Petrology of Rapti River sand, Hetauda-Chitwan Dun Basin, Central Nepal; an example of recycled provenance

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ABSTRACT

The Rapti River in the Central Nepal drains fold-thrust belts of the Lesser and the Sub-Himalayas as demarcated by four major thrusts, and is located in a humid sub-tropical climatic zone. Within the Sub-Himalaya (Siwalik Group), a wide Dun Valley gives way to the long low-gradient Rapti River in the northeast region, therefore, forming a characteristic piggy-back basin within the fold-thrust belts. Sands from the Rapti River were obtained and analysed to characterise composition and texture, to verify its provenance, and to compare with modern and ancient sands/sandstones from different basins having similar tectonic setting. The Rapti River sand is quartzo-lithic in composition. It plots on recycled orogeny provenance field in the QFL and QmFLt triangle diagrams showing no major difference in provenance with other sands/sandstones from different climates. However, the Rapti River sand is remarkably poorer in feldspar but richer in lithic fragments and quartz compared to the other sands/sandstones.

INTRODUCTION

The provenance of sediments includes all aspects of source area including source rocks, climate, relief and hydrodynamics of environment (Pettijohn 1984; Johnsson 1993). Some workers believe in tectonic setting as a major controlling factor (Ingersoll and Suczek 1979; Dickinson et al. 1986; Johnsson 1990), while others in relief (Hayes 1962; Mann and Cavoloc 1973), climate (Breyer and Bart 1978) mixing (Cavazza et al. 1993) and reworking (Cox and Lowe 1995). Johnsson (1990) concluded that basic differences in tectonic setting are not erased even by intense tropical weathering operating for long time. Arribas et al. (2000) concluded that mixing is more important than abrasion in changing sand composition during transport. Cox and Lowe (1995) suggested recycling to be an important process in affecting sand composition. Although several variables tend to affect composition of sand and sandstone, these variables are in fact largely influenced by tectonic settings of sedimentary environments (Johnsson 1990). This paper therefore characterises composition and texture of modern sand as one of the examples from environment of known climate, relief, source rock and tectonic setting.

HETAUDA-CHITWAN DUN BASIN

Topography, drainage and climate

The Hetauda-Chitwan Dun Basin (HCDB) covers 3374 sq. km, and comprises the Lesser Himalaya (elevation 2347 m a.m.s.l.) in the north, and the Sub-Himalaya both in the north (1000 m a.m.s.l.) and the south (800 m a.m.s.l.) of the basin (Fig. 1). The Dun valley is oriented E–W, with a very gentle regional westward slope.

The Rapti River stretches for 118 km from
headwaters to the outlet at an average slope of 0.036 m/m in headwaters in the north and 0.0002 m/m between the emergence in the Sub-Himalaya and the outlet point in the west (Fig. 2). The Rapti River and some major tributaries incise the Mahabharat and the Sub-Himalayas. After emerging into the Dun Valley, the Rapti River meanders with frequent braiding in the middle stretch. The river largely carries gravel and sand.

The HCDB has a humid subtropical climate, with a wet period between June and September and a dry period between November and April. Annual rainfall in headwaters is 1500–2000 mm (DHM 1998), whilst that in the valley (Hetauda Station) is 1847–3323 mm. The maximum and minimum annual air temperatures are 29.3°C and 16.8°C, respectively. The maximum and minimum relative humidity at local times 8:45 and 17:45 are 81% and 71%, and 78% and 67%, respectively. The average annual peak discharge of the Rapti River calculated from the records of DHM (1998) from the Rajaiya Station, at about 1 km downstream from the sampling point R4 (Fig. 3), is 525 m³/s⁻¹. The maximum monthly discharge ranges from 18.5 to 684 m³/s⁻¹, and high flows occur in June–September.

**Geological setting**

The HCDB constitutes partly the Lesser and the Sub-Himalayan fold-thrust belts. The foreland sedimentation prevailed in Neogene after the collision tectonics and then the Sub-Himalayas (Siwaliks) came into existence due to folding and thrusting. Four major thrusts the Mahabharat Thrust, the Samari Thrust, the Main Boundary Thrust and the Central Churia Thrust that extend NW–SE and dip north demarcate five tectono-geomorphic zones from the north to the south (Fig. 3). These zones are (1) the Bhowas Group (Stöcklin and Bhattarai 1982); high-grade metamorphic rocks (schist, gneiss and amphibolite), granite and pegmatite, (2) the Upper Nawakot Group (low-grade metasedimentary and sedimentary rocks; slates, phyllite, chloritic phyllite, quartzite, limestone and dolostone), (3) the Pre-Siwalik Group? (Tamrakar et al. 2002; quartzose sandstone, shale, siltstone and conglomerate), (4) northern belt of the Siwalk Group and (5) southern belt of the Siwalik Group (sandstone, siltstone, mudstone and conglomerate) from the north to the south. Between the northern and the southern belts of the Siwalik Group, a wide Dun Valley extends E–W.

The Dun Valley constitutes five distinct geomorphic surfaces. According to Kimura (1994) the Higher and the Upper surfaces formed as alluvial fans in the foot of the Mahabharat and the Sub-Himalayas during middle Pleistocene (Pre-Dun Phase). The Middle Terraces resulted after upheaval of the hanging walls of the Main Frontal Thrust and the Central Churia Thrust probably during late
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Pleistocene, and sedimentation from Siwalik rocks and earlier terrace deposits from the south to north flowing tributaries. The Lower Terraces formed after crustal deformation, indicate fluvial, swamp and lakes sedimentation (Kimura 1994). Terrace deposits of the Dun Valley are composed of gravel, sand and mud, and are distributed in the central part of the HCDB.

METHODOLOGY

A bulk of 500 g of sand (matrix) associated with gravel in side bar or mid bar of the Rapti River was sampled from each sampling site between Hetauda and Meghauli (Fig. 1) for mineralogical and textural analyses. Each sample was sieved at the interval of 1 . One hundred quartz grains from medium sand grade were estimated for roundness ( ) and maximum projection sphericity ( ) using comparators. Each of the bulk samples was cemented using epoxy, thinned and stained for carbonates with potassium ferricyanide and alizarin red, and also stained for potash feldspar grains with sodium cobaltinitrite. Three hundred grains per thin section were point-counted for modal analyses using Gazzi-Dickinson’s method of counting.

RESULTS

Texture of sand

The samples are very coarse to fine sand, the majority being very coarse sands (Table 1) considering their median size grades. Quartz grains exhibit medium range of (0.75–0.79) and are subangular to subrounded ( = 1.65–3.24). Distribution patterns of roundness in R1 to R5 are similar (Fig. 4). Similarly, the patterns in R6 to R12 are similar, but a remarkable decrease in angular fragments at the expense of subrounded and rounded grains can be seen. and of quartz tend to enhance with downstream distance.
Composition

Quartz

Quartz is the dominant component of the sand (Table 2). Monocrystalline quartz (Qm) ranging from 27 to 54% exceeds polycrystalline quartz (Qp) (15–41%) in every sample. Undulose Qm grains dominate nonundulose Qm grains showing their derivation probably from finely to coarsely crystalline metamorphic rocks such as quartzite, phyllite and schist. The nonundulose Qm grains were perhaps derived from the quartz vein, quartzite, sandstone and siltstone. Qp grains are mostly foliated and were probably derived from the high-grade metamorphic rocks such as schist and gneiss. Polycrystalline equigranular quartz probably came from granite, pegmatite and quartzite. The total quartz (Q) becomes abundant in the downstream segments of the Rapti River, and it shows significant positive correlation with river distance (Fig. 5a) suggesting increase in maturity of sand.

Feldspar

Feldspars (F) represent low amount in sand (between 1 and 4%) and are orthoclase, microcline and twinned plagioclase. The feldspars were probably derived from granitic rocks and metamorphic rocks of the Lesser Himalayas. The huge source rocks of feldspars are distributed in the Lesser Himalaya in the northern region of the HCDB. The amount of feldspar becomes very low in the samples as the river emerges from the Sub-Himalaya in to the Dun Valley, most probably due to dilution of feldspar by weathering and breakdown within the upstream stretch. Hayes (1962) also came into the similar conclusion that feldspars are rapidly destroyed in high-gradient streams of mountain rivers. Once the proportion of feldspars has been diluted, no further variation of feldspar occurs along the low-gradient stretch of the Rapti River.

Lithic fragments

Sedimentary lithic fragments (Ls) that range from 6 to 35% are composed of siltstone, sandstone, shale and carbonate lithics (Lc). Most of the Ls, except some of the Lc, are derived from the Siwalik Group. Carbonate lithics are substantial in R1 and R2 from the upstream portion of the river and they were probably derived from the Upper Nawakot Group.

Metamorphic lithics (Lm) range from 1 to 24% and are represented by schist followed by phyllite, argillite and amphibolite in decreasing abundance. The metamorphic lithics were probably derived from

Table 1: Grain size of sand and shape of quartz grains of sand from the Rapti Rivers

<table>
<thead>
<tr>
<th>Sample</th>
<th>Distance</th>
<th>Median size</th>
<th>Roundness</th>
<th>Sphericity, p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>km</td>
<td>Mean STDEV MEAN STDEV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R1</td>
<td>19.4</td>
<td>-0.3 (VCS)</td>
<td>1.65 0.67 0.75 0.07</td>
<td></td>
</tr>
<tr>
<td>R2</td>
<td>21.7</td>
<td>0.7 (CS)</td>
<td>2.27 1.06 0.77 0.06</td>
<td></td>
</tr>
<tr>
<td>R3</td>
<td>24.0</td>
<td>1.7 (MS)</td>
<td>1.98 0.92 0.76 0.07</td>
<td></td>
</tr>
<tr>
<td>R4</td>
<td>33.2</td>
<td>-0.4 (VCS)</td>
<td>1.96 0.86 0.76 0.06</td>
<td></td>
</tr>
<tr>
<td>R5</td>
<td>50.3</td>
<td>-0.6 (VCS)</td>
<td>1.92 0.96 0.78 0.06</td>
<td></td>
</tr>
<tr>
<td>R6</td>
<td>66.7</td>
<td>-0.6 (VCS)</td>
<td>2.81 1.02 0.79 0.06</td>
<td></td>
</tr>
<tr>
<td>R7</td>
<td>73.2</td>
<td>-0.6 (VCS)</td>
<td>3.24 0.97 0.79 0.06</td>
<td></td>
</tr>
<tr>
<td>R8</td>
<td>78.8</td>
<td>-0.4 (VCS)</td>
<td>3.07 0.98 0.78 0.06</td>
<td></td>
</tr>
<tr>
<td>R9</td>
<td>99.8</td>
<td>2.1 (FS)</td>
<td>2.88 0.93 0.78 0.06</td>
<td></td>
</tr>
<tr>
<td>R10</td>
<td>105.0</td>
<td>0.5 (CS)</td>
<td>2.80 0.97 0.77 0.06</td>
<td></td>
</tr>
<tr>
<td>R11</td>
<td>110.3</td>
<td>0.2 (CS)</td>
<td>3.02 0.88 0.79 0.07</td>
<td></td>
</tr>
<tr>
<td>R12</td>
<td>118.3</td>
<td>1.8 (MS)</td>
<td>2.83 1.06 0.79 0.07</td>
<td></td>
</tr>
</tbody>
</table>

FS = fine sand; MS = medium sand; CS = coarse sand; VCS = very coarse sand; STDEV = Standard deviation

Fig. 4 Percent frequency of roundness categories for quartz of sand samples (VA = very angular, A = angular, SA = subangular, SR = subrounded, R = rounded and WR = well rounded)
the Lesser Himalayas. The total metamorphic lithics (Lm) and carbonate lithics (Lc) show significant negative correlation with downstream distance (Fig. 5b and 5c).

**Modal sand composition and provenance**

The overall QFL composition of the Rapti River sand is Q_{66}, F_{2} and L_{32} (Table 2). The samples are quartzo-lithic sand in which percent quartz exceeds percent lithic fragments (Fig. 6a). The proportion of lithic fragments diminishes from the downstream sites. The QmFLt composition is Qm_{39}F_{2}Lt_{59} and the plot (Fig. 6b) shows more Lt compared to Qm.

The sand samples plot on recycled orogeny field of the QFL diagram (Fig. 7a), and transitional recycled field of the QmFLt diagram (Fig. 7b). In agreement with the present-day environmental setting where collision tectonics and subsequent folding and thrusting provide enormous sediments to the rivers, the plots of the recent river samples indicate a recycled provenance field.

Comparing the data of the headwaters of the Rapti River (X1 and X2; Fig. 7b) after DeCelles et al. (1998) with the data of the present study (in which samples were from the low-gradient stretches) a distinct compositional shift has been obtained. The X1 sand from the most upstream portion is richer in feldspar probably due to proximity of granitic and high-grade metamorphic rocks in the region, therefore it plots on a mixed provenance field. Further downstream, where low-grade metamorphic and sedimentary rocks prevail, the X2 sand shows compositional shift from a mixed to a transitional recycled field. In the low-gradient stretches, feldspars are almost underrepresented possibly due to weathering and destruction of this component or due to excessive input of reworked quartz and lithic fragments along the river course from the earlier storage. Therefore, the compositional shift occurs with diminished feldspars more towards the transitional recycled provenance field (Fig. 7b).

**CONCLUSIONS**

1. Quartz grains, which are angular to subangular, monocrystalline to polycrystalline, undulose to non-undulose were derived from crystalline and high-grade metamorphic rocks. The tendency of increase in quartz roundness in the downstream stretches of the Rapti River suggests incorporation of recycled quartz, which were probably derived from sandstones (Siwalik Group) and the Dun Gravel Deposits.
2. As the river emerges from the Sub-Himalaya into the Dun Valley the amount of feldspar becomes quite low (1–4%) in sands most probably due to dilution of feldspar by weathering and rapid breakdown in headwaters. No further significant variation of feldspar exists along the low-gradient stretch of the Rapti River, however maturity of sand improves downstream significantly.

3. The Rapti River sands plot on recycled orogeny field of QFL diagram, and transitional recycled field

Table 2: Modal composition of the Rapti River sand

<table>
<thead>
<tr>
<th>% Grains</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R1</td>
</tr>
</tbody>
</table>

Monocrystalline quartz (Qm)
- Qm: undulose: Qmu
  - R1: 21 22 25 17 37 21 25 29 21 24 20 33
  - R2: 7 8 10 7 17 7 10 11 7 11 10 21
  - R3: 28 30 35 24 54 28 35 40 27 36 30 54

Polycrystalline quartz (Qp)
- Qp: equigranular: Qpe
  - R1: 9 17 5 8 5 10 12 9 6 9 16 7
  - R2: 0 0 4 1 4 8 0 0 2 1 1 1
  - R3: 10 17 11 7 5 17 13 12 19 19 7 6
  - R4: 4 5 5 13 6 14 6 15 21 14 20 8
  - R5: 15 22 20 21 15 39 19 27 41 35 28 15

Total quartz
- Q: 43 52 55 46 69 67 54 67 69 70 59 69

Orthoclase
- Ko: 0 1 0 1 0 2 0 1 1 0 0 0

Microcline
- Km: 1 0 1 0 0 0 0 1 0 0 0 0

Plagioclase-twinned
- P: 0 2 1 1 2 0 1 3 1 0 2 1

Total feldspar
- F: 1 3 3 2 2 2 1 4 2 1 2 1

Siltstone
- Lstmt: 3 2 2 5 1 2 10 3 8 4 4 1

Sandstone
- Lstmt: 5 1 0 0 0 1 12 2 4 1 1 3

Shale
- Lsh: 13 15 8 8 5 3 5 4 3 5 5 6

Carbonate (detrital)
- Lc: 23 17 12 16 6 7 35 12 23 14 17 11

Total Sedimentary lithic
- Ls: 4 56 50 62 36 62 55 48 66 55 57 33

Unfoliated metaclast
- Lmec: 0 4 2 7 6 3 0 2 0 1 0 0

Q-M-phyllite
- Lphy: 8 7 5 4 4 4 0 2 1 2 5 1

Q-M-schist
- Lsc: 14 1 7 7 1 6 1 3 1 1 5 0

Amphibolite
- Lpm: 1 2 0 0 0 0 0 1 0 0 0 0

Probable metamorphic lithic
- Lpmr: 0 3 5 6 3 2 1 2 0 2 3 4

Total metamorphic lithic
- Lm: 24 17 19 24 16 1 9 2 6 12 7

Lithics
- L: 47 34 31 40 20 24 36 21 25 20 29 18

Total lithics
- Lt: 61 56 50 62 36 62 55 48 66 55 57 33

Biotite
- Mb: 2 3 3 3 2 2 5 3 2 1 3 2

Muscovite
- Mm: 1 1 2 1 2 2 1 0 1 1 2 2

Total mica
- M: 3 4 5 4 4 4 5 3 2 3 5 4

Heavies
- D: 5 3 4 7 4 3 3 3 3 5 3 7

Indeterminant grains
- I: 0 4 3 1 1 0 1 1 0 0 2 0

Recalculated %QFL
- Q %QFL: 47 59 62 52 76 72 60 72 72 77 65 78
- F %QFL: 2 3 3 2 2 2 1 5 2 1 2 2
- L %QFL: 51 38 35 46 22 26 40 23 26 22 33 20

Recalculated %QmFLt
- Qm %QmFLt: 31 34 39 28 59 30 39 44 29 39 34 61
- F %QmFLt: 2 3 3 2 2 2 1 5 2 1 2 2
- Lt %QmFLt: 68 63 57 70 39 68 60 52 70 60 64 37

Recalculated %LsLmLv
- Ls %LsLmLv: 49 51 39 40 31 31 96 56 94 71 59 61
- Lm %LsLmLv: 51 49 61 60 69 69 4 44 6 29 41 39

Qm = Qmu + Qmnu; Qp = Qpe + Qpi + Qpf + Qpc; F = Ko + Km + P; Ls = Lstmt + Lstmt + Lsh + Lc; Lm = Lmec + Lphy + Lsc + Lamp + Lpmr; L = Ls + Lm; Lt = L + Qp; M = Mb + Mm
of QmFLt diagram. These sands are poorer in feldspar compared to the modern and ancient sands or sandstones from the other regions having similar tectonic setting.

4. Despite of compositional variation of sands and sandstones from different climates and environments, all of them plot on recycled provenance fields, and do not show major difference in provenance. Although these sand and sandstones show similar tectonic setting, the difference in major mineralogical components in them happens depending perhaps on relief and climate. The Rapti River sand thus provides an example of recycled orogeny provenance of a long low-gradient stream in humid
sub-tropical basin of the Sub-Himalaya.

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REFERENCES


