Boillot, G., Winterer, E. L., et al., 1988
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30. COMPOSITION OF LOWER CRETACEOUS SANDSTONE, GALICIA MARGIN[1]

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ABSTRACT

The composition of 31 samples of Lower Cretaceous (Valanginian to Aptian) sandstone from ODP Sites 638 through 641 was analyzed using the Gazzi-Dickinson point-counting method. The results show that the source of the Valanginian to Hauterivian sand was a continental block, dominated by granitic and/or high-grade-metamorphic rocks. Although these petrologic results do not allow discrimination between various potential continental block provinces, they suggest, in conjunction with seismic profiles and regional considerations, that the source was the Galicia margin or western Iberia. In contrast, the Barremian and Aptian sand is dominated by carbonate grains that were derived from a carbonate platform, probably on Galicia Bank.

INTRODUCTION

Ocean Drilling Program (ODP) Leg 103 documented a change from carbonate- to siliciclastic-dominated sedimentation on the outer Galicia margin. The change occurred during the Valanginian (Boillot et al., 1985; Boillot, Winterer, et al., 1987), and as sand-sized material is common throughout the Valanginian to lower Aptian section, its composition was studied in order to identify potential source areas for the clastic influx and to aid in reconstructing the tectonic history of the outer Galicia margin.

METHODS OF INVESTIGATION

Forty-four samples, each of roughly 10 cm^3 volume, were selected from the lower Aptian to Tithonian sections of Holes 638B, 638C, 639A, 639D, 640A, and 641C. The average grain size of these samples is greater than 0.0625 mm (very fine sand; Wentworth, 1922). Samples are typically moderately well sorted with subangular to angular grains that range in size from fine to very coarse. The samples were impregnated before being reduced to thin sections, which were stained for potassium feldspar and plagioclase using the method of Norman (1974).

The sections were point counted using the Gazzi-Dickinson method (Gazzi, 1966; Gazzi et al., 1973; Dickinson, 1970; Dickinson and Suczek, 1979), a method that is employed to determine source-rock lithologies. It does so by lessening the compositional effects of grain size (i.e., related to depositional environment and climate; Suttner, 1974; Suttner et al., 1981) on the point-count data. Criteria for the identification of the counted parameters in Table 1 are described in Dickinson (1970), Dickinson and Suczek (1979), Ingersoll and Suczek (1979), Ingersoll (1983), and Ingersoll et al. (1984). Operationally, only grains larger than 0.0625 mm were counted. To be counted as a lithic fragment, the cross hairs of the eyepiece had to overlie a mineral smaller than 0.0625 mm within a grain larger than 0.0625 mm. If the cross hairs fell on a mineral larger than 0.0625 mm, it was counted as that mineral rather than as a lithic fragment.

An additional and somewhat unorthodox parameter also was used, that of framework-replacement carbonate. Replacement and cementation by carbonate is pervasive in these samples, and in many cases, grains are either entirely replaced or altered beyond recognition. Where carbonate replaced a grain that was still identifiable, it was counted as the original framework grain. Where the replacement was so extensive that the original grain could not be identified, it was counted as replacement carbonate. In some cases, it was unclear whether or not the carbonate beneath the cross hairs was within the original grain boundary; judgement was used in these cases. Use of the Gazzi-Dickinson method requires strict adherence to a set of rules governing grain definition. Because of the ambiguity in defining grain boundaries where there is extensive replacement, samples with more than 10% carbonate replacement typically are not studied using this technique (R. V. Ingersoll, pers. comm., 1986). In order to study enough samples to establish trends, however, the upper limit of acceptability was extended to 23% in this study, although it is acknowledged that this reduces the accuracy of the point count. Even with this generous limit of acceptability, only 31 of the original 44 samples could be used.

DESCRIPTION OF THE SANDSTONE CONSTITUENTS

The sandstones can be divided into two groups (Tables 1 and 2): those with dominantly carbonate grains (samples from Hole 641C) and those with dominantly siliciclastic grains (samples from Holes 638B, 638C, 639D, and 640A). Detailed description of the first group is the subject of the carbonate petrology papers in this volume, and details of the second group only are presented here.

Quartz and Feldspar

Quartz is the most abundant framework constituent, averaging 52% of the total quartz, feldspar, and lithic fragments composition (Table 2). It is dominantly monocrystalline, and the few grains that are polycrystalline typically have a nontectonite fabric. Most grains have undulatory extinction, many are rutilated, and some have Boume lamellae. These features suggest that the predominant source of the quartz was a plutonic and/or high-grade-metamorphic terrane (Young, 1976). A few quartz grains are well rounded and have silica overgrowths, suggesting an additional input from a sedimentary source.

Feldspar abundance averages 36% of the total quartz, feldspar, and lithic fragments composition (Table 2), and plagioclase is less common than potassium feldspar (P/F = 0.42; Table 2). Plagioclase is typically untwinned, partially albitized, and finer grained than the potassium feldspar. Plagioclase appears to be preferentially replaced by carbonate (see section on replacement).

Lithic Fragments

The abundance of lithic fragments averages 12% of the total quartz, feldspar, and lithic fragments composition, and most are sedimentary and metasedimentary (Tables 1 and 2). Traditionally, sedimentary and metasedimentary lithic fragments have

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Table 1. Counted parameters of Leg 103 samples, normalized to 100%, excluding replacement carbonate.

		Quartz					Lithic fragments								Other				
		Polycrystalline			Feldspar		Volcanic						Sedimentary						
Age	Sample	Tectonite	Non-tectonite	Mono-crystalline	Plagioclase	Potassium feldspar	Vitric	Felsitic	Micro-litic	Lath-work	Meta-volcanic	Meta-sedimentary	Silici-clastic	Carbonate	Phyllo-silicate	Dense mineral	Shell fragment	Organic	Framework replacement carbonate
late Aptian	641C-7R-1, 140-143 cm	0.0	0.4	0.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	78.9	0.4	0.0	18.6	0.0	6.6
early Aptian	11R-3, 126-128 cm	0.0	0.0	0.4	1.6	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	87.5	0.0	0.0	9.3	0.4	17.6
	11R-3, 135-138 cm	0.0	0.4	2.7	2.7	3.0	0.0	0.0	0.0	0.0	0.0	2.7	0.4	78.7	1.9	0.7	6.8	0.0	12.3
early Aptian/ late Barremian	14R-1, 51-53 cm	0.0	0.0	2.5	2.1	2.5	0.0	0.0	0.0	0.0	0.0	0.8	0.0	72.0	0.8	0.0	19.3	0.0	20.3
	15R-2, 134-137 cm	0.0	0.0	2.5	3.2	2.1	0.0	0.0	0.0	0.0	0.0	0.4	0.0	72.5	0.0	0.0	19.3	0.0	6.6
Hauterivian	640A-7R-2, 6-8 cm	0.0	0.4	43.6	15.2	32.1	0.0	0.0	0.0	0.0	0.0	2.5	0.4	1.7	3.3	0.0	0.0	0.8	19.0
	9R-1, 13-16 cm	0.0	2.1	43.5	20.5	12.1	0.0	0.9	0.4	2.1	0.0	0.0	1.7	13.8	0.85	0.0	2.1	0.0	20.3
late Valanginian/ early Hauterivian	638B-36R-2, 149-151 cm	0.0	2.4	46.2	14.1	18.5	0.0	0.0	0.0	0.4	0.0	7.2	0.0	2.4	7.6	0.0	0.0	1.2	17.0
	36R, CC (2-4 cm)	0.0	1.2	42.0	16.4	19.2	0.0	0.0	0.0	0.0	0.4	9.5	0.0	2.8	6.9	0.0	1.2	0.4	18.3
	37R-1, 0-2 cm	0.0	1.3	41.2	17.6	21.0	0.0	0.0	0.0	0.0	0.0	8.4	0.8	3.8	5.5	0.0	0.0	0.4	20.7
	38R-1, 65-68 cm	0.0	0.8	43.5	16.9	21.1	0.0	0.0	0.0	0.0	0.0	5.5	1.3	0.9	8.0	0.4	0.8	0.8	21.0
	40R-1, 26-28 cm	0.0	2.1	45.6	15.9	18.4	0.0	0.0	0.0	0.0	0.0	6.7	1.7	0.4	8.8	0.4	0.0	0.0	20.3
	41R-1, 65-67 cm	0.0	2.5	42.3	13.0	26.4	0.0	0.0	0.0	0.0	0.0	9.6	0.0	0.0	5.0	0.4	0.0	0.8	20.3
	42R-1, 65-67 cm	0.0	0.8	49.8	14.5	18.9	0.0	0.0	0.0	0.0	0.4	8.4	0.8	0.0	6.0	0.4	0.0	0.0	17.0
	44R-1, 9-12 cm	1.1	1.1	45.7	13.2	24.3	0.0	0.0	0.0	0.0	0.0	8.2	1.1	1.1	3.2	0.0	0.7	0.4	6.6
	44R-1, 105-107 cm	0.4	2.0	52.5	12.3	17.6	0.0	0.0	0.0	0.0	0.0	10.7	0.4	0.8	3.3	0.0	0.0	0.0	18.6
	45R-3, 93-95 cm	0.0	1.9	47.5	17.6	19.5	0.0	0.0	0.0	0.0	0.0	6.4	0.7	0.0	4.9	0.0	0.4	1.1	11.0
	45R, CC (1-4 cm)	0.0	2.0	47.4	20.3	17.1	0.0	0.0	0.0	0.0	0.0	5.6	1.2	0.0	6.0	0.0	0.0	0.4	16.3
	638C-1R-1, 69-72 cm	0.0	2.0	58.7	7.9	15.1	0.0	0.0	0.0	0.0	0.0	10.3	0.8	0.8	2.8	0.0	0.0	1.6	16.0
	3R-1, 45-48 cm	0.0	1.6	45.8	14.2	22.1	0.0	0.0	0.0	0.0	0.0	9.9	1.6	1.2	3.2	0.0	0.0	0.4	15.6
Valanginian	4R-1, 140-143 cm	0.0	3.4	49.6	13.3	17.8	0.0	0.0	0.0	0.4	0.0	8.7	1.9	1.5	3.4	0.0	0.0	0.0	12.0
	5R-1, 37-40 cm	0.4	2.4	52.0	12.2	18.7	0.0	0.4	0.0	0.0	0.0	9.8	0.4	0.0	3.7	0.0	0.0	0.0	18.0
	6R-3, 1-2 cm	0.0	1.3	47.9	19.5	19.9	0.0	0.0	0.0	0.0	0.0	6.4	0.8	0.0	3.8	0.4	0.0	0.0	21.3
	7R-3, 38-40 cm	0.0	2.3	40.2	13.8	22.2	0.0	0.0	0.0	0.0	0.4	10.0	1.2	1.5	8.4	0.0	0.0	0.0	13.0
	8R-1, 131-133 cm	0.0	3.2	48.4	10.1	16.8	0.0	0.7	0.0	0.0	0.0	11.1	1.4	0.4	3.2	0.0	2.2	2.5	7.0
	8R-2, 18-20 cm	0.0	2.6	41.0	12.9	16.4	0.0	0.4	0.0	0.4	0.4	12.9	1.7	6.5	3.9	0.0	0.0	0.9	22.6
	9R-3, 13-15 cm	0.0	0.9	54.4	11.8	11.8	0.0	0.0	0.0	0.0	0.4	13.5	2.5	0.4	3.0	0.4	0.0	0.9	21.0
	10R-1, 9-12 cm	0.0	1.7	57.2	14.8	11.5	0.0	0.0	0.0	0.0	0.4	9.3	1.3	0.4	2.6	0.4	0.0	0.4	21.3
	14R-1, 147-150 cm	0.0	1.2	41.8	8.8	27.5	0.0	0.0	0.0	0.4	0.0	11.5	0.8	0.8	6.4	0.8	0.0	0.0	16.3
	14R-2, 90-92 cm	0.0	2.5	52.9	9.9	21.5	0.0	0.0	0.0	0.0	0.0	8.7	0.4	1.6	2.1	0.0	0.4	0.0	19.3
Tithonian	639D-8R-2, 23-25 cm	0.0	2.4	46.8	18.0	15.6	0.0	0.0	0.0	0.0	0.0	2.0	1.2	12.8	1.2	0.0	0.0	0.0	16.6

Table 2. Calculated parameters.

Age	Sample	Quartz	Feldspar	Lithc fragments	Volcanic lithic fragments	Microlitic volcanic lithic fragments	Sedimentary lithic fragments	Qp/Q[a]	P/F[b]	Lsc/L[c]	Lm/Lms[d]
late Aptian	641C-7R-1, 140–143 cm	1.5	9.5	98	0	1	99	—	1.00	0.99	0.004
early Aptian	11R-3, 126–128 cm	0.5	2.5	97	0	0	100	—	0.67	1.00	0.00
	11R-3, 135–138 cm	3.5	6.5	90	0	3	97	—	0.47	0.96	0.03
early Aptian/ late Barremian	14R-1, 51–53 cm	3	6	91	0	1	99	—	0.45	0.99	0.01
	15R-2, 134–137 cm	3	7	90	0	1	99	—	0.60	0.99	0.005
Hauterivian	640A-7R-2, 6–8 cm	46	49	5	0	55	45	0.009	0.32	0.36	0.55
	9R-1, 13–16 cm	47	34	19	18	0	82	0.046	0.63	0.73	0.00
late Valanginian/ early Hauterivian	638B-36R-2, 149–151 cm	53	36	11	4	72	24	0.050	0.43	0.24	0.75
	36R, CC (2–4 cm)	47	39	14	0	77	23	0.028	0.46	0.23	0.77
	37R-1, 0–2 cm	45	41	14	0	65	35	0.030	0.46	0.29	0.65
	38R-1, 65–68 cm	49	42	9	0	72	28	0.019	0.44	0.11	0.72
	40R-1, 26–28 cm	52	38	10	0	76	24	0.044	0.46	0.05	0.76
	41R-1, 65–67 cm	48	42	10	0	100	0	0.056	0.33	0.00	1.00
	42R-1, 65–67 cm	54	36	10	0	92	9	0.016	0.43	0.00	0.92
	44R-1, 9–12 cm	50	39	11	0	79	21	0.045	0.35	0.10	0.79
	44R-1, 105–107 cm	57	31	12	0	90	10	0.045	0.41	0.07	0.90
	45R-3, 93–95 cm	53	40	7	0	89	11	0.038	0.47	0.00	0.89
	45R, CC (1–4 cm)	53	40	7	0	82	18	0.040	0.54	0.00	0.82
	638C-1R-1, 69–72 cm	64	24	12	0	87	13	0.033	0.34	0.07	0.87
	3R-1, 45–48 cm	49	38	13	0	78	22	0.033	0.39	0.09	0.78
Valanginian	4R-1, 140–143 cm	55	32	13	3	70	27	0.064	0.43	0.12	0.72
	5R-1, 37–40 cm	57	32	11	4	92	4	0.052	0.39	0.00	0.96
	6R-3, 1–2 cm	51	41	8	0	88	12	0.026	0.49	0.00	0.88
	7R-3, 38–40 cm	47	39	14	0	79	21	0.054	0.38	0.12	0.79
	8R-1, 131–133 cm	56	29	15	5	82	13	0.063	0.37	0.03	0.86
	8R-2, 18–20 cm	48	29	23	4	60	36	0.054	0.44	0.29	0.62
	9R-3, 13–15 cm	58	25	17	0	83	17	0.015	0.50	0.03	0.83
	10R-1, 9–12 cm	61	27	12	0	85	15	0.029	0.56	0.04	0.85
	14R-1, 147–150 cm	46	39	15	3	85	12	0.028	0.24	0.06	0.85
	14R-2, 90–92 cm	57	32	11	0	81	19	0.045	0.32	0.15	0.81
Tithonian	639D-8R-2, 23–25 cm	50	34	16	0	13	87	0.049	0.54	0.80	0.13
	Mean	52	36	12	1	78	21	0.039	0.42	0.12	0.79
	Range	45	24	5	0	13	0	0.009	0.32	0.00	0.62
		64	49	23	5	100	87	0.064	0.56	0.29	1.00

[a] Ratio of nontectonite polycrystalline quartz to total quartz.
[b] Ratio of plagioclase to total feldspar (plagioclase and potassium feldspar).
[c] Ratio of carbonate lithic fragments to total lithic fragments (volcanic, metamorphic, and sedimentary).
[d] Ratio of total metavolcanic and metasedimentary lithic fragments to total metamorphic and sedimentary lithic fragments.

been distinguished as separate categories. However, Ingersoll et al. (1984) suggested that they be combined because their distinction is highly subjective in some cases. Both approaches have been used here. The combined category of sedimentary and metasedimentary lithic fragments averages 99% of all lithic fragments, and of these, on average, 79% are metamorphic (Table 2 and Fig. 1).

The sedimentary lithics are a mixture of siliciclastic mudstone and very fine-grained sandstone and carbonate rock fragments. A few grains of siltstone are strongly cemented with oxidized iron, suggesting a red-bed source. Most of the metasedimentary grains are greenschist facies, with chlorite as the most abundant mafic mineral. Figures 2–4 are photomicrographs showing typical sedimentary and metasedimentary lithic fragments. Figure 5 is a photomicrograph of a typical volcanic lithic fragment.

Minor Constituents

Mica is present in all samples, comprising from 0.85% to 8.8% of all framework grains (Table 1). The most common micas are chlorite and chloritized biotite; muscovite is rare. Woody fragments and plant debris (up to 2.5% of all framework grains) are common, especially in the fine-grained samples. Calcareous shell fragments are also present in some samples, as well as trace amounts of glauconite.

Carbonate Replacement

Most of the sandstone samples are strongly cemented and replaced with ferroan calcite (shipboard determination using the staining method of Dickson, 1965). Shipboard carbonate-bomb analysis shows that carbonate abundance in the sandstone samples ranges from 5% to 35% of the whole rock and averages 22.5% (Boillot, Winterer, et al., 1987). The carbonate has a sparry to microsparry texture, and locally, the spar crystals are of the same size as the framework grains and poikolitically enclose them.

The extent of carbonate replacement varies from slight to complete. In some cases, replacement has affected only the surface of the grains or individual twin lamellae (Figs. 6 and 7). In other cases, the entire grain has been replaced. The latter results in diagenetically produced voids in the grain framework (Fig. 8). It appears that plagioclase has been the most extensively replaced mineral, but quartz and potassium feldspar also have been affected. It is thus likely that the original P/F ratio was somewhat higher than the presently measured average value.

SOURCE OF VALANGINIAN AND HAUTERIVIAN SAND

The average quartz-feldspar-lithic fragments composition of the Valanginian and Hauterivian sandstone is 52%-36%-12%,

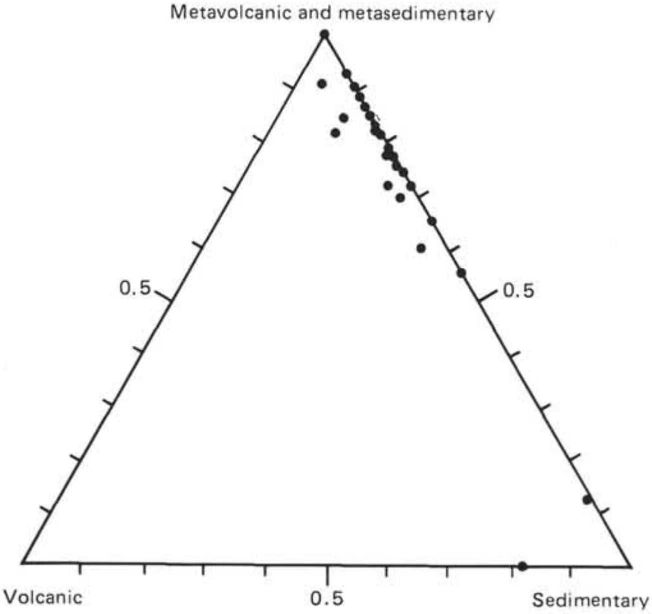

Figure 1. Ternary plot of volcanic, metamorphic, and sedimentary lithic fragments for Hauterivian and older samples. See Tables 1 and 2 for raw data.

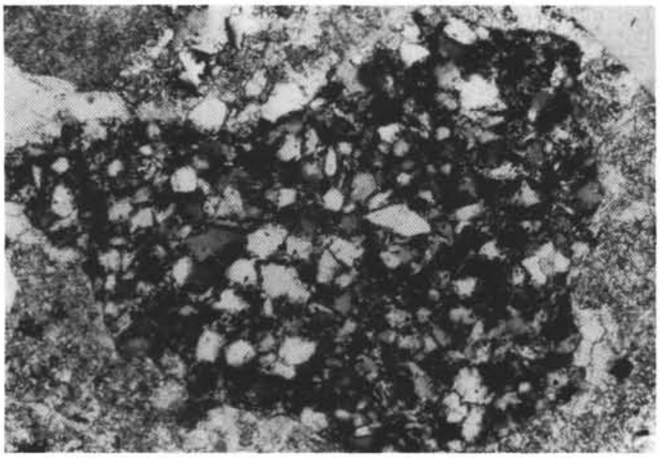

Figure 2. Photomicrograph of a lithic fragment of very fine-grained sandstone, crossed nicols. Sample 103-640A-9R-1, 13-16 cm; field of view 1.06 mm across.

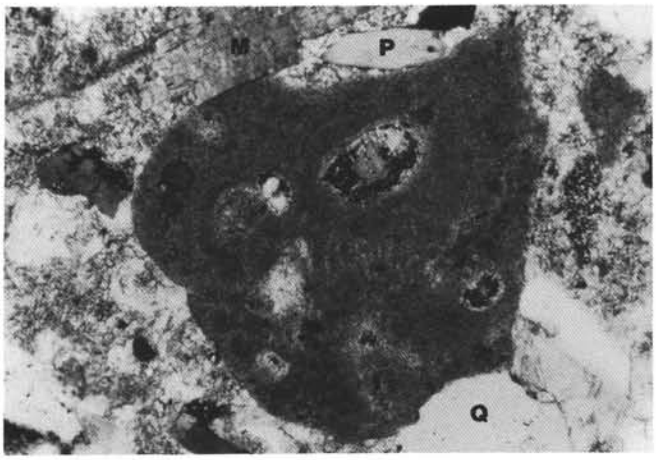

Figure 3. Photomicrograph of a carbonate lithic fragment, plane light. Sample 103-640A-9R-1, 13-16 cm; field of view 1.06 mm across. P = plagioclase; M = mica; Q = quartz.

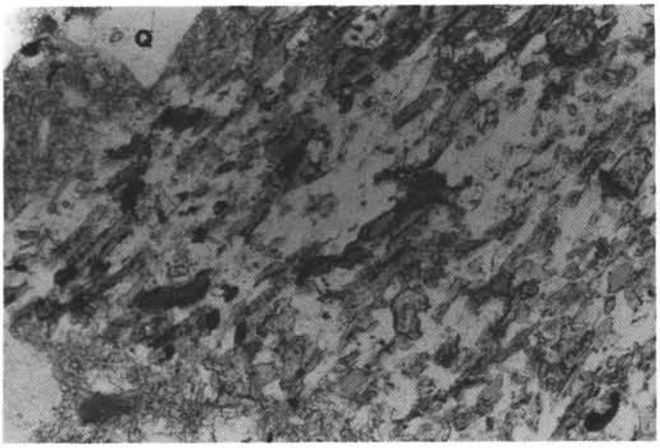

Figure 4. Photomicrograph of a greenschist-facies metasedimentary lithic fragment, plane light. Sample 103-640A-9R-1, 13-16 cm; field of view 1.06 mm across. Q = quartz.

respectively (Table 2 and Fig. 9), a composition that lies just on the edge of the compositional field that suggests a continental block source of moderate maturity and stability (Dickinson and Suczek, 1979; Dickinson and Valloni, 1980). Likewise, the abundance and variety of quartz suggests a granitic and/or high-grade-metamorphic source (Young, 1976); such a source is consistent with a continental block province. The presence of sedimentary and metasedimentary lithic fragments is not inconsistent with a continental block source terrane.

Potential continental block sources for the Valanginian and Hauterivian sand are numerous and widespread. Pre-drift reconstructions of the North Atlantic generally place Galicia Bank against the Grand Banks of Newfoundland near the Flemish Cap (Pitman and Talwani, 1972; Le Pichon et al., 1977; Kristofferson, 1978; Sibuet and Ryan, 1979; Masson and Miles, 1984; Olivet et al., 1984; Srivastava and Tapscott, in press). Results of ODP Leg 103 show that the rift stage of plate separation between Iberia and the Grand Banks began in the Valanginian (Boillot et al., 1985); the results do not preclude earlier aborted rift stages. The interpretation of magnetic anomaly patterns in the North Atlantic suggests that the drift phase of separation began somewhat later, in the late Hauterivian (Srivastava and Tapscott, in press). Thus, the oldest Valanginian sandstones sampled were deposited early in the rifting phase and may have been derived either from the east, the Galicia margin and western Iberia, or from the west, the Grand Banks (Sibuet and Ryan, 1979). The possibility of mass transport parallel to the axis of spreading enlarges the potential source area both northward and southward.

Both western Iberia and the Grand Banks are continental block provinces that may contain the required source lithologies. Dredge hauls on Galicia margin have recovered granitic rocks (biotite and biotite-hornblende tonalites, peraluminous and calcalkaline granites, and cataclastically deformed biotite-bearing granodiorites), metasedimentary rocks (greenschist and low-pressure-amphibolite facies phyllite and schist), metarhyolite, granulite, and Permo-Carboniferous sandstone (Mougenot et

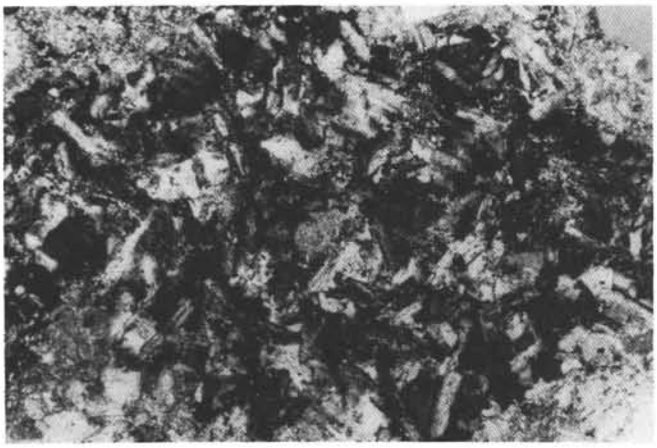

Figure 5. Photomicrograph of a volcanic lithic fragment, crossed nicols. Sample 103-640A-9R-1, 13–16 cm; field of view 1.06 mm across.

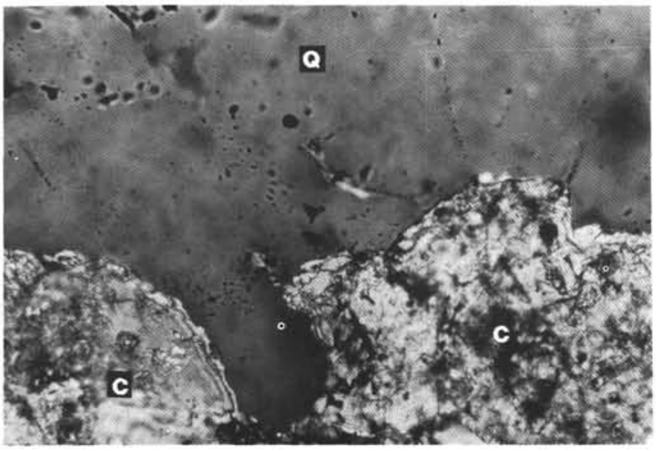

Figure 6. Photomicrograph of the etched and indented boundary of a quartz grain, crossed nicols. Sample 103-638C-8R-2, 18–20 cm; field of view 0.53 mm across. C = calcite; Q = quartz.

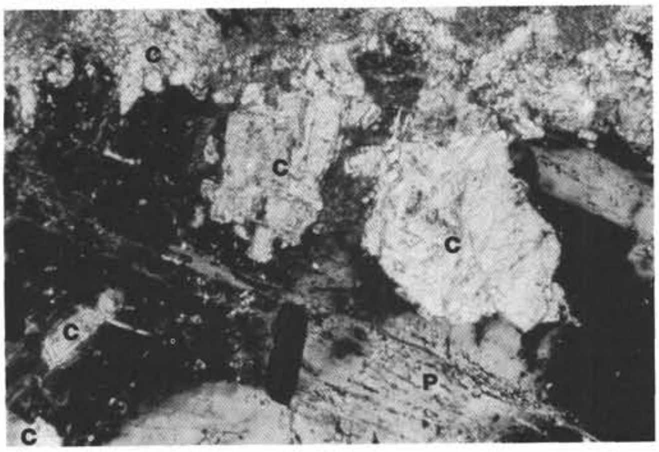

Figure 7. Photomicrograph of ferroan calcite partially replacing a feldspar grain, crossed nicols. Sample 103-640A-9R-1, 13–16 cm; field of view 0.53 mm across. P = plagioclase; C = calcite.

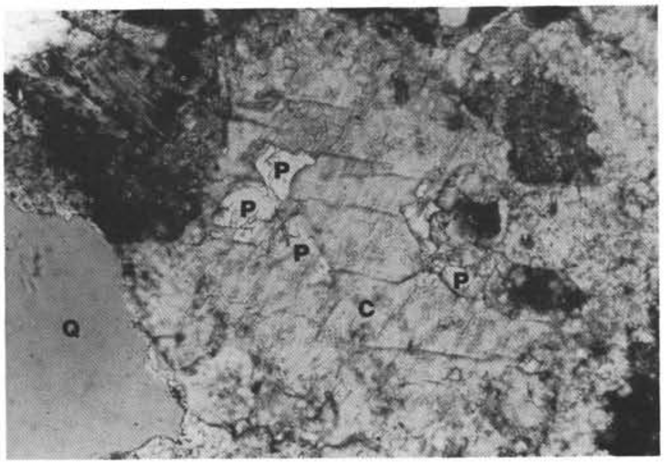

Figure 8. Photomicrograph of a feldspar grain nearly entirely replaced by ferroan calcite, leaving a void in the grain framework, crossed nicols. Sample 103-638B-37R-1, 0–2 cm; field of view 0.53 mm across. C = calcite; P = plagioclase; Q = quartz.

al., 1985; Capdevila and Mougenot, this volume). Capdevila and Mougenot (this volume) have shown that except for the granulites, which are Proterozoic, all the rock types dredged on the Galicia margin have equivalents in the Hercynian complex, which is widely exposed, along with older basement rocks, onshore in western Iberia (Servicos Geologicos de Portugal, 1952).

Drilling and dredging on the Grand Banks and Scotian Shelf also show that basement consists of Paleozoic and older granitic and metasedimentary rocks and Paleozoic sedimentary rock (Jansa and Wade, 1974; Given, 1977; King et al., 1985). Similar rocks crop out on Newfoundland and Nova Scotia (Geological Survey of Canada, 1968).

Based on the petrologic results of this study, each of these continental block provinces is a valid potential source area for the Valanginian and Hauterivian sand of the Galicia margin. More detailed chemical and petrologic work on these samples, on contemporaneous circum-North Atlantic samples, and on the potential source rocks themselves may help to limit the number of potential source areas.

Other, nonpetrologic methods help to identify the location of the source area. An east-west seismic profile suggests that the Valanginian-Hauterivian package thickens into a half-graben eastward from Site 638 (Boillot et al., 1985; Boillot, Winterer, et al., 1987). This implies that the development of the half-graben was at least partially contemporaneous with deposition of the Valanginian-Hauterivian clastic sequence and that the uplifted edge of the half-graben was a barrier to direct sediment influx from the west. A western source is not entirely excluded, however, because transport could have been through a break in or around a termination of the uplifted margin. Interpretation of a number of seismic profiles across Galicia Bank suggests that it may have been exposed during the Early Cretaceous, making it the most likely source for the sand (Boillot et al., 1979; Montadert et al., 1979; Winterer et al., 1986).

LITHOLOGIC VARIATION

The two most striking lithologic variations in the samples studied are (1) an abrupt influx of siliciclastic sand in the Valanginian and (2) an influx of carbonate sand that is first manifested in the Hauterivian (Samples 103-640A-7R-2, 6–8 cm, and

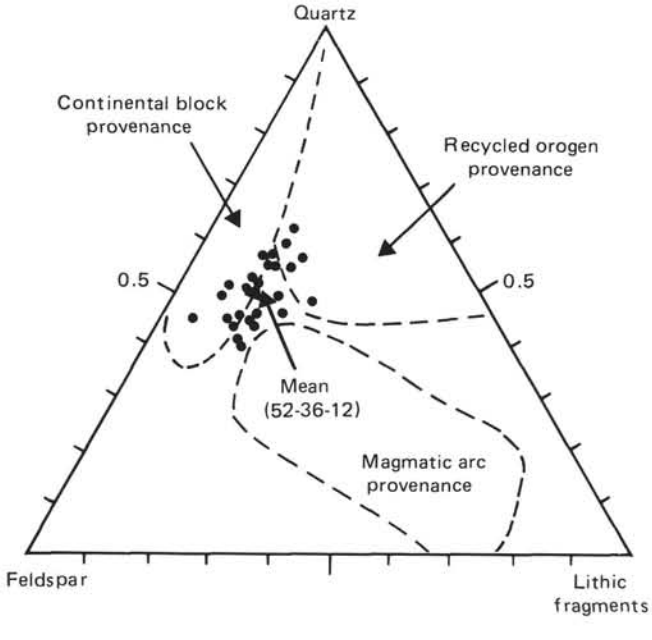

Figure 9. Ternary plot of total quartz, total feldspar, and total lithic fragments. See Tables 1 and 2 for raw data. Provenance fields from Dickinson and Suczek (1979).

103-640A-9R-1, 13-15 cm); the carbonate sand dominates the composition of the Barremian and Aptian samples (Tables 1 and 2; Boillot et al., 1985; Boillot, Winterer, et al., 1987).

Influx of Siliciclastic Sand

Results of ODP Leg 103 show that on the outer Galicia margin, an Upper Jurassic dolomite is overlain by a Valanginian calpionellid marlstone. This is in turn overlain by a Valanginian and Hauterivian siliciclastic sequence containing turbidite sandstone (Boillot, 1985; Boillot, Winterer, et al., 1987). This influx of siliciclastic detritus is part of a regional, circum-North Atlantic transition from carbonate- to siliciclastic-dominated sedimentation that occurred during the Late Jurassic and Early Cretaceous and is commonly termed Purbeckian-Wealdan (Allen, 1965; Casey, 1971). Within this broad, diachronous change in composition, the Valanginian is commonly marked by an influx of sand (Vail et al., 1977; Vail and Todd, 1981). A complete description of the regional change in composition and the influx of coarse clastics in the Valanginian is beyond the scope of this paper; however, a few examples from areas presently and palinspastically near the Galicia margin are described in the following.

In the Lusitanian Basin in western Portugal, the change from carbonate to siliciclastic sedimentation occurs in the Upper Jurassic (lower Kimmeridgian) (Rey, 1972). At Ericeira, the base of the Valanginian is an erosional unconformity where approximately 50 m of fluvial sandstone and pebbly conglomerate overlies fine-grained coastal plain deposits (Rey, 1972). In the Santander area of northern Spain, the Wealdan sequence is roughly 2000 m thick and consists of two unconformity-bounded megasequences (Pujalte, 1981). The base of the lower megasequence is a 75-m-thick conglomerate, the Saja Formation, barren of fossils but thought to be latest Jurassic (Malm) in age. It unconformably overlies Middle Jurassic (Dogger) carbonates. The lower part of the upper megasequence is Valanginian sandstone and conglomerate, the Barcena Mayor Formation (Pujalte, 1985). At Deep Sea Drilling Project (DSDP) Sites 370 and 416 in the deep Moroccan basin, the Tithonian and Berriasian section is finer grained and more calcareous than the Valanginian and Hauterivian (Lancelot et al., 1978, 1980).

On the other side of the Atlantic, on the Scotian Shelf and Grand Banks, the transition from carbonate (Scaterie Member and Whale unit of the Verrill Canyon Formation) to siliciclastic sedimentation (MicMac Formation, dominantly mudstone with only local occurrences of sandstone) occurs in the Middle Jurassic (Bathonian) (Jansa and Wade, 1974, 1975). A major influx of sand occurs at the base of the Missisauga Formation, which is Early Cretaceous (Berriasian?) in age. Farther south, on Georges Bank, in the shoreward COST well, G-1, the transition occurs in the Middle Jurassic (Bajocian). In the more basinward COST well, G-2, the transition is more gradual and occurs higher, in the Upper Jurassic (Oxfordian). In each well there is an influx of sand in the Valanginian (Poag, 1982).

These are just a few of the many examples that can be cited showing the change from carbonate- to siliciclastic-dominated sedimentation throughout the North Atlantic. In the cited examples, the change was diachronous, ranging from Middle Jurassic (Bajocian) to Early Cretaceous (Hauterivian). The overall compositional change probably was controlled by the opening of the North Atlantic and associated changes in atmospheric and oceanic circulation. Abrupt influxes of sand, such as the one in the Valanginian, commonly overlie sequence boundaries that formed during tectonically enhanced eustatic sea-level falls (Vail et al., 1977; Vail and Todd, 1981).

Influx of Carbonate Sand

The second major lithologic variation is the influx of carbonate sand that began in the Hauterivian. The abundance of lithic fragments in the total quartz-feldspar-lithic fragments composition rises from an average of 12% in the Valanginian to more than 90% in the Barremian and Aptian (Table 2). The carbonate percentage of lithic fragments increases from an average of 12% in the Valanginian to more than 96% in the Barremian and Aptian (Tables 1 and 2).

The change from siliciclastic- to carbonate-dominated shelves was widespread in the eastern North Atlantic during the late Early Cretaceous. For example, in the Santander basin of northern Spain, carbonate deposition was reestablished during the Aptian with the formation of the "Urgonian Complex" (Pujalte, 1981, 1985; Pascal, 1983). On the Goban Spur, DSDP Site 549 recovered lower Barremian to Albian calcareous siltstone and Cenomanian and younger chalk overlying lower Barremian to upper Hauterivian noncalcareous sandy mudstone (de Graciansky et al., 1985).

In sharp contrast to the eastern North Atlantic, carbonate sedimentation was not reestablished on the Grand Banks or Scotian Shelf until latest Cretaceous time (Jansa and Wade, 1974; Gradstein et al., 1975; Given, 1977). On Georges Bank and Cape Hatteras, there was no Cretaceous carbonate deposition, except for a few thin Upper Cretaceous limestones (Poag, 1982; van Hinte et al., 1985). The absence of Hauterivian to Aptian carbonate sedimentation along the western margin of the North Atlantic between Cape Hatteras and the Flemish Cap shows, not surprisingly, that these areas could not have been the source of the Hauterivian to Aptian sands recovered on ODP Leg 103.

The depositional history of the Lusitanian Basin onshore in Portugal does not match well with that interpreted from the section recovered on Leg 103, making it an unlikely source for the carbonate sand found on the outer Galicia margin. The Lusitanian Basin had widespread carbonate deposition in the Hauterivian, mixed carbonate and siliciclastic in the Barremian and dominantly nonmarine siliciclastic in the Aptian; widespread carbonate sedimentation was not reestablished until the Albian (Rey, 1972). Paleotransport directions measured in the Aptian section suggest some input from a western source (Rey, 1972), implying that Galicia Bank was high at the time. Galicia Bank could have been a carbonate platform during the Hauterivian to Aptian, shedding detritus both eastward into the Lusitanian Basin and westward into the area drilled during Leg 103.

SUMMARY

The composition of Valanginian and Hauterivian sandstone recovered on ODP Leg 103 indicates derivation from a continental block province. Indirect evidence suggests that the Galicia margin and/or western Iberia were the most likely source of the sand. The change from carbonate- to siliciclastic-dominated sedimentation in the Valanginian on the outer Galicia margin was part of a regional circum-North Atlantic transition that occurred during the Late Jurassic and Early Cretaceous.

Carbonate grains dominate the composition of the Barremian and Aptian sand. These were probably derived from a carbonate platform on Galicia Bank.

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