PROVENANCE OF TRIASSIC FELDSPATHIC SANDSTONES IN THE IBERIAN RANGE (SPAIN): SIGNIFICANCE OF QUARTZ TYPES[1]

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ABSTRACT: The base of the Triassic in the Iberian Range is represented by detrital sediments (Buntsandstein facies) deposited initially in a continental environment, finally evolving into a marine environment that is represented at the top of the sequence. The lithology of this facies is dominated by arkosic sandstones. The aim of this study is to reconstruct the nature and position of the source areas of these sandstones. Provenance research was carried out by quartz-grain typology.

Eleven stratigraphic sections were sampled. The amount of interstitital matrix has been considered in selecting samples because mechanical compaction suffered by sandstones with little matrix may give rise to a significant increase in the undulosity of monocrystalline quartz.

The Ollo de Sapo gneissic formation, located in the Hesperian Massif, has been mentioned as source rocks of feldspathic sandstones in previous works. In order to verify the provenance of feldspathic sandstones, in artificial sands derived by grinding gneisses, and sand samples collected at stream heads that drain the gneiss outcrops, we followed the methodology of Basu et al. (1975).

Analytical results indicate that two different areas within the Triassic basin were notably influenced by different source areas: a) a western zone, the nearest to the gneissic source rocks, where monocrystalline, nonundulatory quartz grains predominate ($Qm \leq 5°$); and b) an eastern zone farther from the gneissic source area, where polycrystalline quartz grains (Qp) and undulatory, monocrystalline quartz grains ($Qm > 5°$) increase. Sediment evolution during transport processes is markedly reflected by the increase in $Qm \leq 5°/(Qp + Qm > 5°)$ ratios in the westernmost zone, away from the source area. Low values in the above-mentioned ratios in the eastern zone are interpreted as results of local influence by low-ranking metamorphic source areas. Finally, this method also allows for the monitoring of the evolution of sediment maturity throughout the basin.

INTRODUCTION

The Triassic in the Iberian Range (Fig. 1A) is represented by the Germanic facies (detrital Buntsandstein, dolomitic Muschelkalk, and lutitic-evaporitic Keuper). Buntsandstein, the object of this study, is mainly composed of arkosic sandstones and forms a clastic wedge. Near the base of the Buntsandstein, the sandstones are associated with conglomerates, but upwards, they alternate with layers of siltstones. The thickness of the clastic wedge increases gradually to the southeast away from the Hesperian Massif (Fig. 1A) and reaches a maximum thickness of more than 1,000 m. Sedimentation was characterized by alluvial fans which evolved into tidal (deltaic-estuarine) environments towards the top of the section (Capote et al. 1982; Arribas 1984). Deposition took place within a graben that developed according to the aulacogen model of Alvaro et al. (1979). The orientation of the aulacogen was northwest–southeast, and the thickness of its sedimentary fill increased toward the southeast.

Petrological data concerning the Buntsandstein sandstones have been reported previously (García-Palacios et al. 1977; Marfil et al. 1977; De la Peña et al. 1983; and Arribas 1984). The principal source area was granitic-gneissic in composition and was located in the Hesperian Massif to the northwest of the basin of deposition. The gneisses of the Ollo de Sapo Formation in the massif are the most probable source rocks for the studied deposits (Fig. 1A). We have attempted to verify the source rocks by the study of heavy minerals, but have not achieved satisfactory results becuase of a) small amounts of heavy minerals in the sandstone (< 0.3%), and b) the lack of variation in heavy mineral types throughout the basin. However, we were able to achieve a better understanding of the origin and the compositional and textural evolution of the sandstones of the Buntsandstein by a study of quartz types in these sandstones. Additionally, we were also able to reconstruct the nature and location of the source area in a more precise way than has previously been accomplished. In this paper we describe the details of our study of quartz typology and our conclusions about the Buntsandstein.

METHODOLOGY

The methodology of Basu et al. (1975) for analysis of the undulosity and polycrystallinity of detrital quartz grains can provide relatively specific data about provenance. Following this methodology, we have studied samples from nine stratigraphic sections that crop out at Atienza, El Pobo de Dueñas, La Alameda, Moncayo, Aranda de Moncayo, Tierga, Tabuenca, Cálcena, and Morata de Jalón, and two other sections from cores obtained at Sigüenza and Mazarete (see Fig. 1B for location). Samples for analysis were chosen in the manner recommended by Basu et al. (1975). They recommend a grain-size range between 0.25 and 0.50 mm; samples that contain a significant amount of matrix were chosen in order to avoid postdepositional effects of compaction that may modify the original undulosity of detrital quartz grains.

In previous works on these sandstones (Marfil and Buendía 1980; Arribas 1980; Sentchordi and Marfil 1983; Arribas 1984), the relation of matrix to the amount of monocrystalline quartz grains with undulosity greater than 5° has been observed. In Figure 2, the plot of the matrix content versus the ratio of monocrystalline quartz with undulosity greater than 5° to total monocrystalline quartz is shown. Note that the content of monocrystalline quartz

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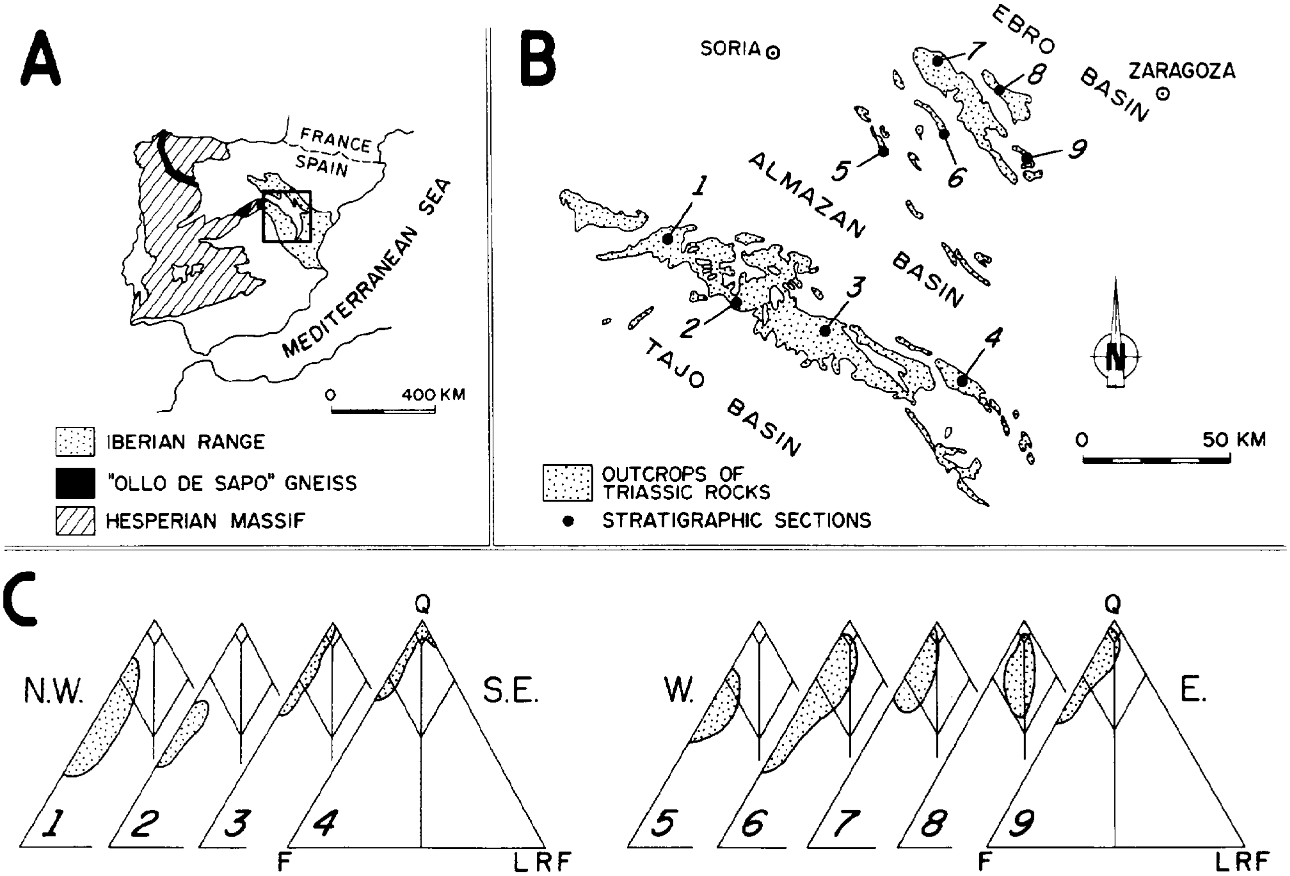

FIG. 1.—A) Map of Iberian Peninsula showing location of study area in the Iberian Range (Spain); B) location of study sections in the Iberian Range: 1-Atienza, 2-Sigüenza, 3-Mazarete, 4-El Pobo de Dueñas, 5-La Alameda, 6-Aranda del Moncayo, 7-Moncayo, 8-Tabuenca, 9-Morata de Jalón; C) triangular composition diagrams showing its variation along the basin—NW to SE in the meridional branch and W to E in the septentrional branch (see B for location of numbers).

with undulosity greater than 5° increases abruptly when the matrix contents are lower than 10–15 per cent. This shows that the original undulosity of detrital quartz grains can be diagenetically altered. For this reason, only samples with more than ten percent matrix content have been used in this study. Likewise, samples with high cement content were avoided because syntaxial quartz cement and the carbonate cement corrosion produce an important modification in the depositional textures of quartz grains.

Using these criteria, 67 samples were selected from more than 1,000 that we have examined. In each thin section, 200 to 500 quartz grains were counted, depending on the homogeneity of the samples. Statistical analysis of four types of quartz grains (monocrystalline with undulosity of less than or equal to 5° or undulosity greater than 5° and polycrystalline with 2 to 3 or more than 3 crystal units per grain) was carried out for each sample.

Since there is a possibility that the Ollo de Sapo type of gneisses of the Hesperian Massif (Fig. 1A) was the dominant source rock for the Triassic arenites, a sampling of them was also made. Fresh samples of these gneisses were ground to obtain an artificial sand. In addition, sands located at the head of the streams that drain the Ollo de Sapo type of gneisses were also sampled. In both cases, medium-grained clean sands (0.25–0.50 mm) were obtained by sieving. The quartz grains were then concentrated by heavy liquids, elutriation, and magnetic separation. Following this treatment, the quartz grains were cemented with polyester resin to make thin sections. The same methodology for the statistical analysis of types of quartz grains in the Triassic sandstones was applied to the sands derived from the gneisses, counting 500 quartz grains per sample. This procedure allowed us to evaluate the gneissic rocks as possible source materials for the sandstones under investigation.

PETROLOGY

All the Triassic sandstones are arkoses, subarkoses, or quartzarenites. An evolution of mineralogic maturity in these sandstones toward the east-southeast (distal zone) can be discerned (Fig. 1C). Unstable lithic fragments of low-rank metamorphic rocks (slate and micaceous schists)

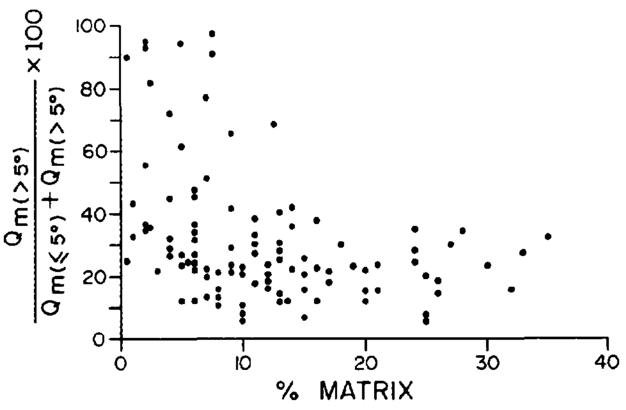

FIG. 2.—Plot of the ratio of undulose quartz grains (> 5°) to total monocrystalline quartz grains versus the matrix content in the Triassic sandstones of the Iberian Range.

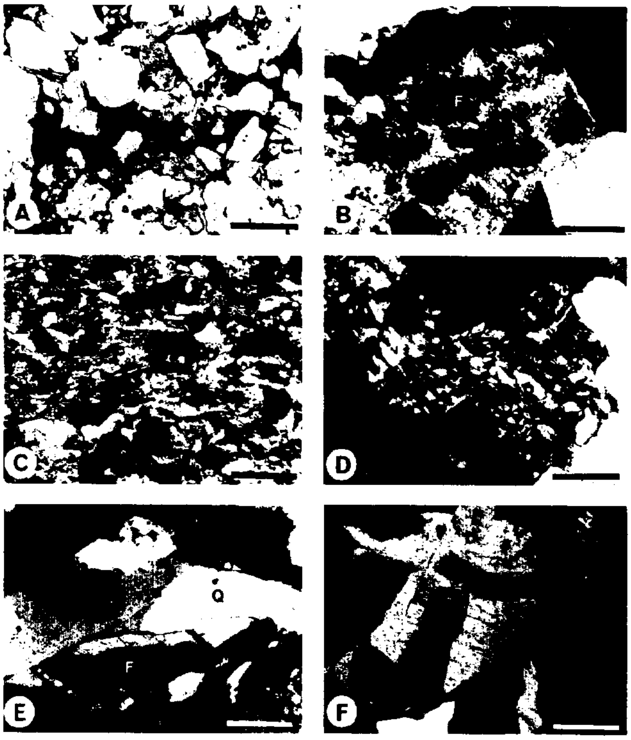

FIG. 3.—Some compositional and diagenetic aspects of Triassic sandstones: A) Pseudomatrix from a "rip-up" clast giving a local framework collapse. PN, scale bar: 0.5 mm. B) Illite epimatrix from a K-feldspar grain showing relicts of its original composition (F). CN, scale bar: 0.1 mm. C) General view of micaceous arkose with a great amount of clay matrix. CN, scale bar: 0.5 mm. D) Kaolinite pore filling showing some mechanical compaction. CN, scale bar: 0.2 mm. E) K-feldspar (F) and quartz (Q) overgrowths. The K-feldspar cement predated quartz cement. CN, scale bar: 0.1 mm. F) poikilotopic dolomite cement (D) showing corrosion on grains. CN, scale bar: 0.2 mm.

and mud-pebble ("rip-up") clasts are common and occur as subordinate detrital components (Fig. 3A). In general, there is an increase in potassium feldspar and a decrease in rock fragments towards the top of the sequence. The heavy mineral association throughout the basin remains relatively constant and is not characeristic of any specific source rock. The different species present in the whole basin are, in order of abundance: tourmaline, zircon, apatite, rutile, and garnet. Only in the western part of the basin, near inferred source areas, have we identified a heavy mineral association (sillimanite-staurolite-andalusite-garnet) of high-rank metamorphic source rocks.

The Triassic sandstones are generally moderately to well sorted. The modal size ranges from 0.125 to 0.250 mm in the northern branch of the Iberian Range and from 0.250 to 0.500 mm in the southern branch. Roundness ranges from subrounded to subangular (Powers 1953). In general, textural maturity increases from northwest to southeast within the basin.

The compositional and textural features of these sandstones have been significantly modified by diagenetic processes. Therefore, a knowledge of the diagenetic changes is needed before starting any provenance interpretation. The amount of interstitial matrix ranges from 5 percent to more than 15 percent. The presence of this matrix largely reflects diagenetic modification of detrital feldspar (illite-kaolinite epimatrix) (Fig. 3B) and deformation of unstable lithic fragments (pseudomatrix) (Fig. 3A). Note that diagenetic alteration of these framework grains leaves one with only quartz as the key mineral for provenance interpretation. Mechanical compaction is especially important in the arkoses due to the high proportion of micas (up to 17%) (Fig. 3C), and to the presence of labile rock fragments. As a result of this kind of compaction, framework constituents collapse during the earliest stages of diagenesis (Dickinson 1970; Nagtegaal 1980). As a consequence, the porosity is commonly quite low. However, we assume that most of the compactive stress has been dissipated through the clay minerals (in matrix) and the detrital quartz grains retain their original optical characteristics. Pore-filling clay cement (kaolinite-dickite) (Fig. 3D) and mixed-layer pore lining (illite-smectite) are also common. Other mineralogical types of cements and/or replacements include quartz, K-feldspar, dolomite, and subordinate Fe oxides and barite (Fig. 3E, F).

RESULTS AND DISCUSSION

Data on the four quartz types within Triassic sandstones, modern stream sands, and the artificial sands from Ollo de Sapo gneisses were plotted (Fig. 4B) in a double triangle after Basu et al. (1975). Samples corresponding to the artificial sands from the ground gneisses fall on the limit between the field of low-rank metamorphic and middle- and high-rank metamorphic rocks. However, modern sands located at the head of the streams that drain the gneissic areas are situated in a higher-rank field than the artificial sands and show a tendency toward a lower content of polycrystalline quartz, with more than 3 crystal units per grain. This fact reflects the beginning of the evolution of the types of quartz released from the gneissic source rocks under present weathering conditions (Mediterranean–continental climate).

Most of the Triassic sandstone samples reflect deri-

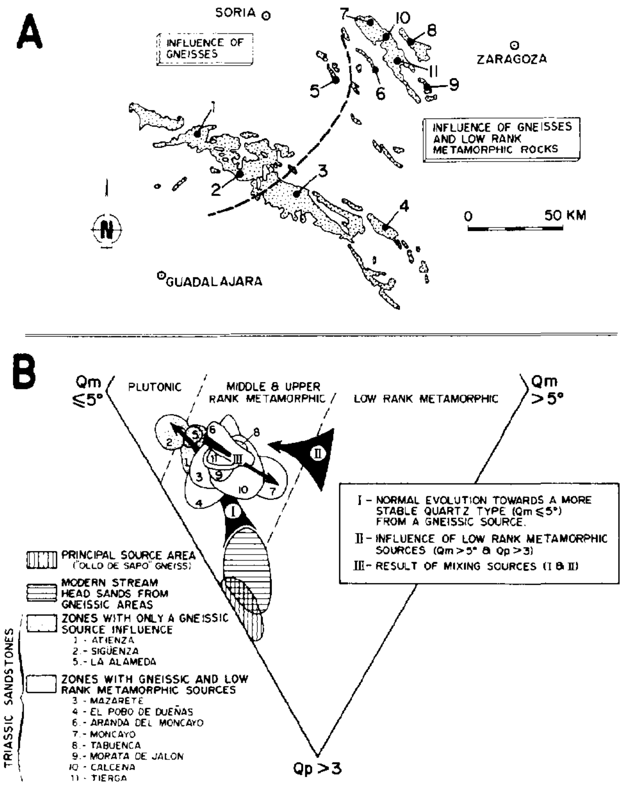

FIG. 4.—A) Boundary between sandstones with only gneissic influence and others with mixed source areas (gneissic and metamorphic) deduced from quartz typologies (see Figure 3B for location of numbers). B) Diagram of quartz types (Basu et al. 1975) of the sandstones of different sections along the Iberian Range in relation to the samples of the "Ollo de Sapo" gneisses.

vation from source areas of middle- and high-rank metamorphic rocks, near but separate from the field of plutonic source rocks. However, most samples from the column at Sigüenza plot within the field of plutonic source rocks. The predicted evolution toward enrichment in monocrystalline quartz with undulosity of less than or equal to 5° in a distal direction is maintained in the western columns (Atienza, Sigüenza, and La Alameda), which are nearest to the inferred source areas (Fig. 4A). This agrees with the conclusions of Blatt and Christie (1963) and Blatt (1967, Fig. 1) about the greater stability of monocrystalline quartz with undulosity of less than or equal to 5° as compared with polycrystalline quartz and monocrystalline quartz with undulosity greater than 5°.

However, based on the positions of the samples belonging to the most eastern columns, farthest away from the inferred source areas, a possible contradiction is observed. These columns present an increase both in monocrystalline quartz grains with undulosity greater than 5° and in polycrystalline quartz with more than 3 crystal units per grain. This observation will be discussed further below.

The different locations in the diagram for the samples corresponding to the modern stream sands derived from gneissic rocks and for the Triassic sandstones, also derived from gneissic source rocks, can be interpreted as follows. We infer that the modern sands have not been affected by any appreciable transport and thus still contain a high percentage of polycrystalline quartz grains. The location of the modern stream sands in the diagram, therefore, indicates the theoretical starting point from which the sedimentary evolution of gneissic debris begins. The predicted trend of evolution towards higher stability is represented in Figure 4B by an arrow (I) and is reflected by data for columns nearest to the source rocks, as noted above. However, there is a reversal in the predicted evolutionary trend toward the southeast, starting at Sigüenza in the southern branch of the Iberian Range and La Alameda in the northern branch (Fig. 4B, arrow III). This apparent reversal of evolution of the sandstones from El Pobo de Dueñas and Mazarete (southern branch) can be interpreted to be the result of a mixture of local contributions from low-rank metamorphic source rocks (Fig. 4B, arrow II). This view agrees with the data of García-Palacios et al. (1977). They observed in the sandstones of these areas the highest quantities of micas and elongated quartz, which they attributed to a provenance of schistose rocks. The effect of the mixture of different parent rocks also exists, and the contribution by low-rank metamorphic rocks is heightened in the northern branch of the Iberian Range, where the content of unstable quartz types (monocrystalline quartz with undulosity greater than 5° and polycrystalline quartz) is even higher, reaching a maximum in the sandstones from the Moncayo area.

The contamination of gneissic quartz types in the southeast is apparently accomplished by dilution of arkosic debris that is derived from gneissic sources, with more quartzose materials derived from lower-rank metamorphic sources (Fig. 1C, A). The reversal in the predicted trend of the evolution of quartz types is matched by the compositional trend from arkoses to quartzarenites within the basin and supports our conclusions regarding mixing.

CONCLUSIONS

1) Based on the method for study of quartz typology proposed by Basu et al. (1975), we can confirm the dominant gneissic nature of the source areas for the Triassic arkoses of the Iberian Range.

2) In the most western zones of the study area (1, 2, and 5 in Fig. 4A), the predicted evolution of sandstone composition towards higher stability from west to east is also confirmed. It is based on a general and gradual enrichment of monocrystalline quartz grains with undulosity of less than or equal to 5° in relation to the content of the quartz types from the gneissic source areas.

3) In the more eastern zones, detrital material derived from the dominant gneissic areas is contaminated by local contributions of debris from low-rank metamorphic source rocks (locations 3, 4, 6, 7, 8, 9, 10, and 11 in Fig. 4A).

4) We note in this specific case that the method for quartz typology is more useful than the study of heavy minerals because heavy minerals are present in nondi-

agnostic assemblages for a concrete source-rock identification and are also too scarce for convenient study.

5) We consider that the methodology of Basu et al. (1975) should not be applied arbitrarily to any restricted or isolated area within a basin and that the evolution of the material during transport should be taken into consideration. Likewise, Basu et al.'s (1975) recommendation on the importance of high matrix content to prevent postdepositional modifications affecting the undulosity of quartz grains has been confirmed in the sandstones studied. This is an extremely important factor to bear in mind; otherwise, wrong conclusions may be reached. In any case, this method should be tested further in other areas where independent information regarding source rocks is available.

6) The results of this paper indicate that this methodology is useful, not only to identify the nature of source rocks, but also to study the spatial evolution of sediments within a basin in relation to their maturity, as indicated by the proportions of quartz types of variable stability.

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