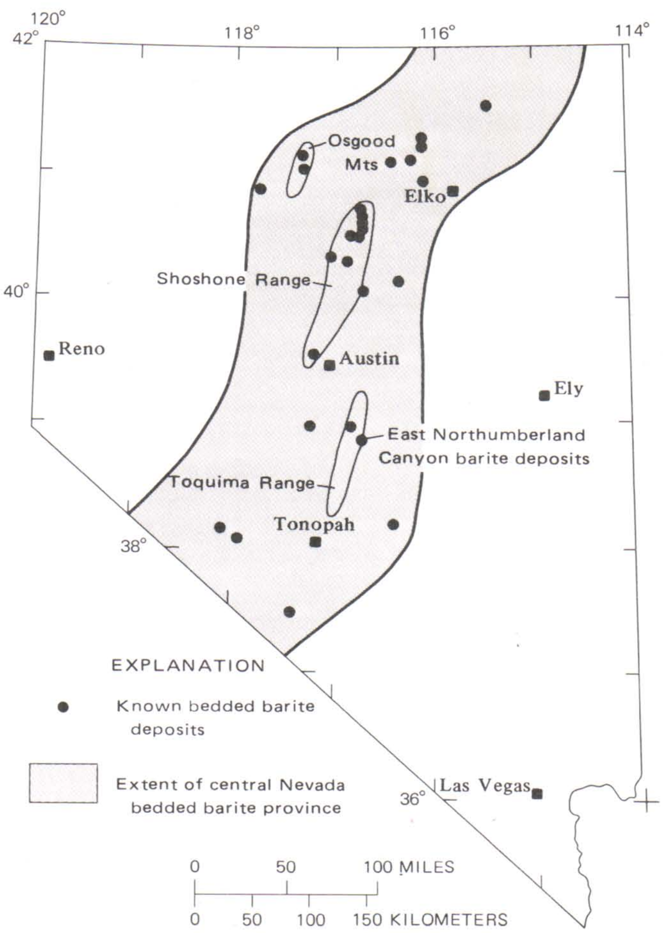

FIGURE 1.—Locality map of Nevada showing known bedded barite deposits and bedded barite province.

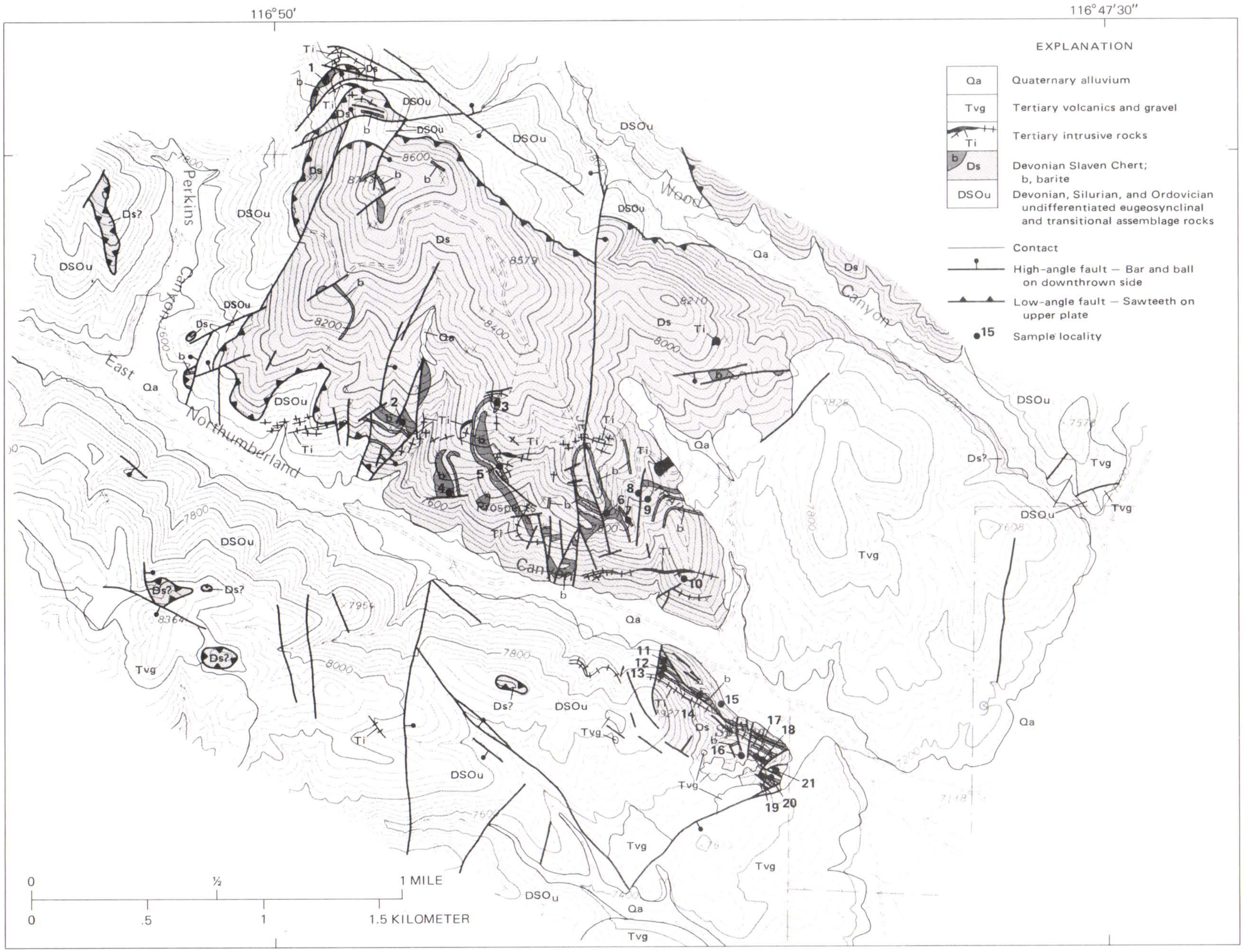

FIGURE 2.—Generalized geologic map of the East Northumberland Canyon area showing sample localities. Base from U.S. Geological Survey Northumberland Pass topographic quadrangle map, scale 1 : 24 000, 1971.

unit approximately 18 meters thick and thinner barite units, which contain some intercalated chert and shaly mudstone and which are part of an allochthonous eugeosynclinal sequence composed principally of dark-gray and black chert and siliceous mudstone of the Devonian Slaven Chert. Deposits which are believed to be equivalent occur on both the north and south sides of the canyon near its mouth. Other bedded barite deposits are found at the Lost Soldier property in the upper drainage area of West Northumberland Canyon on the west side of the Toquima Range. These deposits, which are probably equivalent to those near the mouth of East Northumberland Canyon, have been slightly recrystallized in places due to the thermal effect of a nearby Jurassic pluton. Between the East and West Northumberland bedded barite deposits, clear barite crystals occur as fracture fillings near the Northumberland gold deposit south of Northumberland Pass. All of these barite occurrences were analyzed in this study.

The marine beds that contain bedded barite in East Northumberland Canyon were assigned to Ordovician strata by Kay and Crawford (1964). Since then, these beds have been recognized as the Slaven Chert of Middle and Late(?) Devonian age. However, new fossil evidence now indicates the age of the Slaven spans much of the Devonian (J. T. Dutro, Jr., written commun., 1977). A conodont fauna of very late Devonian age has been obtained from a thin impure cherty limestone layer near the base of the allochthonous eugeosynclinal sequence in the canyon (Poole and Sandberg, 1975). In addition, a fragmentary brachiopod valve possibly belonging to the Famennian (late Late Devonian) rhychonelloid genus *Dzieduszyckia* has been found in a conglomeratic barite bed (Poole and Sandberg, 1975). Numerous attached pedicle and brachial valves of *Dzieduszyckia* were seen in a single horizon in bedded barite of the Slaven Chert in the Shoshone Range, north-central Nevada. Many of the brachiopod shells, which are well preserved and similarly oriented, appear to have been buried at or near their normal habitat. Cloud and Boucot (1971) reported *Dzieduszyckia* in the Slaven Chert at several localities in the Shoshone Range. The Slaven Chert in this area is in part a sedimentary facies and is the time equivalent of the barite-bearing section at East Northumberland Canyon.

Eugeosynclinal siliceous rocks several hundred meters thick were deposited in northern California and western Nevada during the late Devonian; then, in latest Devonian time (during the Antler orogeny), they were tectonically transported eastward into thrust contact with transitional and miogeosynclinal, dominantly carbonate rocks of comparable (locally greater) thickness (Poole and others, 1967). The Antler orogeny may have resulted from a possible increased subduction rate beneath an offshore island arc along the western margin of the eugeosynclinal basin near the end of Devonian time. If this inferred plate-tectonic model is correct, the Late Devonian eugeosyncline would have occupied a marginal ocean basin between the continental edge and the island arc (Poole, 1974). The absence of recognizable Antler orogenic sediment in the Upper Devonian eugeosynclinal deposits indicates that initial downwarping of the marginal ocean basin was mild and that only a small volume, if any, of orogenic sediments was deposited in the Slaven Chert. The Upper Devonian carbonate shelf or miogeosyncline east of the eugeosyncline was characterized by a marked north-northeast-trending belt of thick carbonate deposits (Poole and others, 1967, figs. 9, 10). The eugeosynclinal facies are being further evaluated to provide a better understanding of the depositional setting and origin of the bedded barite and chert deposits.

EVIDENCE OF A SYNGENETIC-DIAGENETIC ORIGIN

A syngenetic-diagenetic origin of the bedded barite at East Northumberland Canyon is indicated by several lines of evidence. The bedded barite, consisting of several varieties including massive-laminated,[1] disseminated, rosette, conglomeratic, and concrectionary barite, displays features of primary sedimentation and early diagenesis. The barite rosettes were formed by growth of radiating barite blades and commonly nucleated on radiolarian tests, which suggests they were formed on the sea floor or in soft pelagic sediments. Graded bedding in barite beds is evident where bedding layers of rosettes decrease in size upward and grade into fine-grained massive-laminated barite. Conglomeratic barite that contains angular and rounded clasts of broken barite rock and chert, fragmental large barite rosettes, and phosphatic nodules is intercalated with beds of massive-laminated and rosette barite; this relationship attests to erosion and resedimentation during barite deposition. Barite concretions in mudstone may have been segregated during early diagenesis from mudstone containing disseminated barium and sulfate.

A $^{87}Sr/^{86}Sr$ ratio of 0.7083 for a massive-laminated dark-gray barite sample from the south side of East Northumberland Canyon is consistent with a marine origin for the barite, although the ratio is also within the range of ratios for Cenozoic volcanic rocks in the region (C. E. Hedge, written commun., 1974).

[1] Internally laminated massive weathering.

Late Devonian conodonts recovered from the cherty limestone layer in the eugeosynclinal section at East Northumberland Canyon are dark yellowish brown in color and indicate a moderate postdepositional temperature history (Poole and Sandberg, 1975), judged from the method of Epstein, Epstein, and Harris (1975). The dark-yellowish-brown color of the conodonts indicates that they have not been subjected to prolonged temperatures above 200°C.

Madsen (1974) described "spongy-surface" chert from Devonian (reported by Madsen as Ordovician) chert layers interbedded with bedded barite rock at East Northumberland Canyon. The chert's texture was inherited from authigenic cristobalite forming bedded porcelanite. Bedded porcelanite was considered by Madsen to be of sedimentary origin. Metamorphosed chert consists of quartz that has an equigranular texture unlike that of the spongy-surface chert. Madsen pointed out that experiments by Ernst and Calvert (1969) on porcelanite from the upper Tertiary Monterey Formation of California showed that in relatively pure water the fine-grained cristobalite would recrystallize to quartz in about 180 million years at 20°C and in about 4–5 m.y. at 50°C. The occurrence of spongy-surface chert at East Northumberland Canyon, therefore, suggests that the beds have not been subjected to prolonged high temperatures since deposition, and this finding is compatible with the moderate temperature history inferred from the conodont alteration color.

STABLE ISOTOPE STUDIES

Table 1 presents $\delta^{34}S$ data on bedded and vein barites occurring in East and West Northumberland Canyons and on occurrences of barite crystals in veins near the Northumberland gold deposit. Table 2 presents $\delta^{18}O$ data on cherts and $\delta^{18}O$ and $\delta^{13}C$ data on carbonates from the Slaven Chert at East Northumberland Canyon. The locations of most of the samples are shown in figure 2. Samples DRS-28-67A, B, C, and D were collected at the Northumberland gold deposit 5.5 kilometers N. 5° W. of the junction of Perkins and East Northumberland Canyons, and samples 67FP-46 and 67FP-45 were collected 1.6 km N. 21° W. and 7.5 km N. 26° W., respectively, of the junction of Perkins and East Northumberland Canyons.

The $\delta^{34}S$ values were determined by the technique described by Thode, Monster, and Dunford (1961). This method was used because total sulfate can be extracted from the impure barites without special purification procedures. The $\delta^{18}O$ values in cherts were determined by BrF_5 extraction (Clayton and Mayeda, 1963) after boiling in aqua regia to remove organic material. Isotope data on carbonates were determined as described by McCrea (1950). All measurements were made on a modified Nuclide 6–60–RMS mass spectrometer. The isotope data are presented in the familiar δ notation relative to international standards for each isotope: the oxygen isotope data are relative to SMOW (Craig, 1961), the carbon isotope data are relative to PDB (Craig, 1957), and the sulfur isotope data are relative to Cañon Diablo troilite (Ault and Jensen, 1962). Analytical precision for all measurements was ±0.1 permil or better.

Sulfur isotope data and barite

Most of the bedded barite at East Northumberland Canyon is massive-laminated. The $\delta^{34}S$ values of 10 samples of the massive-laminated barite range from 20.9 to 28.6 permil, while 7 of the 10 samples have $\delta^{34}S$ values near 25 permil. The $\delta^{34}S$ values of oceanic sulfate have varied from about 10 to 33 permil throughout geologic time, as indicated by analyses of marine evaporites (Holser and Kaplan, 1966; Thode and Monster, 1965; Claypool and others, 1972). During the Devonian, the $\delta^{34}S$ of seawater underwent large systematic variations and was between 24 and 30 permil during the Late Devonian. Values in this range are fairly rare for the $\delta^{34}S$ of seawater sulfate throughout geologic time. Available data on recent marine barites have $\delta^{34}S$ values similar to present-day seawater sulfate (Goldberg and others, 1969). The $\delta^{34}S$ data on the massive-laminated barite at East Northumberland thus strongly suggest a Late Devonian marine origin for the sulfate in the bedded barite.

Even though most of the $\delta^{34}S$ values of the massive-laminated barites cluster near 25 permil, a considerable range of values was obtained for individual beds. This is in contrast to published data on individual evaporites, which normally show very small ranges in $\delta^{34}S$ values for an entire formation (Holser and Kaplan, 1966).

Samples from measured sections on both the north and south sides of East Northumberland Canyon were analyzed (table 1). There appear to be no general systematics to the distribution of $\delta^{34}S$ values of the massive-laminated barites, although the values decrease toward the top of the section at locality 11. There is also no apparent correlation between $\delta^{34}S$ values and the silica, carbon, iron, organic, or clay content of the barites when the data are compared with the chemical data reported by Shawe and others, (1967). Furthermore, the iron (pyrite) content of the barites is apparently very low. Barite deposition ob-

TABLE 1.—$\delta^{34}S$ *data on barites near East Northumberland Canyon, Nye County, Nev.*
[n.d.—not determined. n.a.—not applicable.]

Field sample no.	Meters above base	Locality no. (fig. 2)	Description	$\delta^{34}S$ (permil) Massive-laminated	Disseminated	Recrystallized	Rosettes	Concretion	Veins
			East Northumberland Canyon, south side						
DAB-6	2.5		Massive	24.9	-----	-----	-----	-----	-----
DRS-24-A-67	0.5	13	4-7 mm rosettes in 20 percent chert matrix.	-----	-----	-----	38.4	-----	-----
DRS-24-B-67	0.5		1-5 mm rosettes in 20 percent chert matrix.	-----	-----	-----	31.8	-----	-----
DAB-5	1	12	Massive	25.1	-----	-----	-----	-----	-----
DRS-25-67	14		<1 mm rosettes in 5-10 percent silica matrix.	-----	-----	-----	29.1	-----	-----
DAB-4	13		Sugary, massive	20.9	-----	-----	-----	-----	-----
DAB-3	7		Massive	22.6	-----	-----	-----	-----	-----
DAB-2	4	11	1-3 mm rosettes in 5 percent silica matrix.	-----	-----	-----	30.0	-----	-----
DRS-27-67	2		Massive	24.9	-----	-----	-----	-----	-----
DAB-1	1		Laminated	25.3	-----	-----	-----	-----	-----
67FP-142A	n.d.	19	Massive-laminated	23.9	-----	-----	-----	-----	-----
67FP-142B	n.d.	19	8-9 mm rosettes in barite matrix	-----	-----	-----	36.5	-----	-----
67FP-142C	n.d.	19	Concretion conglomeratic barite	-----	-----	-----	-----	33.6	-----
67FP-59	n.d.	18	do	-----	-----	-----	-----	40.2	-----
67FP-65	n.d.	22	Concretion in mudstone	-----	-----	-----	-----	56.3	-----
67FP-162A	n.d.	20	Massive-interlaminated with chert	25.5	-----	-----	-----	-----	-----
67FP-162B	n.d.	20	3-5 mm rosettes in black chert	-----	-----	-----	45.3	-----	-----
			East Northumberland Canyon, north side						
DRS-55-68	7		7-8 mm rosettes in silica matrix	-----	-----	-----	42.2	-----	-----
DRS-52-68	4		Shaley barite	-----	22.8	-----	-----	-----	-----
DRS-51-68	1.5	3	Baritic mudstone	-----	27.1	-----	-----	-----	-----
DRS-50-68	1		2-3 mm rosettes in shale	-----	-----	-----	35.6	-----	-----
DRS-49-68	0.5		Massive-laminated	22.1	-----	-----	-----	-----	-----
DRS-48-68	0		3-4 mm rosettes in siltstone	-----	-----	-----	42.1	-----	-----
DRS-10-68	n.d.	9	3-4 mm irregular rosette layer	-----	-----	-----	42.4	-----	-----
DRS-72-68	n.d.	2	Detrital massive barite	28.6	-----	-----	-----	-----	-----
67FP-188A	n.d.	11	"Bull's eye" phosphatic concretion	-----	-----	-----	-----	35.6	-----
DRS-31-68A	n.d.	6	Massive recrystallized	-----	-----	21.6	-----	-----	-----
DRS-31-68B	n.a.	6	Vein cutting recrystallized barite	-----	-----	-----	-----	-----	40.9
DRS-61-68	n.a.	4	Hydrothermally silicified vein	-----	-----	-----	-----	-----	39.0
DRS-141-67	n.a.	8	Vein in chert	-----	-----	-----	-----	-----	36.4
DRS-35-68	n.d.	5	Recrystallized white massive	-----	-----	26.4	-----	-----	-----
DRS-38-68	n.d.	7	Recrystallized light-gray massive	-----	-----	25.0	-----	-----	-----
			West Northumberland Canyon (Lost Soldier Mine)						
67FP-45	n.d.	n.a.	White recrystallized	-----	-----	21.6	-----	-----	-----
67FP-46	n.d.	n.a.	Gray recrystallized	-----	-----	24.2	-----	-----	-----
			Northumberland gold deposit						
DRS-28-67A	n.a.	n.a.	Coarse clear crystal	-----	-----	-----	-----	-----	39.3
DRS-28-67B	n.a.	n.a.	do	-----	-----	-----	-----	-----	29.8
DRS-28-67C	n.a.	n.a.	do	-----	-----	-----	-----	-----	24.5
DRS-28-67D	n.a.	n.a.	do	-----	-----	-----	-----	-----	31.7

viously involved more than just supersaturation and precipitation of barium with seawater sulfate on the ocean floor; the range of $\delta^{34}S$ values of the massive-laminated barites resulted from the mixing of sulfate from various sources and (or) bacteriogenic processes. We hope that future detailed petrologic, chemical, and isotopic studies of these barites will reveal the reason why their $\delta^{34}S$ values vary so much from the presumed constant value for seawater sulfate. Such an insight should help clarify the depositional environment of the bedded barites. Such insight is also essential to evaluate the use of $\delta^{34}S$ values as a stratigraphic tool for correlating bedded barites in Nevada.

Disseminated barite also occurs in the barite interval at East Northumberland Canyon, and all gradations between silty barite and baritic mudstones occur. Our $\delta^{34}S$ values for one sample each of silty barite and baritic mudstone are 22.8 and 27.1 permil, respectively. These values are in the range of those for massive-laminated barites and also indicate a seawater origin for the sulfate in the disseminated barite.

In West Northumberland Canyon, probable stratigraphic equivalents of the East Northumberland bedded barites have been slightly recrystallized and depleted of carbon, and the barite has been partly replaced by silica locally near a Jurassic pluton ad-

TABLE 2.—*Stable isotope data on chert and carbonates from Slaven Chert*
[Map locality numbers refer to localities shown on figure 2]

Field sample number	Map locality number	Description	$\delta^{18}O$ (permil)
		Chert	
68FP-66	21	Banded light- and dark-gray chert----	28.9
67FP-158	17	Laminated Black chert----------------	29.1
67FP-142D	19	1-cm-thick black chert in barite (see table 1).	24.8
67FP-162A	20	Interlaminated wavy barite and chert.	26.6
67FP-162A	20	"Wormy" barite in black chert--------	28.9
		Chert matrix in barite rosettes------	28.0
68FP-89A	14	Chert between major barite beds.	28.2
		Carbonate[1]	
68FP-82	15	Medium- to fine-grained impure limestone 10 cm thick within lower part of exposed chert and barite sequence underlying barite interval.	26.9
DRS-4-68	10	Gray dolomite 30 cm thick overlying barite interval.	25.7

[1]Both carbonate samples had $\delta^{13}C$ values of -7.5 permil.

jacent to the Northumberland gold deposit. Such recrystallization, bleaching, and partial replacement by silica has occurred also in bedded barites in the vicinity of Tertiary dikes and sills in East Northumberland Canyon.

The $\delta^{34}S$ values of six samples of massive-laminated barite which have undergone various degrees of recrystallization near intrusives range from 21.6 to 26.4 permil. There is no apparent correlation between $\delta^{34}S$ values and the degree of recrystallization. The $\delta^{34}S$ values are within the range of those obtained from unrecrystallized massive-laminated barite in East Northumberland Canyon. This indicates that no detectable sulfur isotope fractionation occurred during recrystallization and hydrothermal alteration of the barite near the intrusives. Consequently, in most instances it should be possible to infer the origin of bedded barite and possibly make correlations even where the barite has been intensely recrystallized.

Ten samples of rosette barite have $\delta^{34}S$ values of 29.1 to 42.4 permil. All of these values are larger than those for massive-laminated barites. The preliminary $\delta^{34}S$ values of barite rosettes do not appear to correlate with their size, location or position in section, or the nature of their matrix (mudstone, chert, or barite).

The rosettes presumably formed during a period of slow sedimentation on the sea floor or diagenetically below the sediment-water interface. The large $\delta^{34}S$ values for the rosettes are typical of values that result from partial reduction of seawater sulfate by microorganisms in a closed system (Nakai and Jensen, 1964). A critical test of whether this process occurred would be a comparison of $\delta^{34}S$ with with corresponding $\delta^{18}O$ data. Mizutani and Rafter (1969) showed experimentally that the rate of ^{18}O enrichment of SO_4 remaining in solution is about one-fourth of that of ^{34}S enrichment during bacteriogenic reduction of seawater sulfate. Sakai (1971) used this fact to conclude that bacteriogenic reduction of seawater sulfate was involved in the formation of Tertiary barite concretions obtained off the west coast of Japan.

Two samples of barite concretions in mudstone have $\delta^{34}S$ values of 35.6 and 33.6 permil, and two samples of barite matrix from conglomeratic barite which is composed of clasts of barite, chert, baritic to phosphatic nodules, and barite rosettes have $\delta^{34}S$ values of 33.6 and 40.2 permil. These values are similar to those for the rosettes and to those obtained from Tertiary barite concretions off the coasts of New Zealand (Rafter and Mizutani, 1967), California (Goldberg and others, 1969), and Japan (Sakai, 1971) and suggest that the nodules and conglomeratic matrix also formed in local closed chemical systems either on the sea floor or in the directly underlying sediments where bacterial reduction of seawater sulfate took place.

Barite occurs as crosscutting veins in two forms in the Northumberland area: as veins in chert and bedded barite and in breccia zones on both sides of East Northumberland canyon and as crystals in open fractures near the Northumberland gold deposits. The $\delta^{34}S$ values of these occurrences range from 31.2 to 40.9 permil and are distinctly larger than those observed for the massive-laminated barite. Especially interesting is sample DRS–31–68, in which the vein barite has $\delta^{34}S$ of 40.9 permil and the recrystallized host bedded barite has $\delta^{34}S$ of only 21.6 permil.

The $\delta^{34}S$ values of large clear barite crystals near the Northumberland gold mine range from 24.5 to 39.3 permil. However, the $\delta^{34}S$ values of hydrothermal sulfates must be interpreted in terms of the $\delta^{34}S$ values of the hydrothermal fluid before inferences can be made about the origin of sulfur in these sulfates (Ohmoto, 1972; Rye and Ohmoto, 1974). Such interpretation requires a knowledge of the physical-chemical environment of vein barite deposition. We have not been able to collect sulfides occurring with the vein barites nor do we have enough information on our samples to evaluate the chemical environment of vein barite deposition. Furthermore, the veins are probably low-temperature, and kinetic factors often dominate low-temperature systems when aqueous sulfate is present. However, all of the vein data could be explained if the sulfate were derived from massive bedded barite in the area having an average $\delta^{34}S$ value of 25 permil and redeposited from hydrothermal fluids at low temperatures under a range of f_{O_2} conditions. Such a variation of f_{O_2} conditions would not be unlikely in an area that has both bedded barite and organic-rich cherts and mudstones.

Carbon and oxygen isotope data on cherts and carbonates

The $\delta^{18}O$ and $\delta^{13}C$ values for various cherts and carbonates from the Devonian Slaven Chert are presented in table 2. The formation as a whole is predominantely impure chert and mudstone, whereas the barite interval is relatively free of chert but in places contains thin chert layers with chert in various proportions to barite. Carbonates are sparse in the Slaven Chert. A 10-cm-thick layer of impure limestone occurs at the base of the exposed Slaven Chert, and a 30-cm-thick layer of dolomite occurs higher in the section.

The $\delta^{18}O$ values of cherts range from 24.8 to 28.9 permil. The values for most samples are near 28 permil, which is within the lower part of the range commonly observed for "unaltered" Devonian marine cherts (Perry, 1967; Knauth and Epstein, 1976). Samples 67FP–142D and 67FP–162A and B are intimately associated with barite, and their low $\delta^{18}O$ values may reflect changes during diagenesis. The $\delta^{18}O$ values of the carbonates are also typical of unaltered Devonian marine carbonates (Keith and Weber, 1964).

However, $\delta^{13}C$ values of the carbonates (-7.5 permil) are considerably lower than those of most marine carbonates, which normally have $\delta^{13}C$ values within the range ± 4 permil as far back as 3×10^9 years (Becker and Clayton, 1972). Similar ^{13}C depletions have been observed in marine carbonates associated with Precambrian iron formations and have been interpreted to indicate that the carbonate precipitated in organic-rich environments which were not open to the larger oceanic carbon reservoir. Such an interpretation for the East Northumberland $\delta^{13}C$ data is consistent with the $\delta^{34}S$ data on the barite rosettes, which suggests that, at least locally, the environment of deposition was restricted and may have involved organic matter.

CONCLUSIONS

1. The $\delta^{34}S$ values of bedded, massive-laminated barite in the Slaven Chert from East Northumberland Canyon range from 20.9 to 28.6 permil, with most values near 25.0 permil, a value typical of Upper Devonian marine sulfate. A Late Devonian age for the Slaven Chert at East Northumberland Canyon is indicated by new fossil evidence. Although both the sulfate and barium must have come from the Devonian ocean, the ultimate source of the barium is not clear.
2. The fact that $\delta^{34}S$ value of the massive-laminated barite vary almost 8 permil, whereas these values in individual marine evaporites in other areas are nearly constant, suggests that either bacteria and (or) mixing of sulfur from two sources was locally involved in barite deposition or diagenesis.
3. The initial sedimentary $\delta^{34}S$ values of massive-laminated barite were apparently retained during recrystallization, replacement by silica, and the loss of organic carbon associated with hydrothermal alteration.
4. Once the cause of $\delta^{34}S$ variations in massive-laminated barites is determined, it may be possible to use $\delta^{34}S$ as a stratigraphic tool in dating barites in the Nevada barite province.
5. Barite rosettes and concretions have $\delta^{34}S$ values ranging from 29.1 to 56.3 permil, suggesting that they formed in a partially closed system either on the ocean floor or within the sediments, where bacterial reduction of seawater sulfate occurred.
6. The $\delta^{34}S$ values on crosscutting vein barites in the area, including those from the Northumberland gold deposit, are much larger than those for bedded barites and, considering the local isotope geochemistry, are consistent with the possibility that the sulfur in the veins was derived from bedded barites.
7. The $\delta^{18}O$ data on most cherts and carbonates in the bedded barite interval in the Slaven Chert are typical of Devonian marine cherts and carbonates, while $\delta^{13}C$ values of the carbonates suggest they were deposited in organic-rich environments that had restricted communication with the carbon reservoir of the open ocean.
8. Evidence from conodont color alteration and chert textures indicates that the barite-bearing interval at East Northumberland Canyon did not experience prolonged high temperatures or deep burial and that the eugeosynclinal allochthon emplaced during the Antler orogeny was a "thin-skinned" feature which apparently resulted from surficial thrusting during tectonic emplacement above transitional and miogeosynclinal rocks of the lower and middle Paleozoic outer continental shelf.

REFERENCES CITED

Ault, W. U., and Jensen, M. L., 1962, Summary of sulfur isotope standards, *in* Jensen, M. L., ed., Biogeochemistry of sulfur isotopes: Natl. Sci. Found., Symposium Proc., New Haven, Conn., Yale Univ., Apr. 12–14, 1962, p. 16–29 [1963].

Becker, R. H., and Clayton, R. N., 1972, Carbon isotopic evidence for the origin of a banded iron formation in Western Australia: Geochim. et Cosmochim. Acta, v. 36, no. 5, p. 577–596.

Claypool, G. E., Holser, W. T., Kaplan, I. R., Sakai, H., and Zak, I., 1972, Sulfur and oxygen geochemistry of evaporite sulfates: Geol. Soc. America Abs. with Programs, v. 4, no. 7, p. 473.

Clayton, R. N., and Mayeda, T. K., 1963, The use of bromine pentafluoride in the extraction of oxygen from oxides and silicates for isotopic analysis: Geochim. et Cosmochim. Acta, v. 27, p. 43–52.

Cloud, P. E., Jr., and Boucot, A. J., 1971, Dzieduszyckia in Nevada, *in* Dutro, J. T., Jr, ed., Paleozoic perspectives—a paleontological tribute to G. Arthur Cooper: Smithsonian Contr. Paleobiology, no. 3, p. 175–180.

Craig, Harmon, 1957, Isotopic standards for carbon and oxygen and correction factors for mass-spectrometric analysis of carbon dioxide: Geochim. et Cosmochim. Acta, v. 12, nos. 1–2, p. 133–149.

——— 1961, Standard for reporting concentrations of deuterium and oxygen-18 in natural waters: Science, v. 133, no. 3467, p. 1833–1834.

Epstein, A. G., Epstein, J. B., and Harris, L. D., 1975, Conodont color alteration—an index to organic metamorphism: U.S. Geol. Survey Open-File Report 75–379, 54 p.

Ernst, W. G., and Calvert, S. E., 1969, An experimental study of the recrystallization of porcelanite and its bearing on the origin of some bedded cherts: Am. Jour. Sci., v. 267–A (Schairer Volume), p. 114–133.

Goldberg, E. D., Somayajulu, B. L. K., Galloway, James, Kaplan, I. R., and Faure, Gunter, 1969, Differences between barites of marine continental origins: Geochim. et Cosmochim. Acta, v. 33, p. 287–289.

Holser, W. T., and Kaplan, I. R., 1966, Isotope geochemistry of sedimentary sulfates: Chem. Geology, v. 1, no. 2, p. 93–135.

Kay, Marshall, and Crawford, J. P., 1964, Paleozoic facies from the miogeosynclinal to the eugeosynclinal belt in thrust slices, central Nevada: Geol. Soc. America Bull., v. 75, no. 5, p. 426–454.

Keith, M. L., and Weber, J. N., 1964, Carbon and oxygen isotopic composition of selected limestones and fossils: Geochim. et Cosmochim. Acta, v. 28, p. 1787–1816.

Knauth, P. L., and Epstein, Samuel, 1976, Hydrogen and oxygen isotope ratios in nodular and bedded cherts: Geochim. et Cosmochim. Acta, v. 40, p. 1095–1108.

Madsen, B. M., 1974, Origin of spongy cherts: U.S. Geol. Survey Jour. Research, v. 2, no. 6, p. 685–687.

McCrea, J. M., 1950, On the isotopic chemistry of carbonates and paleotemperature scale: Jour. Chem. Physics, v. 18, p. 849–857.

Mizutani, Y., and Rafter, T. A., 1969, Oxygen isotopic composition of sulphates, pt. 4, Bacterial fractionation of oxygen isotopes in the reduction of sulphate and in the oxidation of sulphur: New Zealand Jour. Sci., v. 12, p. 60–68.

Nakai, Nobuyaki, and Jensen, M. L., 1964, The kinetic isotope effect in the bacterial reduction and oxidation of sulfur: Geochim. et Cosmochim. Acta, v. 28, p. 1893–1912.

Ohmoto, Hiroshi, 1972, Systematics of sulfur and carbon isotopes in hydrothermal ore deposits: Econ. Geol., v. 67, p. 551–578.

Perry, E. C., Jr., 1967, The oxygen isotope chemistry of ancient cherts: Earth and Planetary Sci. Letters, v. 3, p. 62–66.

Poole, F. G., 1974, Flysch deposits of the Antler foreland basin, western United States, *in* Dickinson, W. R., ed., Tectonics and sedimentation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 22, p. 58–82.

Poole, F. G., Baars, D. L., Drewes, Harald, Hayes, P. T., Ketner, K. B., McKee, E. D., Teichert, Curt, and Williams, J. S., 1967, Devonian of the southwestern United States, *in* Oswald, D. H., ed., Internat. symposium on the Devonian System, Calgary, Alberta, Canada, Sept. 1967: Alberta Soc. Petroleum Geologists, v. 1, p. 879–912.

Poole, F. G., and Sandberg, C. A., 1975, Allochthonous Devonian eugeosynclinal rocks in Toquima Range, central Nevada: Geol. Soc. America Abs. with Programs, v. 7, no. 3, p. 361.

Rafter, T. A., and Mitzutani, Y., 1967, Oxygen isotopic composition of sulphates, pt. 2, Preliminary results on oxygen isotopic variation in sulphates and the relationship to their environment and to their $\delta^{34}S$ values: New Zealand Jour. Sci., v. 10, p. 816–840.

Rye, R. O., and Ohmoto, Hiroshi, 1974, Sulfur and carbon isotopes and ore genesis—A review: Econ. Geol., v. 69, p. 826–842.

Sakai, Hitoshi, 1971, Sulfur and oxygen isotopic study of barite concretions from banks in the Japan Sea off the Northeast Honshu, Japan: Geochemical Journal, v. 5, p. 79–93.

Shawe, D. R., Poole, F. G., and Brobst, D. A., 1967, Bedded barite in East Northumberland Canyon, Nye County, Nevada: U.S. Geol. Survey Circ. 555, 8 p.

———, 1969, Newly discovered bedded barite deposits in East Northumberland Canyon, Nye County, Nevada: Econ. Geology, v. 64, no. 3, p. 245–254.

Thode, H. G., and Monster, Jan, 1965, Sulfur-isotope geochemistry of petroleum, evaporites, and ancient seas, *in* Fluids in subsurface environments: Am. Assoc. Petroleum Geologists Mem., no. 4, p. 367–377.

Thode, H. G., Monster, Jan, and Dunford, H. B., 1961, Sulphur isotope geochemistry: Geochim. et Cosmochim. Acta, v. 25, p. 159–174.