The origin of the Neihart Quartzite, a basal deposit of the Mid-Proterozoic Belt Supergroup, Montana, U. S.A.

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Abstract-The Neihart Quartzite is the basal quartz arenite unit (,: 270 m thick) of the MidProterozoic Belt Supergroup of western North America. Petrographic studies indicate a source area with plutonic granitic, metamorphic and felsic volcanic rocks. Extreme textural maturity and bimodality indicate an episode of aeolian transport for the detrital quartz grains. The lower 80 % of the Neihart Quartzite were probably deposited by braided streams, whereas the upper 20 % were deposited in shoreline environments. Residual material that was `stored up' on the pre-Beltian cratonic surface and underwent aeolian reworking was the likely source material for most of the Neihart Quartzite. Less mature sediments in the top portion of the Neihart Quartzite indicate uplift and erosion of new source material during Neihart deposition. Other known cratonic quartz arenites, such as the St. Peter Sandstone (Ordovician), Lamotte Sandstone (Cambrian) and Flathead Quartzite (Cambrian), are thin (tens of metres thickness) and exhibit sheet-like geometry. In contrast, the Neihart Quartzite and its probable lateral equivalents are considerably thicker and increase in thickness towards the central portions of the basin. It thus appears that Belt sedimentation began with accumulation of a basal quartz arenite unit, and that sand for that unit was transported by braided streams from the surrounding craton to a gradually subsiding Belt basin.

1. Introduction

The Mid-Proterozoic Belt basin contains a thick sequence (20 km) of predominantly shales and siltstones with interbedded carbonate and sandstone units. Sedimentation took place intermittently from 1450 to 850 Ma (Harrison, 1972), and conglomerates and angular unconformities are rare. Recent palaeogeographic reconstructions indicate that the Belt Supergroup accumulated in an epicontinental basin where the Siberian and North American craton where formerly joined together (Stewart, 1976; Sears & Price, 1978; Piper, 1982). Sedimentary sequences in cratonic basins tend to have quartz arenites at the base (Pettijohn, Potter & Siever, 1972), a generalization that holds true for the lowermost known sediments of the Belt Supergroup.

The only basal quartz arenite unit in the Belt Supergroup that rests unequivocally on basement gneisses, the Neihart Quartzite (Ross, 1963; Harrison, 1972), occurs in the easternmost portion of the Belt basin (Fig. 1) in the vicinity of the town of Neihart. It was named by Weed (1899, 1900), who recognized that it rests nonconformably on coarse granitoid gneisses, that it contains cross-bedding, and that it has a gradational contact with the overlying Chamberlain Shale. Other occurrences of Neihart Quartzite in the Little Belt Mountains were described by Hruska (unpublished M.Sc. thesis, Montana College of Mineral Sciences and Technology, 1967) and McClernan (unpublished M.Sc. thesis, Montana College of Mineral Sciences and Technology, 1969) in the course of local mapping projects. Neihart Quartzite and Chamberlain Shale are considered lateral equivalents of the Prichard Formation in the western Belt basin (Harrison, 1972). The turbidites of the Prichard Formation accumulated in the deepening western and central portion of the basin after initial quartz arenite deposition. Possible lateral equivalents of the Neihart Quartzite occur at three other localities in the Belt basin (Fig. 1). Because the Neihart Quartzite is the oldest sediment unit of the Belt Series, a good understanding of its source and deposition is of considerable importance for an understanding of Belt basin evolution. However, despite the obvious significance of the Neihart Quartzite, descriptions by above authors are very brief and generalized. In the course of a sedimentologic and stratigraphic investigation of the eastern Belt basin, the author of this report had opportunity to examine the Neihart Quartzite in the summers of 1981, 1982, and 1987. It is the objective of this contribution to report petrographic and sedimentary features of the Neihart Quartzite that yield information about: (1) the source rocks of the earliest Belt sediments; (2) conditions on the pre-Belt cratonic surface; and (3) early stages of Belt sedimentation. Of particular interest is the question of whether the Neihart Quartzite is a typical cratonic quartz arenite of sheet-like geometry that may already have existed before the Beltian transgression, or if it accumulated in response to crustal subsidence at the beginning of Belt sedimentation. The observations that are reported in the following paragraphs are taken from the author's Ph.D.

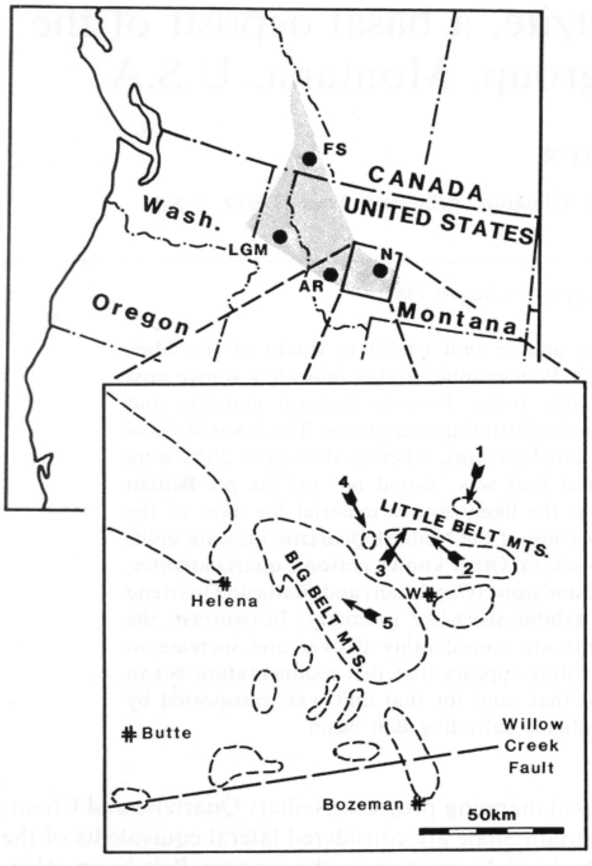

Figure 1. Location map. Present day outline of Belt basin shown with stipple pattern. Black dots indicate occurrences of quartz arenites at the base of the Belt Series. N = Neihart, AR = Anaconda Range, LGM = Little Goat Mountain, FS = Ft. Steele. Enlarged portion of map shows Belt Series outcrop areas (enclosed by dashed lines) in the eastern portion of the Belt basin. Arrows indicate occurrences of Neihart Quartzite: 1 = Type locality near Neihart in the northern Little Belt Mountains; 2, 3, and 4 are occurrences of Neihart Quartzite in the southern Little Belt Mountains that were mapped by Hruska (unpublished M.Sc. thesis, Montana College of Mineral Sciences and Technology, Butt, 1967) and McClernan (unpublished M.Sc. thesis, Montana College of Mineral Sciences and Technology, Butt, 1969); 5 = Inclusions of Neihart Quartzite in the Big Belt pluton (M. W. Reynolds, personal. communication, 1983).

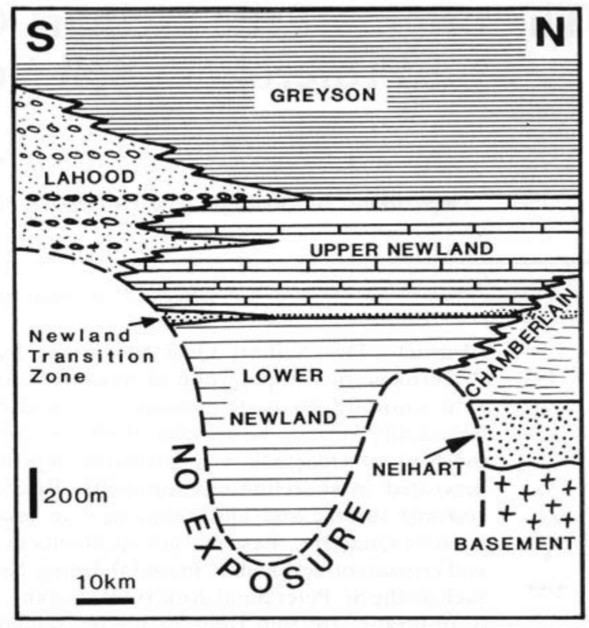

Figure 2. Stratigraphic overview for the easternmost portion of the Belt basin. Based on data from McMannis (1963), Boyce (unpublished Ph.D. thesis, University of Texas at Austin, 1975) and Schieber (unpublished Ph.D. thesis, University of Oregon, 1985). Thickness of stratigraphic units: Neihart Quartzite ~ 270 m, Chamberlain Shale
600 m, Lower Newland zz 500-1200 m, Newland Transition Zone .: 50-100 m, Upper Newland 500-900 m, Greyson Formation x 1800-3000 m, LaHood Formation & 20002500 m. Not shown in the diagram is the Spokane Formation, a red bed unit which when present in the Big Belt and Little Belt Mountains is usually unconformably overlain by Palaeozoic strata.

dissertation (Schieber, unpublished Ph.D. thesis, University of Oregon, 1985), and augmented with observations made in 1987. A brief history of Belt sedimentation in the Little Belt Mountains and vicinity is given in Schieber (1986 a, 1986 b), and is paraphrased below.

Three large scale transgressive-regressive cycles allow subdivision of the sedimentary history of the eastern Belt basin into six distinct episodes. Lateral migration of braided stream, nearshore, and shallow basinal facies during initial transgression of the Beltian sea resulted in superposition of Neihart Quartzite by Chamberlain Shale (Fig. 2). With uplift during the second depositional episode, an east-west trending half-graben formed through syndepositional faulting in the south, and coarse elastic regressive sediments were carried basinwards (Newland Transition Zone, LaHood Formation; Fig. 2). With renewed transgression during the third episode, shale-carbonate cycles of the Upper Newland Formation were deposited while coarse elastic sediments of the LaHood Formation continued to accumulate along the faulted southern basin margin (Fig. 2). A thick elastic wedge of the LaHood Formation, known as the lower member of the Greyson Formation (Nelson, 1963) in the central portions of the basin, advanced into the basin from the south during the fourth episode. Basin bounding faults became inactive during the fifth episode, the area as a whole subsided, and abundant shale (the upper member of the Greyson Formation) accumulated. Sedimentation exceeded subsidence during the sixth episode, and alluvial red beds of the Spokane Formation (not shown in Fig. 2) were deposited.

The Belt basin experienced strong magmatic activity and deformation in late Mesozoic and early Tertiary times (Harrison, Griggs & Wells, 1974).

Thrusting with transport distances of up to 200 km occurred along the eastern border of the Belt basin during late Cretaceous to Paleocene time (Harrison, Kleinkopf & Wells, 1980). Thrusting and folding was followed by uplift, erosion and normal faulting. Metamorphic overprint is common in Belt sediments and usually ranges from lower greenschist grade to amphibolite grade. The Little Belt Mountains (Fig. 1) are one of the few outcrop areas where Belt sediments were not affected by metamorphism.

2. Lithofacies

Two facies types are distinguished in the Neihart Quartzite, the massive quartzite facies and the mixed quartzite facies.

2.a. Massive quartzite facies

This facies consists primarily of coarse to very coarse sandstone, and forms conspicuous escarpments near the town of Neihart. Beds of this facies are of white to pink colour on fresh surfaces, and may contain lenses of rounded granules and pebbles of quartz and red chert (up to 7 cm in size; Keefer, 1972). Within a single bed fine, coarse and very coarse sand can be found in intimate association, and therefore it is not practical to define a variety of rock types in this facies. Point counts of 20 thin sections show that beds in this facies consist primarily of monocrystalline quartz grains (80-95 %) with weak or absent undulatory extinction. The next most abundant grain type is polycrystalline quartz (1-15 %) with (a) a polygonal fabric of interlocking crystals, and (b) with elongate, lenticular, interlocking, sutured crystals (Fig. 3). Sandstone beds also contain small amounts of detrital chert grains (0-3 %) which may be reddish because of dispersed hematite inclusions (Fig. 4). In several samples embayed quartz grains (0-3 %) were found (Fig. 5), where the embayments are filled with a fine crystalline groundmass. The sandstones are poorly sorted, and

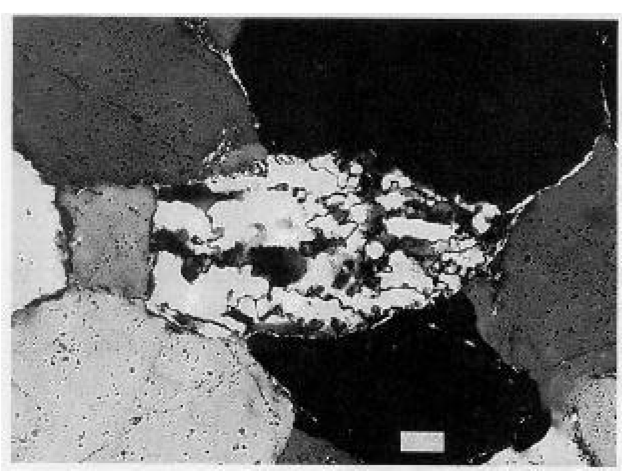

Figure 3. Photomicrograph of metamorphic polycrystalline quartz grain. Note flattened quartz crystals and sutured crystal boundaries. Scale bar is 0.1 mm long.

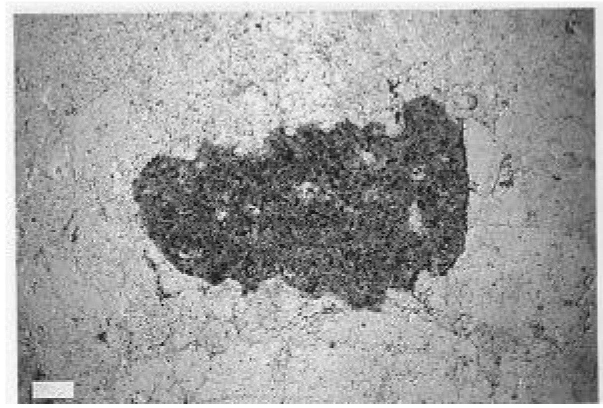

Figure 4. Photomicrograph of reddish chert grain. Dark blobs and dusting in this grain are caused by hematite. Scale bar is 0.1 mm long.

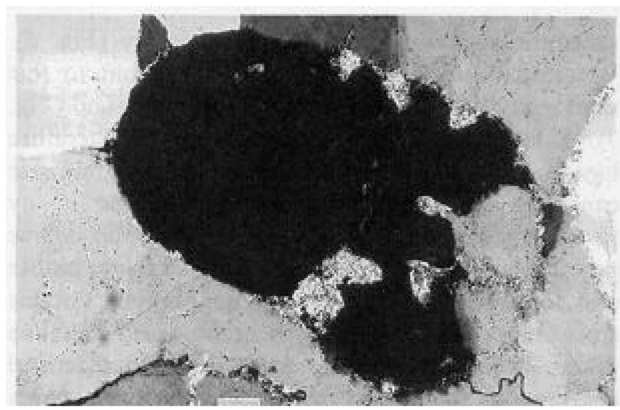

Figure 5. Photomicrograph of embayed quartz grain. The embayments are filled with a fine crystalline groundmass. Scale bar is 0.1 mm long.

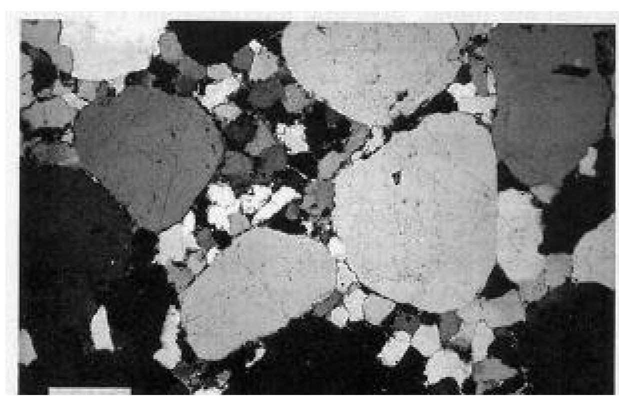

Figure 6. Photomicrograph of massive quartzite facies.

Shows well rounded coarse quartz grains of high sphericity and interstitial spaces filled with finer grains. Note bimodal character of sandstone. Scale bar is 0.5 mm long.

about 60-70% of the grains range from 0.5-4mm in size. These larger grains are rounded to well rounded and of high sphericity (Fig. 6). The spaces between these coarser grains are either filled with quartz overgrowth cement, or with medium to fine

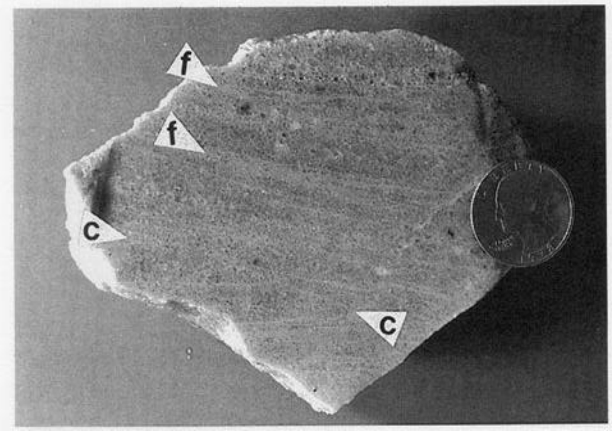

Figure 7. Photo of handspecimen of trough cross-bedded massive quartzite. Shows alternating coarse and fine (arrows f) cross-beds and internal erosion surface (arrows c). Coin is 24 mm in diameter.

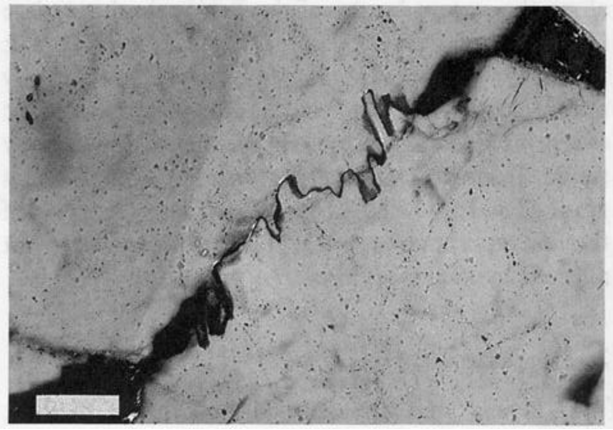

Figure 8. Stylolithic interpenetration of two adjacent quartz grains. Scale bar is 0.1 mm long.

sand (grain size 0.15-0.35 mm) that is subangular to subrounded and of medium sphericity (Fig. 6). Within sandstone beds laminae of medium to fine sand may alternate with laminae of coarse sand (Fig. 7). Sandstone beds in this facies show therefore bimodal grain size distribution, and mean grain size can vary considerably over short distances in any given sandstone bed. Quartz grains of the coarse population may have inclusions of muscovite, biotite and tourmaline. The fine sand population contains trace amounts of well rounded zircon and tourmaline grains. In addition a small number of rounded detrital chert grains were observed. Remaining pore spaces are mainly filled with quartz overgrowth cement, but may in places also contain clay minerals. Clay minerals are also found as very thin films around quartz grains. In places mudclasts of variable size (up to several cm across) are found. Stylolitic interpretation of quartz grains occurs in places (Fig. 8). According to most sandstone classification schemes, the rocks of this facies are best described as quartz arenites (Folk, 1974; Pettijohn, 1957; Gilbert, 1954).

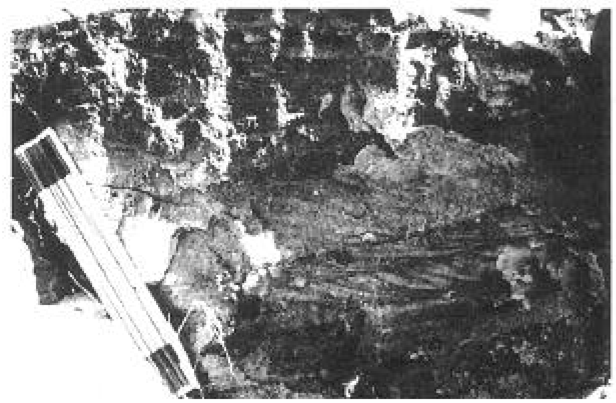

Figure 9. Planar cross-stratification in massive quartzite facies. Ruler is 24 cm long.

Figure 10. Photo of trough cross-stratified bed in massive quartzite facies. Hammer is 31 cm long.

2.a.1. Sedimentary features

The massive quartzite facies consists of 0.1-1.5 m thick beds of coarse to very coarse quartz arenite with even to slightly undulose bedding planes. On fresh surfaces it is apparent that in many cases the massive, thick beds are actually bedsets consisting of several thinner, superimposed beds.

Observed sedimentary structures are:

(a) planar and trough cross-bedding (cross-bedded units up to 30 cm thick, Figs. 9 and 10)

(b) parallel lamination

(c) erosion surfaces between cross-bedded units

(d) lenses of quartz pebbles and pebble-rich intervals in sandstone beds.

No repetitive patterns in the spatial arrangement of sedimentary structures were observed. Individual cross-beds of cross-bedded units are 2-20mm thick, and thicker cross-beds may contain subangular to subrounded granule to pebble sized grains in their lower portion. Trough cross-stratification (Fig. 10) is predominant.

2.b. Mixed quartzite facies

This facies consists of fine to very fine sandstone(predominant) silty shale and micaceous silty beds. The fine to very fine sandstone is whitish to greenish grey in colour and contains about 60 % subangular quartz grains of medium sphericity between 0.04-0.2 mm in size. Some beds may have small proportions of coarse sand, either scattered or at the bottom of laminae. The rock also contains minor amounts (1-3 %) of mica flakes (0.1-0.4 mm long), mostly muscovite, and trace amounts of detrital zircon and tourmaline. The micas are usually approximately parallel to bedding, and are concentrated along boundaries of laminae. Muscovite flakes generally show sharp outlines, may be broken and bent between grains, and may show `fanning out' into pore spaces. Diagenetic alteration of muscovite flakes led to flakes of illite and kaolinite (clay minerals determined by XRD and optically). Iron oxyhydroxides, derived from weathering of interstitial pyrite, may in places constitute several per cent of the rock volume. Pore spaces are filled with quartz overgrowth cement (predominant), very fine clay minerals and altered and expanded micas (muscovite altered to illite and kaolinite). In many places fine seams of clay minerals surround quartz grains. Despite the comparatively large content of micas and clays, these sandstones can still be classified as quartz arenites (Folk, 1974; Pettijohn, 1957; Gilbert, 1954).

Silty shales are interbedded with fine to very fine sandstone and are the next abundant rock type in this facies. They consist of alternating laminae of silt and clay, laminae are between 0.2-5 mm thick, and are of wavy-lensy character. Silt laminae are greenish grey in colour, clay laminae are dark grey in colour. Silt laminae consist to about 60 % of subangular to angular quartz silt (0.02-0.06 mm) of medium to low sphericity. In addition they contain 1-2 % mica flakes (0.03-0.1 mm long, mostly muscovite, +biotite), and trace amounts of detrital zircon and tourmaline. Pore spaces are filled with fine clays (illite, ±kaolinite) and some chlorite. Iron oxyhydroxide pseudomorphs after pyrite (euhedral crystals and framboids, 0.05-0.1 mm) are found in minor amounts. In places quartz grains are cemented by quartz overgrowth cement. The clay laminae (mainly illite) contain variable amounts of quartz silt (5-20 %) and 5-10 % mica flakes (muscovite, ± biotite).

Micaceous silty beds are only of minor importance in terms of volume. They may form softer weathering partings between sandstone beds, or may form discontinuous, lenticular beds within sandstone beds. These beds are 1-50 mm thick, are of whitish to greenish grey colour, contain 10-50 % quartz silt, 30 % or more clay (illite), about 20 % mica flakes (0.05-0.2 mm long, muscovite, ±biotite), minor amounts of detrital zircon, and traces of detrital tourmaline. Mica flakes are aligned parallel to bedding and may be bent between quartz grains.

Figure 11. Sets of parallel laminated sand in massive quartzite bed from mixed quartzite facies. Note truncation surface between bundles of parallel laminations (arrow). Hammer is 31 cm long.

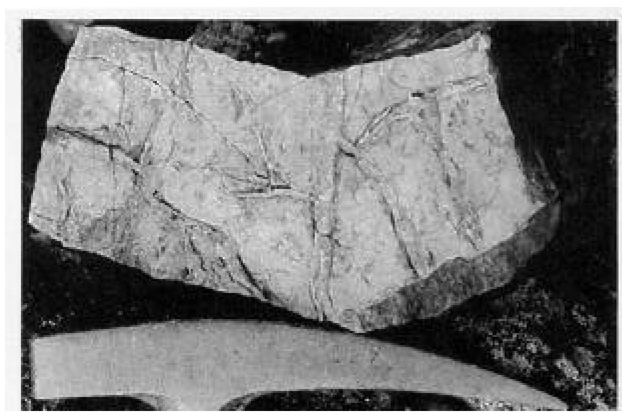

Figure 12. Mudcracks at base of sandstone bed in mixed quartzite facies. Hammer head is 18 cm long.

2.b.1. Sedimentary features

The mixed quartzite facies consists of massive beds of fine to very fine sandstone (30-100 cm thick) that alternate with heterolithic intervals that contain thinner beds of sandstone (up to 20 cm thick) interbedded with silty shales. The heterolithic intervals are between 40 cm and several metres thick.

The massive sandstone beds are characterized by 2-10 cm thick bedsets of even parallel laminated sand with low angle discordances between sets (Fig. 11). Laminae within sets are between a few tenths of a mm to 2 mm thick, and may show reverse grading.

Sandstone beds in the heterolithic intervals have undulose bedding planes, may be lenticular in shape, and may grade laterally into siltstone and silty shale. A variety of sedimentary structures have been observed, such as small ripple cross-lamination, wavy parallel lamination, flaser bedding, lenticular bedding, wavy bedding, symmetrical ripples on bed surfaces (5-10 cm wavelength), intricately interwoven crosslamination (Boersma, unpublished Ph.D. thesis, University

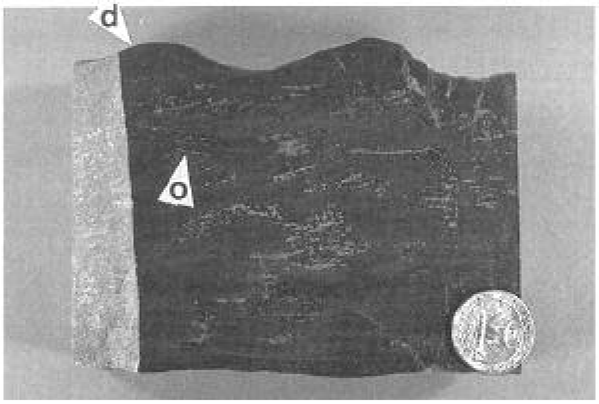

Figure 13. Cut specimen from sandstone bed in mixed quartzite facies. Shows symmetrical ripples on top. Note form discordant laminations (arrow d), cross-stratal offshoots (arrow o), and bundle-wise upbuilding. Coin is 24 mm in diameter.

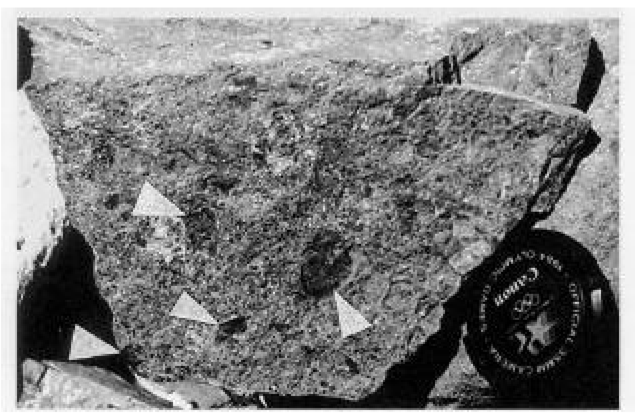

Figure 14. Clay galls in sandstone bed from mixed quartzite facies (arrows). Lens cap is 55 mm in diameter.

of Utrecht, 1970), mudcracks(Fig.12), and loadcasts. The symmetrical ripples on bed surfaces show chevron structures, bundlewise upbuilding of laminae, form discordant laminations, and crossstratal off-shoots (Fig. 13). Mudclasts (up to 2 cm in size), the larger ones of which show a gentle curvature, are common in the sandstone beds of the heterolithic intervals (Fig. 14). Silt beds in silty shale intervals may show low angle cross-lamination and micro-scale flaser and lenticular bedding (Reineck & Wuderlich, 1969).

3. The possible origin of the Neihart Quartzite

3.a. Provenance

Despite the supermaturity of the Neihart Quartzite, it is still possible to derive provenance information from the detrital grains. For example, the polycrystalline quartz grains show in most cases more than six crystal units per grain, a feature that suggests contribution from a metamorhpic source according to Blatt (1967). Foliated quartz sand grains (Fig. 3) also indicate metamorphic rocks in the source region. Sand grains and pebbles of hematitic chert (Fig. 4) may attest to iron-formations in the source area, similar to those that are presently exposed in the crystalline basement rocks south of the Willow Creek fault (Fig. 1 ; see e.g. Cohenour & Kopp, 1980; Casella *et al.* 1982), and other. Embayed quartz grains (Fig. 5) that have been found in thin sections indicate that the source area also contained silicic volcanic rocks (Webb & Potter, 1969). Radiometric age determinations on pre-Belt basement, sediments, lava flows, intrusions and galena mineralization in the Belt Series were reviewed by Harrison (1972), who concluded that Belt sedimentation commenced at about 1450 My. Volcanic quartz grains in the base of the Belt sequence would imply pre-Belt volcanism somewhere on the western North American craton. Conway (unpublished Ph.D. thesis, California Institute of Technology, 1976), and Hahn & Hughes (1984) report volcanic activity at about 1700 My in Arizona and Idaho respectively. Other volcanic centres of that period may be hidden under the sediment cover of the western North American craton, and may have contributed material to the initial deposits of the Belt sequence. Most of the coarse, monocrystalline quartz grains with weak or absent undulatory extinction were probably derived from granitic plutonic sources (Basu *et al.* 1975). From above considerations we may conclude that the Neihart Quartzite was derived from plutonic, metamorphic and volcanic source rocks, and that large areas of deeply eroded continental crust were present in the source region. That latter assumption is supported by the fact that granitoid gneisses directly underlie the Neihart Quartzite in the Little Belt Mountains.

Considerations of the age of the pre-Belt basement suggest that there was a long period of erosion prior to deposition of the Neihart Quartzite. K-Ar ages of pre-Beltian (Hudsonian) basement rocks are fairly uniform and indicate an age of approximately 1700 My (Baadsgaard & Peterman, 1962; Giletti, 1966). Harper (1967) suggested that uniformity of K-Ar ages in shield areas represents passage of a deep crustal zone through a horizon of thermal stability for K-Ar isotopes by regional uplift rather than representing orogenic events. If that idea is applied to the pre-Belt basement, several kilometres of material (representing a hiatus of several hundred million years) must have been removed by erosion prior to Belt deposition (Harrison, 1972). The residual of that material might well have been the source material for the Neihart Quartzite.

Petrographic features of the massive quartzite facies, in particular exceptional textural maturity, are suggestive of abrasion during aeolian transport (Kuenen, 1960; Pettijohn, Potter & Siever, 1972), or may indicate a multicyclic history. The bimodality of these sandstones can be considered as another indicator of an aeolian transport episode (Folk, 1968).

Well rounded grains of tourmaline and zircon might indicate a multicycle history of the Neihart Quartzite (Pettijohn, Potter & Sieves, 1972). However, because the source material of the Neihart Quartzite was most likely `stored' on the craton for a long time interval, and because no indicators of recycled older sediments, such as quartz grains with abraded overgrowths, have been found, a long period of aeolian reworking seems a more plausible explanation.

3.b. Depositional environments

The lower portion (massive quartzite facies) of the Neihart Quartzite (Fig. 15), characterized by trough and planar cross-stratification, pebble lenses, erosion surfaces and poorly sorted coarse sandstones, was most likely deposited in a fluvial environment (Selly 1970; Miall, 1977; Reineck & Singly 1980). Such an interpretation is supported by considerations of current velocities necessary to transport pebbles in the Neihart Quartzite. The largest pebbles are about 7 cm in size, and would require current velocities on the order of 2-5 m/s to be transported (Gustavson, 1978). Current velocities of these magnitudes are quite common in rivers, but are only achieved during rare storm events in shallow seas (Reireck & Singly 1980). The absence of recognizable repetitive patterns of sedimentary structures probably indicates deposition in braided streams (Selley, 1970; Miall, 1977). The dominant trough cross-stratified portions of the lower portion of the Neihart Quartzite can be interpreted as channel deposits, whereas the planar cross-stratified beds may be due to migration of cross-channel bars (Walker & Cant, 1984). The Neihart Quartzite lacks well defined channels, an observation that is consistent with a braided stream interpretation, because braided channels in sand material tend to be broad and shallow. Such channels are typically preserved as thin, lenticular sand bodies, but only in exceptionally large outcrops will the lenticular character be visible. In average outcrops they will simply appear as stacked sandstone beds with slightly undulose contacts, typical for outcrops of the lower portion of the Neihart Quartzite. The thickness of sandstone beds in the massive quartzite facies suggests that these channels were on average not deeper than 1-2 m, and, by comparison with other examples of sandy braided streams (Mull, 1985), were probably between tens to hundreds of metres wide.

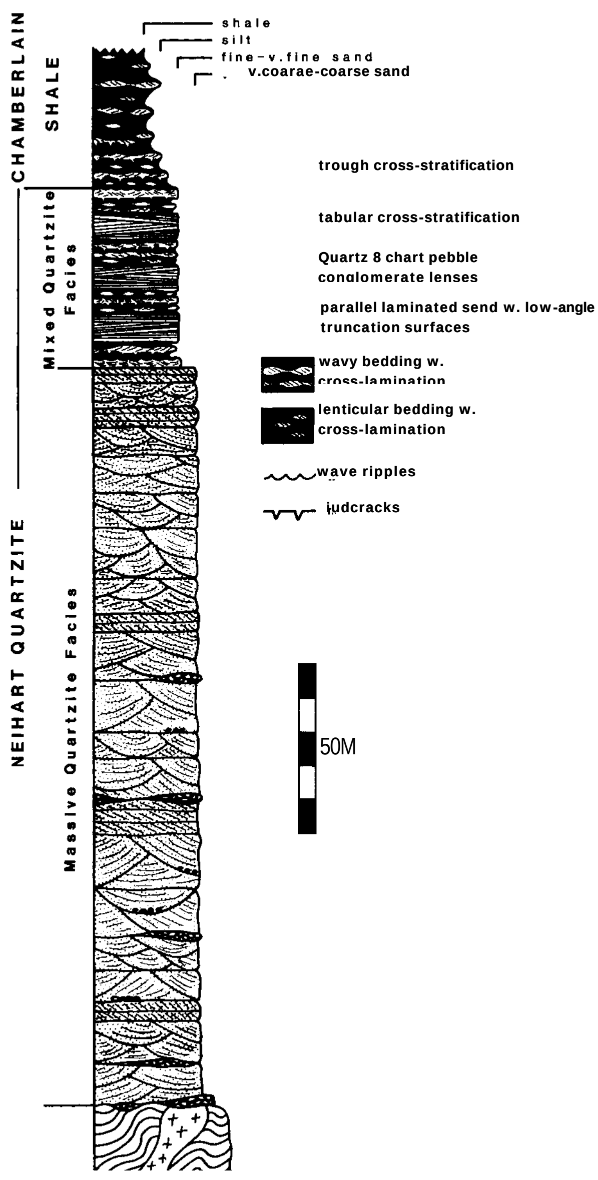

Figure 15. Summary stratigraphic column of the Neihart Quartzite from the type area near Neihart, Montana.

Sedimentary features of the upper portion of the Neihart Quartzite (mixed quartzite facies), such as abundance of wave ripples (symmetrical ripple marks, intricately interwoven cross-lamination; Boersma, unpublished Ph.D. thesis, University of Utrecht, 1970), lenticular-, wavy- and flaser bedding (Reineck & Singly 1980). in association with mudcracks and mudclasts, suggest deposition in nearshore lagoons (shale accumulation) and on mudflats, probably in association with longshore bars and beaches. Sand deposition on beaches is indicated by parallel lamination and low angle truncation surfaces in massive sandstone beds (McKee, 1957; Howard & Reineck, 1972). Inverse grading in individual laminae of these beds also indicates deposition on beaches (Clifton, 1969). A coastal morphology similar to that depicted by Masters (1967) for the Upper Cretaceous Mesaverde Group might have existed during deposition of the upper portions of the Neihart Quartzite.

4. The Neihart Quartzite in the context of basin evolution

Quartz arenites that have been studied elsewhere are noted for their extreme textural maturity, the paucity of interbedded shales and their sheet-like geometry (Brett, 1955; Fahrig, 1961; Donaldson, 1966; Shearer & James, 1984; Dott *et* al. 1986). It is thought that in the case of these sandstones a blanket of sand was spread across the cratonic surface by fluvial and aeolian processes, and was later on reworked during marine transgression to variable degrees (Dott *et* al. 1986).

The Neihart Quartzite compares well with other quartz arenites in terms of textural maturity and paucity of shales. Only in the upper portions, in the transition to the overlying Chamberlain Shale, are shale interbeds common (Fig. 15). None of the criteria of aeolian deposition, such as adhesion ripples and large-scale cross-stratification, has been observed in the Neihart Quartzite, and the available evidence indicates deposition by braided streams. That latter circumstance suggests that at the beginning of Belt deposition a regional slope had developed, along which streams moved sediment to the growing Belt basin. Quartz grains in the upper portion of the Neihart Quartzite (mixed quartzite facies, Fig. 15) show much less textural maturity than those of the lower portion of the Neihart Quartzite (massive quartzite facies), an indication that they did not undergo aeolian reworking. The additional presence of relatively abundant mica and of shale interbeds indicates that, in contrast to the massive quartzite facies, these are first cycle sediments. The development of a regional slope in conjunction with a supply of first cycle sediment implies that the onset of Belt sedimentation was accompanied by uplift in the hinterland of the Belt basin. Depositional environments that are inferred for the Neihart Quartzite lead to the conclusion that coarse sand was deposited by braided streams on coastal plains, whereas fine material was deposited along the shoreline in beaches, mudflats and lagoons. Such a configuration implies that the craton was sloping very gently towards the Belt basin, because in the case of a steeper slope, one should expect to find coarser grain sizes in the shoreline deposits. It also implies that newly uplifted source areas that supplied sediment to the upper portion of the Neihart Quartzite were either far removed from the basin margin or were of quite low elevation.

The fact that typical cratonic quartz arenites exhibit extreme textural maturity and a sheet-like geometry, led to speculations that the Neihart Quartzite, by virtue of its great textural maturity, was similarly deposited as a blanket sand and covered large portions of the western North American craton (Schieber, unpublished Ph.D. thesis, University of Oregon, 1985; Freeman & Winston, 1987).

The outcrop area of clearly identifiable Neihart Quartzite is limited (Fig. 1), and does not serve to demonstrate sheet-like geometry. As stated above (Section 1), there are three occurrences of possible lateral equivalents of the Neihart Quartzite in the Belt basin (Fig. 1), but it is obvious from the considerable spatial separation of these occurrences (Fig. 1) that their correlation with the Neihart Quartzite is tenuous. The occurrence at Little Goat Mountain/Idaho (Fig. 1) was described by Hietanen (1963, 1969) as a 550 m thick quartzite unit that overlies pre-Belt anorthosites and is in gradational contact with the overlying Prichard Formation. Metamorphism and deformation at that locality is intense, but recent investigations by Robert E. Kell (personal communication, 1984) have affirmed that the quartzites do overlie basement rocks and grade upwards into the Prichard Formation. This occurrence is therefore a strong candidate as a lateral equivalent (in a lithostratigraphic sense), because like the Neihart Quartzite it rests on pre-Belt basement. The Ft. Steele Formation, an 1800 m thick quartzite and conglomerate unit, is found at the base of the Belt Series in British Columbia (Fig. I). It was deposited in a fluvial environment and is overlain by a thick sequence of turbidite deposits, the Aldridge Formation, a lateral equivalent of the Prichard Formation (Price, 1964; McMechan, 1981). Even though the base of this unit is not exposed, it is quite likely that the Ft. Steele Formation was deposited in the initial stages of Belt sedimentation, before the basin deepened and turbidite deposition became widespread. It has therefore good potential to be a lateral equivalent of the Neihart Quartzite. Calkins & Emmons (1915) described from the Anaconda Range (Fig. 1) a 300 m thick quartzite unit at the base of the Belt sequence (Prichard Formation) as Neihart Quartzite. The base of the sequence is not exposed, the rocks are strongly metamorphosed, and assessment of sedimentary environments is not possible. This occurrence is therefore considered the most questionable of the proposed correlatives of the Neihart Quartzite.

If the thicknesses of these four presumably correlative quartzite units (Fig. 1) are considered, it appears that quartzite deposits at the base of the Belt sequence thicken towards the west, just as has been observed for other stratigraphic units of the Belt Series along east-west transects (Price, 1964; Harrison, 1972; McMechan, 1981). In contrast to `Standard' quartz arenites that are of the order of 40-50 m thick and attained sheet-like geometry due to initial aeolian and fluvial sand dispersal (Dott *et* al., 1986), the basal Belt quartzite shows a wedge-like geometry and is considerably thicker (270-1800 m).

The contrasting, apparently wedge-shaped, geometry of the basal Belt quartzite can be explained with recent palaeogeographic reconstructions (Stewart, 1976; Sears & Price, 1978; Piper, 1982). These studies suggest that similar to other cratonic basins (e.g. Brown *et* al., 1982; Klein & Hsui, 1987), basement rifting is the underlying cause for subsidence in the Belt basin. Sears & Price (1978) suggest that a branching rift system was initiated between the Siberian and North American craton at approximately 1500 Ma. Thus, it is quite possible that accumulation of Belt sediments was prompted by rift-related subsidence. However, even though rifting may have been initiated at about 1500 Ma, subsidence analysis of the Cordilleran miogeocline shows that active rifting and continental breakup did not occur before 600-555 Ma (Armin & Meyer, 1983; Bond & Kominz; 1984). If sediment thickness (20 km) and duration of sediment accumulation (600 Ma) in the Belt basin are compared with those of more thoroughly studied Palaeozoic cratonic basins (Sloss, 1972, 1979), it is apparent that the Belt basin is a quite unusual cratonic basin and that possibly the underlying mechanisms (Klein & Hsui, 1987) are not identical. If one assumes that basal Belt quartzites accumulated in a rift-induced gradually subsiding basin, thicker quartzite deposits should accumulate in the central portions of that basin. Cratonic separation (Sears & Price, 1978) would lead to a wedge-shaped basal quartzite in the remaining half of the basin. Thus, thickness trends of basal Belt quartzites indicate the early presence of a depocentre, and suggest that the quartzites were probably carried by rivers from the surrounding craton into a gradually deepening depression, rather than being a cratonic sand sheet that was partially reworked by the transgressing Beltian sea. With the above scenario, overall thickness of the basal Belt quartzite and its thickening towards the basin centre can be explained.

5. Conclusions

There are three categories of conclusions that can be drawn from this study. A first category that is based on direct geological evidence, a second category that represents reasonable extensions of the data based on current geological knowledge, and a third category that is primarily speculative and must await confirmation by additional data.

5.a. Conclusions of the first category

(1) Two distinct lithofacies types can be distinguished in the Neihart Quartzite.

(2) The Neihart Quartzite was derived from plutonic, metamorphic and volcanic source rocks.

(3) Large areas of deeply eroded crustal rocks were present in the source area.

(4) Bimodality and extreme textural maturity of the Neihart Quartzite indicates an episode of aeolian transport for most of the sand grains.

(5) The sediments of the upper portion of the Neihart Quartzite (mixed quartzite facies) are probably first cycle sediments.

5.b. Conclusions of the second category

(1) The first facies type, the massive quartzite facies, was most probably deposited by braided streams.

(2) The second facies type, the mixed quartzite facies, was deposited along the shoreline in a complex of lagoons, mudflats and beaches.

(3) There was a long period of erosion prior to deposition of the Neihart Quartzite. Several kilometres of material were eroded during that period.

(4) The residual of that material was the source material for the Neihart Quartzite and was reworked by winds prior to Neihart deposition.

(5) Relative uplift occurred in the hinterland of the Belt basin at the time of Neihart deposition.

5.c. Conclusions of the third category

(1) The Neihart Quartzite is probably part of an extensive quartz arenite unit that was deposited at the base of the Belt sequence.

(2) This basal quartzite unit thickens towards the basin centre, rather than having a sheet-like geometry.

(3) Considerable thicknesses of basal Belt quartz arenite accumulated in response to subsidence at the beginning of Belt sedimentation.

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