Diagenetic origin for quartz-pebble conglomerates

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ABSTRACT

The occurrence of quartz-pebble conglomerates (QPC) in the rock record increases backward through time from the Tertiary through the Precambrian. The positive correlation between QPC abundance and age is valid both for numbers of reported QPC and for QPC as a percentage of all conglomerate, and at both the era and the period level. QPC are usually interpreted as being due to intense chemical weathering, protracted transport, or sediment recycling, but none of these can account for the age distribution of QPC, which is the opposite of the global mass-age distribution for sedimentary rocks. Precambrian and Tertiary conglomerates with similar sources and sedimentology have vastly different clast populations, nonquartzose clasts being much more abundant in the younger rocks. Comparison of the petrology of QPC and polymict conglomerates shows that QPC have consistently higher proportions of diagenetic secondary matrix and pressure-solved grain contacts. We conclude that diagenetic factors play an important role in QPC formation by preferentially destroying less durable clasts.

Keywords: clasts, diagenesis, pressure solution, quartz-pebble conglomerates.

INTRODUCTION

In quartz-pebble conglomerates (QPC), more than 90% of the clasts consist of vein quartz, chert, or quartzite (Boggs, 1992). Some ancient QPC are >100 m thick and cover areas ~25 km^2 (Trevena, 1979; Ethridge et al., 1984; Mosher et al., 1993; Cherichetti et al., 1998), and interbedded sandstone-QPC sequences can be >1000 m thick and cover hundreds of square kilometers (Kingsley, 1984), but no volumetrically significant deposits of this type are forming at present. Small quartz-pebble accumulations may occur locally in drainages directly overlying quartzite bedrock, but thick or laterally extensive modern units are not known. In the geologic record, however, substantial QPC accumulations are found in sequences derived from lithologically diverse source rocks. In addition, QPC become more common further back in the geologic record.

QPC are generally considered to have specific paleoclimatic or paleogeographic implications. Current sedimentology textbooks state that they represent tectonically quiescent conditions under which chemical and mechanical weathering were very efficient (e.g., Prothero and Schwab, 1996, p. 76; Selley, 2000, p. 383; Boggs, 2001, p. 151). Processes invoked to explain QPC include prolonged mechanical abrasion (Abbott and Peterson, 1978; Kingsley, 1984), intense chemical weathering (Dal Cin, 1968; Reimer and Mossman, 1990), or recycling of older conglomerate (Youngson and Craw, 1996). Many QPC, however, were deposited on alluvial fans, implying a short interval between erosion and deposition and thus little time for breakdown of labile clasts. In addition, independent evidence for intense weathering conditions at source or in the depositional basin is generally lacking. There are abundant examples of such problematic deposits (e.g., Smith, 1967; Ethridge et al., 1984; Kingsley, 1984; Kraus, 1984; Bayne, 1987; Mosher et al., 1993).

QPC host many gold and uranium orebodies, and there is active debate about connections between the mineralization and diagenesis (e.g., Robinson and Spooner, 1984; Reimer and Mossman, 1990). Conglomerates also form petroleum reservoirs (e.g., Glover, 1982; Cronin and Kidd, 1998), and prediction of porosity, permeability, and reservoir quality depend on understanding their diagenetic histories. More generally, understanding QPC genesis bears on interpretations of paleogeography, paleoclimate, and depositional environments. We present evidence that QPC may form during diagenesis by alteration of polymict conglomerate precursors.

AGE DISTRIBUTION OF QUARTZ-PEBBLE CONGLOMERATES

Sedimentary rocks show a well-documented inverse relationship between preserved volume and age (Gilluly, 1969; Garrels et al., 1972; Ronov et al., 1980; Ronov, 1983). QPC, in contrast, tend to be more common in older sequences. It is not possible to measure the global mass-age distribution of conglomerates directly, because the units are generally below the scale of regional geologic maps. We have therefore used the American Geological Institute GeoRef database as a proxy (Appendix[1]) and have tallied references to conglomerates and QPC of different ages (Table 1; see footnote 1).

Conglomerate records (QPC plus non-QPC) constitute 2%–3% of the GeoRef records for each time interval from Tertiary to Archean, reflecting the fact that conglomerates form a minor but consistent proportion of sedimentary rocks (Table 1, column B; see footnote 1). In addition, the records for conglomerates (QPC plus non-QPC) show a marked decrease with increasing age, which closely matches the global mass-age distribution of sedimentary rocks (Fig. 1). QPC data, however, have a very different age distribution. The number of records for Paleozoic QPC is double that for the Cenozoic and Mesozoic, and for the Precambrian it increases further, by a factor of three (Fig. 2). The trend does not reflect variation in conglomerate volume through time, because the QPC numbers change as a proportion of total conglomerate records (Table 1, column C; see footnote 1). Likewise, the consistency of the proportion of conglomerate records for each time interval, including the Proterozoic and Archean (Table 1, column B; see footnote 1), demonstrates that the pattern is not an artifact of era or period length.

QPC are most prominent in the Precambrian. Whereas average Phanerozoic values are <1%, QPC account for 6.4% of Proterozoic and 6% of Archean conglomerate records. The database for Precambrian QPC of known age is small and the time intervals are large in comparison with the Phanerozoic (Table 1, column D; see footnote 1), but the pattern is the same: the number and proportion of QPC increase strongly with increasing age. This consistent trend toward increasing abundance of QPC in older rocks is in direct contrast to the age distribution of preserved sedimentary rock, and requires explanation.

DIAGENETIC EFFECTS ON THE COMPOSITION OF CLASTIC ROCKS

Diagenesis plays a major role in the compositional evolution of clastic rocks. Chemical alteration coupled with mass transfer of ma-

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[1]Data Repository item 2002031, Appendix, Description of the search terms used and the rationale, Table 1, GeoRef data for conglomerates and QPC, and Table 2, Point-count data for thin sections of conglomerate interclast material, is available from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, editing@geosociety.org, or at www.geosociety.org/pubs/ft2002.htm.

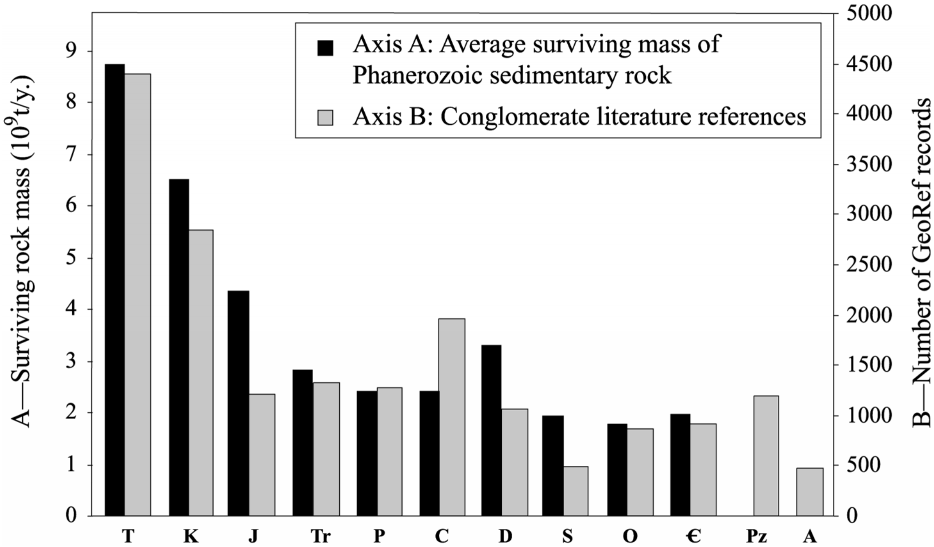


Figure 1. Comparison between numbers of GeoRef records for conglomerates (both quartz-pebble conglomerates [QPC] and non-QPC) and mass-age distribution of sedimentary rocks. Survival rate for each time interval (axis A) is given in metric tons per year (graph shows data from Gregor, 1985; other models are very similar).

terial can produce extensive secondary porosity (Siebert et al., 1984; Surdam et al., 1984) and ultimately diagenetic quartz arenites (e.g., Milliken, 1988; Abdel Wahab, 1998). Most studies have focused on sandstones, but the principles should be equally applicable to conglomerates.

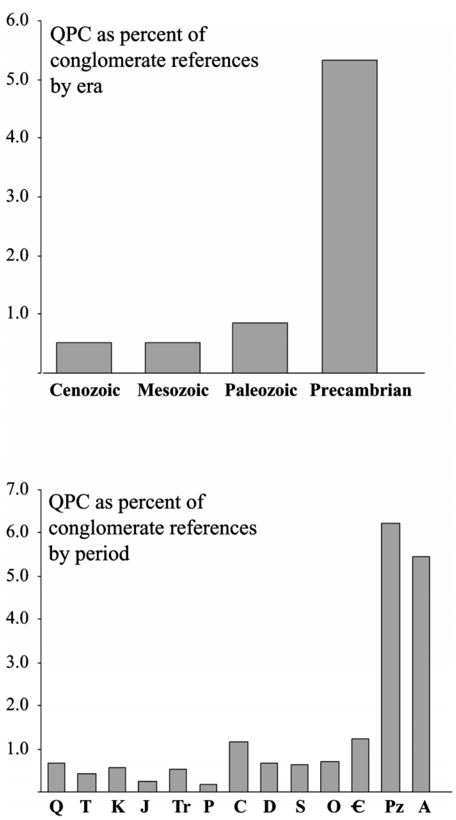


Figure 2. Quartz-pebble conglomerate (QPC) records for each time interval as percentage of all conglomerate (QPC plus non-QPC) records (see also Table 1 [text footnote 1]).

Volume loss, mostly through dissolution of feldspar and rock fragments, is commonly 20%–30% (Wilkinson et al., 1997; Abdel Wahab, 1998). Intergranular volumes <30% are commonly seen in well-sorted sandstones, indicating dissolution and loss of grain mass (Houseknecht, 1987, 1989). There are marked compositional gradients with depth due to intrastratal dissolution (Cavazza and Gandolfi, 1992), and volume loss of almost 40% is known in deeply buried sandstone (Milliken et al., 1994). In the absence of overpressuring, secondary porosity can be eliminated by compaction (Harris, 1989), in which case there may be no record whatsoever of the former presence of a labile grain population.

To our knowledge, there are no studies of porosity loss, diagenetic mass transfer, or intrastratal solution in conglomerates. Pressure solution in QPC is very common, however, at both the macroscopic and microscopic levels (Mosher, 1976, 1981). Diagenetic quartz arenites have also been shown to display an anomalously high proportion of strongly welded and pressure-solved grain contacts (Harris, 1989).

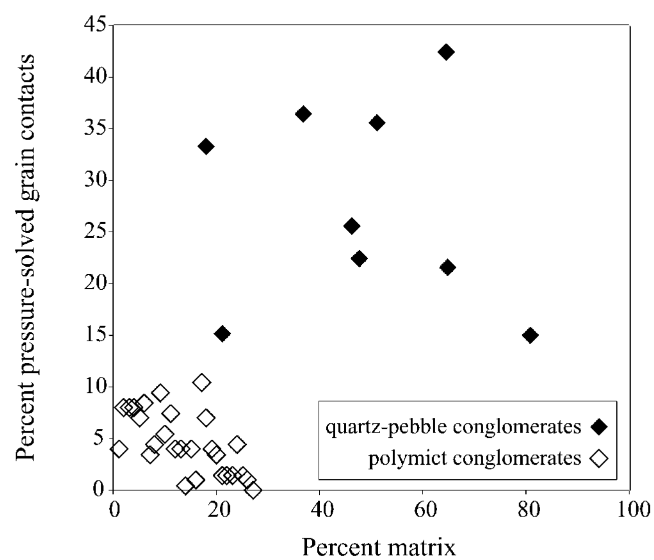
DIAGENESIS IN POLYMICT AND QUARTZ-PEBBLE CONGLOMERATES

To test whether there are systematic diagenetic differences between QPC and polymict conglomerates, we examined conglomerates that had been subject to diagenetic processes for several hundred million years (Table 2; see footnote 1). Data were collected from interclast material because (1) diagenetic processes operate throughout the rock and so can be examined either at the clast or interclast level; (2) diagenetic products are concentrated in the interclast spaces; and (3) the mineralogic products of diagenesis are fine grained and therefore best examined microscopically.

All samples were unidirectional-flow deposits, clast supported, and well sorted. Sampled intervals contained traction structures such as parallel stratification, crude cross-stratification, imbrication, or intercalated flat-laminated sand lenses, indicating vigorous current activity. Such deposits contain very small amounts of primary matrix (Visher, 1969). Samples were not taken from diamictites, Bouma sequences, or other sediment gravity-flow deposits.

The interclast material in polymict conglomerates is dominated by sand-sized grains, with low proportions of matrix (Table 2 [see footnote 1]; Fig. 3). Water-laid QPC, however, consistently have large proportions of fine matrix. We interpret matrix volumes >10% (a conservative figure; see Visher, 1969) as secondary because they are inconsistent with the sample sedimentology. In addition, petrologic

Figure 3. Point-count data for interclast material in conglomerates. Value for pressure-solved grain contacts is sum of nested + interpenetrating contacts. Complete data are given in Table 2 (see text footnote 1).



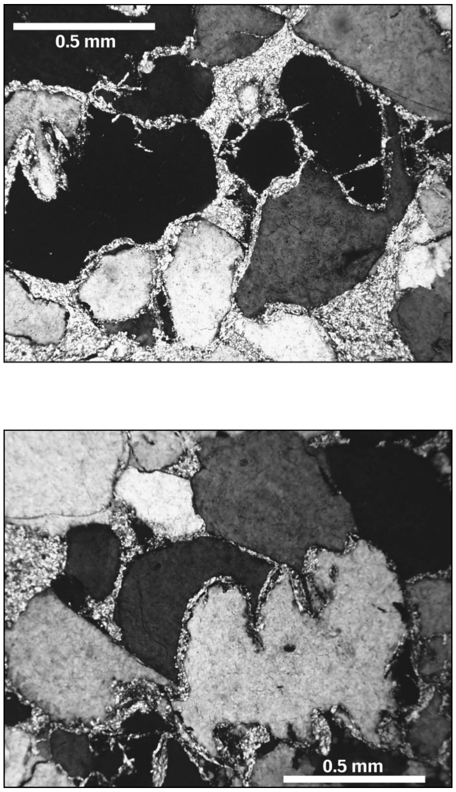


Figure 4. Pressure-solved grain contacts in quartz-pebble conglomerates from Mazatzal Group. Framework grains are quartz. Interstitial material is sericitic matrix.

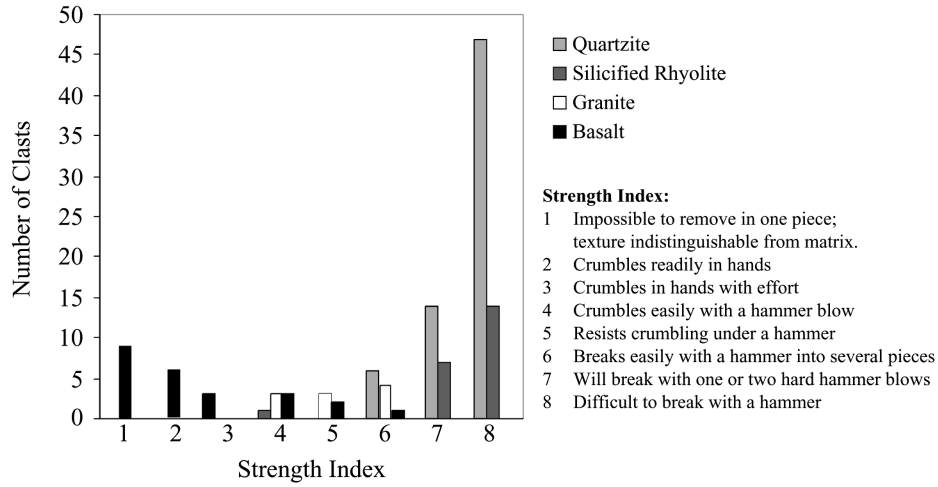


Figure 5. Strength data for clasts from Tertiary Gila assemblage conglomerates of Tonto Basin.

indicators, such as matrix-filled pore spaces and floating sand-sized grains (Dickinson, 1970), are commonly seen in the high-matrix rocks.

The most likely source of the matrix is the breakdown of labile detrital components (Dickinson, 1970). Postdepositional addition is unlikely because the observed volumes often greatly exceed the 3%–9% maximum volume reported for infiltrated material (Moraes and De Ros, 1992). In addition, infiltrated clays, which are deposited from through-flowing muddy water, generally form grain coatings (Matlack et al., 1989), whereas the matrix in the QPC completely occludes pore space.

QPC exhibit substantially more pressure solution than do polymict conglomerates. Grains in polymict conglomerates generally have convex to straight grain edges, with tangential or linear contacts (Table 2 [see footnote 1]; Fig. 3). Grain contacts in QPC, in contrast, may be strongly modified (Fig. 4), with high proportions (15%–45%) of nested and interpenetrating contacts (definitions follow Taylor, 1950). The strong petrographic distinctions between QPC and polymict conglomerates are summarized in Figure 3. Polymict samples cluster at the low-matrix, low-pressure-solution corner of the diagram, whereas the QPC data spread out to much higher values of one or both parameters.

CONGLOMERATE COMPOSITIONS: SAME SOURCE AREA, DIFFERENT AGES

Conglomerates with very similar source rocks and depositional settings but very different ages (Proterozoic and Tertiary) are found in central Arizona. The Proterozoic Mazatzal Group is in depositional contact with a varied provenance, including silicified rhyolite (now chert), mafic igneous rocks, granitic plutons, schist, and quartzite (Wrucke and Conway, 1987), and the basal conglomerate was deposited in a proximal alluvial fan system (Trevena, 1979). The Miocene-Pliocene Gila Conglomerate was also deposited on an alluvial fan complex (Scarborough, 1989; Nations, 1990). Its source area includes the same rocks that contributed to the Mazatzal Group, in addition to Tertiary basalt and the Mazatzal Group. The clast compositions of the two units are, however, profoundly different. The Tertiary Gila Conglomerate contains quartzite, rhyolitic chert, schist, granite, and basalt; nonquartz clasts range from 22% to 55% by volume (Lang, 1999). Clasts in the Proterozoic Mazatzal Group conglomerate, in contrast, are 100% quartzose, consisting of rhyolitic chert, quartzite, and vein quartz (Trevena, 1979; Bayne, 1987; Cox and Lowe, 1995).

The Mazatzal Group has undergone extensive diagenetic alteration. Almost all interstitial material in the Mazatzal Group conglomerate has been converted to phyllosilicate secondary matrix, and the associated quartzites are diagenetic quartz arenites (Cox and Lowe, 1996). In addition, interstitial grain contacts in the conglomerates are strongly pressure solved (Fig. 4). We infer that the Mazatzal Group conglomerate originated as a polymict deposit similar to the Gila Conglomerate. The secondary matrix represents the diagenetic breakdown of labile clasts, and the pressure solution records dissolution, mass transfer of soluble material, and consequent volume loss.

Processes operating currently provide a snapshot of the early stages of this transformation and suggest preadaptation to diagenetic QPC formation. The Tertiary Gila Conglomerate has never been buried. It is uncompacted and unlithified, but there has been substantial postdepositional compositional modification. Basalt, granite, and schist cobbles retain their shapes and textural characteristics and are therefore identifiable; but they have been altered to clays in situ and have little or no internal strength (Fig. 5). Clasts with a low strength index will not survive as recognizable lithologies during compaction and diagenesis, but will be crushed and redistributed as phyllosilicate-rich interstitial material. The high surface area of the fine-grained alteration products also makes them more susceptible to dissolution and mass transfer. We infer that much compositional modification leading to the development of diagenetic QPC may take place before deep burial.

CONCLUSIONS

This study indicates that, in many cases, QPC owe their composition to diagenetic processes. It is probable that clast disintegration and dissolution, followed by porosity collapse and pressure solution along grain boundaries, is responsible for the composition and texture of QPC. The volume of phyllosilicate-rich secondary material remaining in QPC is a minimum estimate of the volume of labile clasts lost during diagenesis, because a substantial proportion of the original clast material has probably been removed in solution. The extent of mass transfer is impossible to quantify, but the proportion of pressure-solution volume loss may provide a reasonable estimate of the relative magnitude of the effect.

We do not suggest that all QPC formed diagenetically. Intense weathering and protracted transport can certainly produce such deposits. However, the prevalence of QPC in settings where conditions are not optimal for their formation as primary deposits strongly suggests that postdepositional modification often plays a major role. The possibility that diagenesis may substantially alter conglomerate compositions means that careful examination of rock texture and interclast composition is required before paleoenvironmental conclusions can be drawn.

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