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BAIN DIAMICITE:
LITHOLOGY, AGE AND ORIGIN

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ABSTRACT

The Bain diamictite is a part of the Plio-Pleistocene Siwalik Group of northwest Pakistan. The type section is exposed in the Bhittani Range on the south edge of the Kurram river drainage basin near its confluence with the Indus. A counterpart section, reported here for the first time, occurs in the Shinghar Range north of the Kurram River. The unit in both areas is an unsorted, unstratified deposit that has heterogenous lithology, including significantly large volcanic clasts and basal ash stringers. Cooling or drying cracks occur on the upper surface in at least one locality. Clast lithologies indicate a transport direction from the highlands of Afghanistan in the WNW. Previous workers have considered the Bain diamictite to be a tillite, but the low elevation of about 500m and lack of possible glacial source area prior to main Himalayan orogenesis rule this out. Instead a debris-flow or volcanic-lahar origin from Dasht-i-Nawar caldera 300–400km away in Afghanistan is most likely. The probable volume of $30x10^9m^3$ *of the deposit is compatible with most probable pre-caldera volcano topography and post-eruption caldera size, but is still perhaps the world's largest known lahar.*

LITHOLOGIC DESCRIPTION

Amidst the Plio-Pleistocene molasse sequence of the Siwalik Group exposed in the Bhittani Range of the Trans-Indus Salt Range in northwestern Pakistan, is the Bain diamictite (Figs. 1 & 2). The outcrops and lithology of this unit are unique in the area; they contrast with the sandstone/siltstone couplets of the underlying and overlying fluvial deposits. Anyone familiar with this unit can recognize it from a distance as it is a stratigraphic marker. Its boulders can be quickly identified among other clasts in a modern stream and traced back to their source. Local people refer to it specifically as the "puka wuta", or "strong rock",

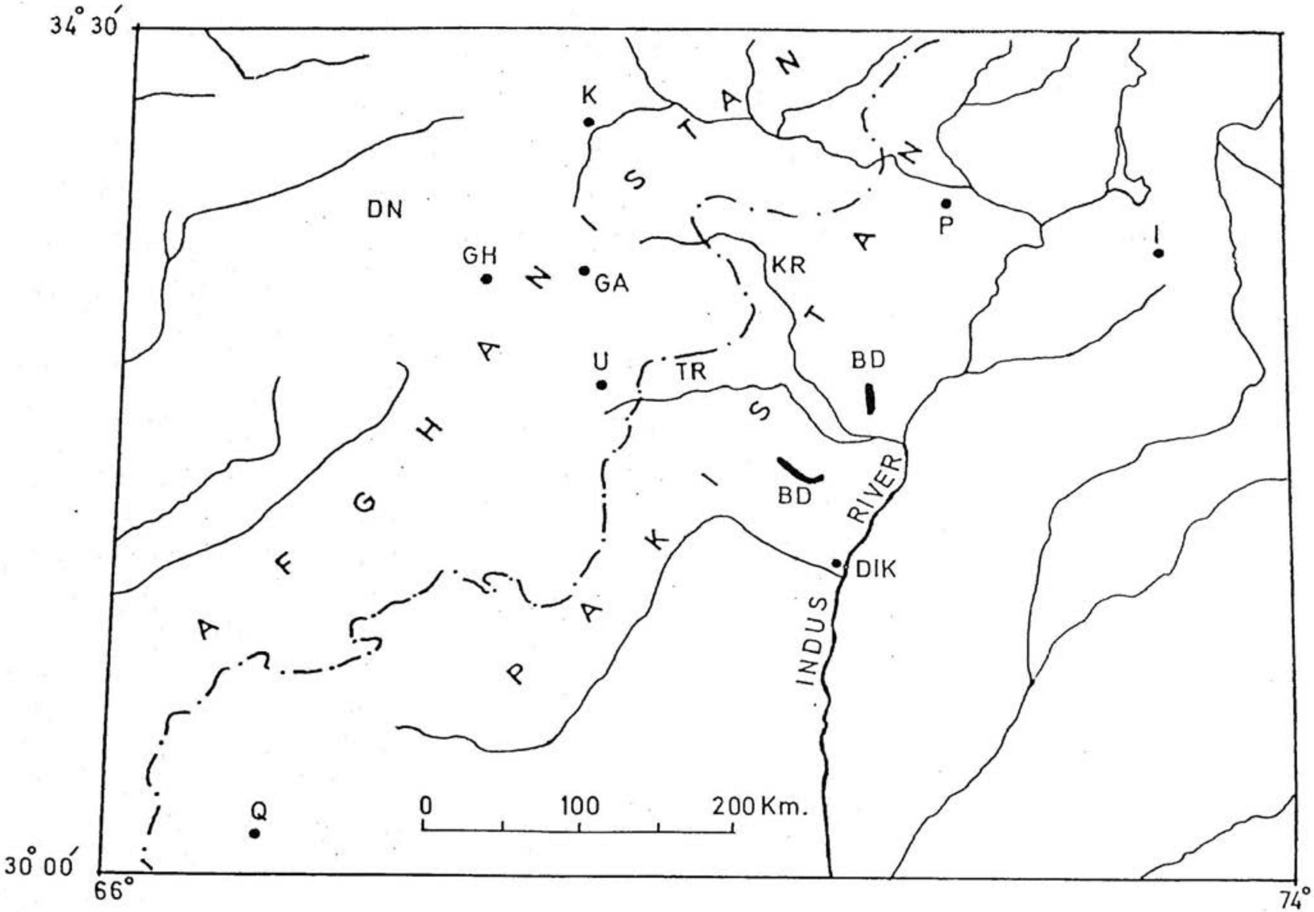

Figure 1. Location map of Bain diamictite in Pakistan. Explanation: BD — Bain diamictite; GA — Gardez; GH — Ghazni; I — Islamabad; DIK — Dera Ismail Khan; DN — Dasht-i-Nawar caldera; K — Kabul; KR — Kurram river; TR — Tochi river; P — Peshawar; Q — Quetta; U — Urgun.

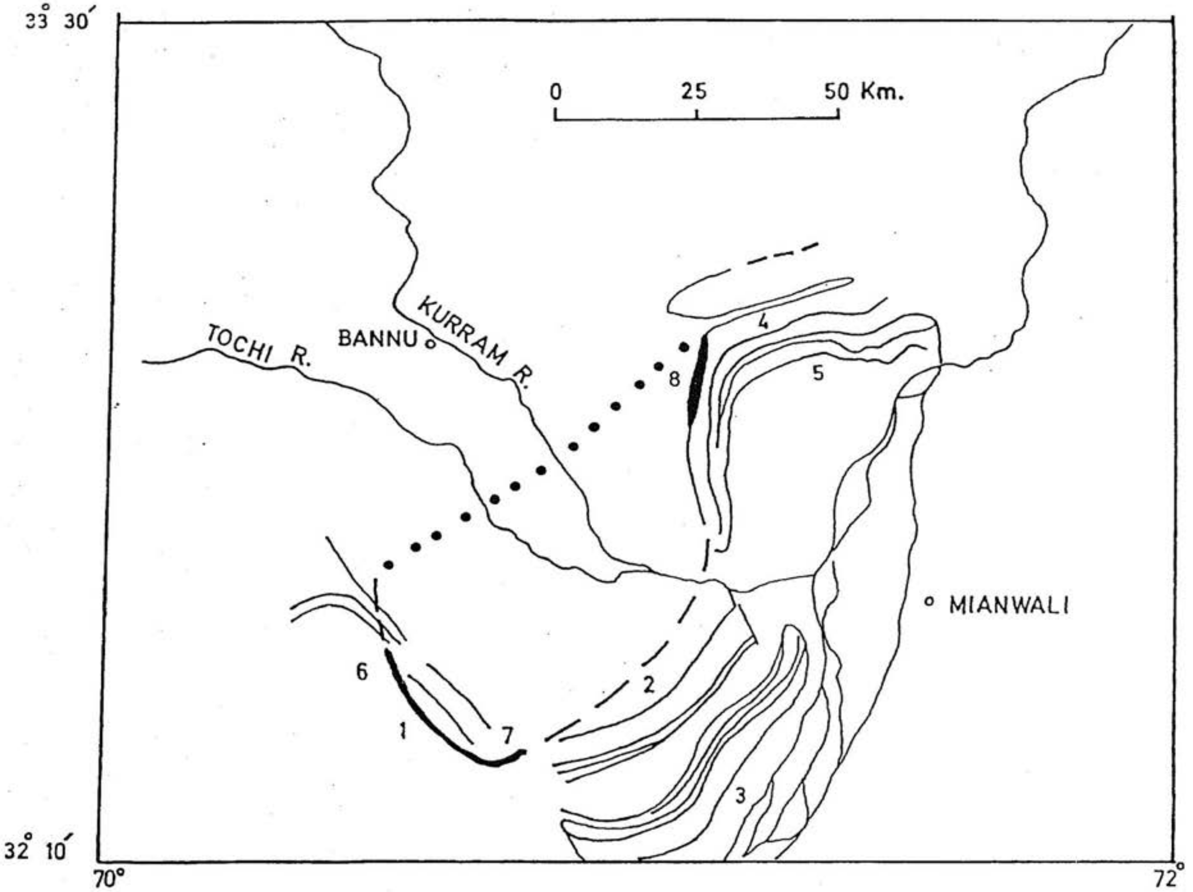

Figure 2. Schematic diagram of the Trans-Indus Salt Range in which the location of the Bain diamictite is shown by a heavy dark line. Large dashed line indicates the probable position where the Bain flow came to an abrupt stop at the edge of a gentle-gradient paleoplain. Small dotted line indicates possible termination upstream of Bain deposit. Explanation : 1 — Bhittani range; 2 — Marwat range; 3 — Khasor range; 4 — Shinghar range; 5 — Surghar range; 6 — Bain Pass and Garhi Landa; 7 — Pezu Pass and Sheikh Budin; 8 — Spalmi Tangi and Zarkai Tangi.

to differentiate it from the surrounding more friable units, and note its disappearance north of the type section. These characteristic features led Morris (1938) to differentiate it from the rest of the fluvial couplets, and to call it the "Bain Boulder-bed", with a type section in Bain Pass. We use the term "diamictite" herein instead of "Boulder-bed", in keeping with more modern terminology.

The Bain diamictite has a matrix-supported heterogenous lithology and clast size, with fragments ranging from boulders up to 1.5m in diameter to silt and clay matrix. This distinctive, resistant, cliff-forming unit is light gray, 10YR 7/1. Few sedimentary structures were observed throughout the extent of the outcrops visited, except for some polygonal cracks on an upper contact and a few large boulders towards the bottom in some places. Scratches on the larger fragments occur rarely and are not linear, as with glacial erratics. Slickensides occur with a variety of orientations in several localities; in one case a fault was clearly involved, in other cases the origin is less clear. Clasts of various sizes are randomly oriented from base to the top, and their lithology varies widely as well. The common sedimentary rock fragments include quartzites of various colors, fine- and coarse-grained graywackes, shales and mudstones, gypsum and anhydrite, and limestone. Among the igneous-rock fragments, those of granite, diorite, gabbro, serpentine, dolerite and basalt are present, along with genetically significant pumice fragments. The largest boulders are also volcanic and tend to be consolidated acidic pyroclastics. Metamorphic rock fragments are gneiss, mica schist, green and black slates, and jasper. Many of the pebble and cobble clasts of different lithologies are rounded to well rounded, reflecting a probable pre-diamictite fluvial origin. The fine-grained constituents are sand- and silt-sized quartz and feldspar grains that are mostly angular and suggest minimal abrasion during transportation. Thin sections show the presence of unaltered andesine and green hornblende.

The most abundant clasts in the unit are various sizes of limestone, followed by dark graywacke. The most diagnostic of transport direction are the clasts of mudstone, shale and slate, most of which are soft and fissle. The source of these friable fragments is reported to be the Jurassic and Cretaceous rocks of South Waziristan (Stuart, 1922; Coulson, 1937). The source of the brownish quartzite also lies in Waziristan (R.A.K. Tahirkheli, personal communication). Most of the limestone fragments are those of *Alveolina* Limestone brought down from the highlands of Afghanistan and Waziristan.

Careful observation of the various size grades of clasts of the same lithology shows gradation from boulder-sized fragments to sand- and silt-sized grains. The grains are not strongly cemented, but calcium carbonate present in the matrix acts as cement. This is in marked contrast to the sandstone of the surrounding Siwalik sequence that are cemented only weakly or not at all.

Except for the few basal boulders, clast size of this diamictite generally does not vary laterally or vertically. In the Bain Pass area occurs an underlying bed, 15–20cm thick, that consists of dominant clasts or moderate to well rounded pebbles with little fine matrix as has the main unit above. It is not clear whether or not this pebble layer is genetically associated with the Bain diamictite or is part of the underlying units. Other fluvial conglomeratic beds do occur elsewhere in the area. This underlying pebble bed is not present in the Garhi Landa section or in the vicinity of Pezu Pass (Fig. 2). Instead a dark grayish-green, less indurated unit forms the basal part of the diamictite at other outcrops. In some other exposures, lithology is uniform from base to top. At a few outcrops, thin stringers of ash occur discontinuously in the lowermost part of the unit.

The thickness of this diamictite varies from the Bain Pass to the Pezu Pass area. The maximum thickness, 15–20m, occurs near Bain Pass and the Garhi Landa sections (Fig. 2). Although within the extent of a single outcrop the trickness remains uniform, a lesser thickness of up to 5m occurs near the Sheikh Budin foothills. The lower and upper boundaries of the diamictite are smooth and planar. Scouring and channeling effects do not occur at any exposures examined. In some areas the diamictite overlies Siwalik channel sandstones, elsewhere it rests above finer overbank deposits.

Reported here for the first time, another diamictite unit of exactly the same lithology and other features discussed above is present amidst the Siwalik sequence measured at the Spalmai Tangi section in the Shinghar Range. The maximum thickness of the diamictite is 5m, and for a few kilometers to north and south of the Spalmai Tangi section, the thickness gradually decreases before terminating abruptly. Based on its similarites with the type Bain, it is evident that the two diamictites were deposited by the same process, had the same source, and are therefore correlated with each other.

AGE

The Siwalik sediments of the Trans-Indus Salt Range have been dated using the techniques of magnetic-polarity stratigraphy (Khan, 1983) controlled by age-diagnostic fossils and a date of 2.79±0.24 MYBP (Johnson and others, 1982) for an ash well below the diamictite. The Garhi Landa section in the Bhittani Range and the Spalmai Tangi section in the Shinghar Range were selected because these sections display the best exposures of the Bain diamictite. The results of the magnetic-polarity stratigraphy at both localities (Figs. 3 & 4) show that the diamictite unit occurs below the Olduvai Subchron. The Reunion Subchron was not observed in either of these sections. It is not certain, therefore, if these diamictite units were deposited before or after the Reunion Subchron. It appears, however, that the time of their deposition is within the range of 2.0–2.2 MYBP. The significant point from these dates is that in both of these sections, the same diamictite units occur at the same stratigraphic horizon. This suggests that the diamictite units of Bhittani and Shinghar Ranges were deposited at the same time. This greatly substantiates the conclusion that these units were deposited by the same process event and therefore had the same source.

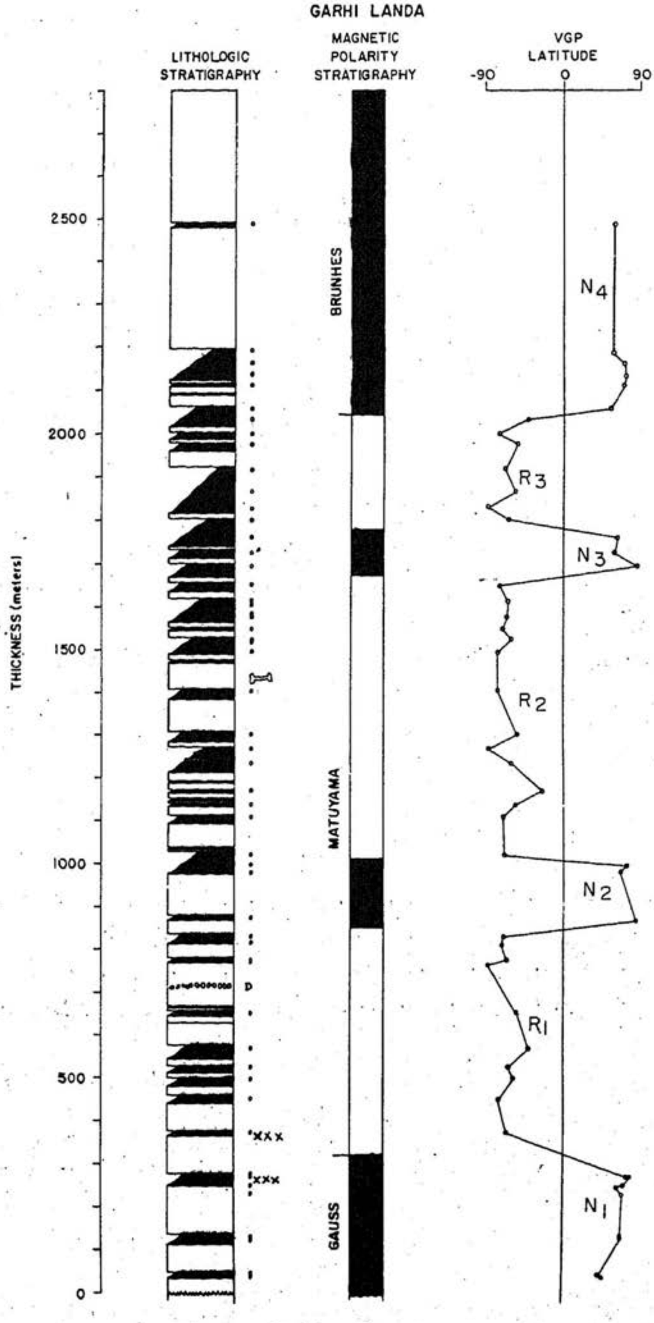

Figure 3. Plot of Virtual Geomagnetic Pole (VGP) positions versus stratigraphic thickness at Garhi Landa site in Bhittani range. The black (white) blocks in the lithologic stratigraphic column represent vertical accretion of siltstone/claystone (lateral accretion of sandstone) deposits in the molasse sequence. The boundaries of the magnetic-polarity reversals are placed at intermediate positions between two successive sites having opposite polarities. Black (white) zones of magnetic polarity stratigraphic column represent normal (reverse) magnetic polarities. The bone symbol on the right side of the lithologic stratigraphic column marks location of *Stegedon* fossils diagnostic of Plio-Pleistocene age. The letter D marks the Bain diamictite and the — xxx —marks ash beds.

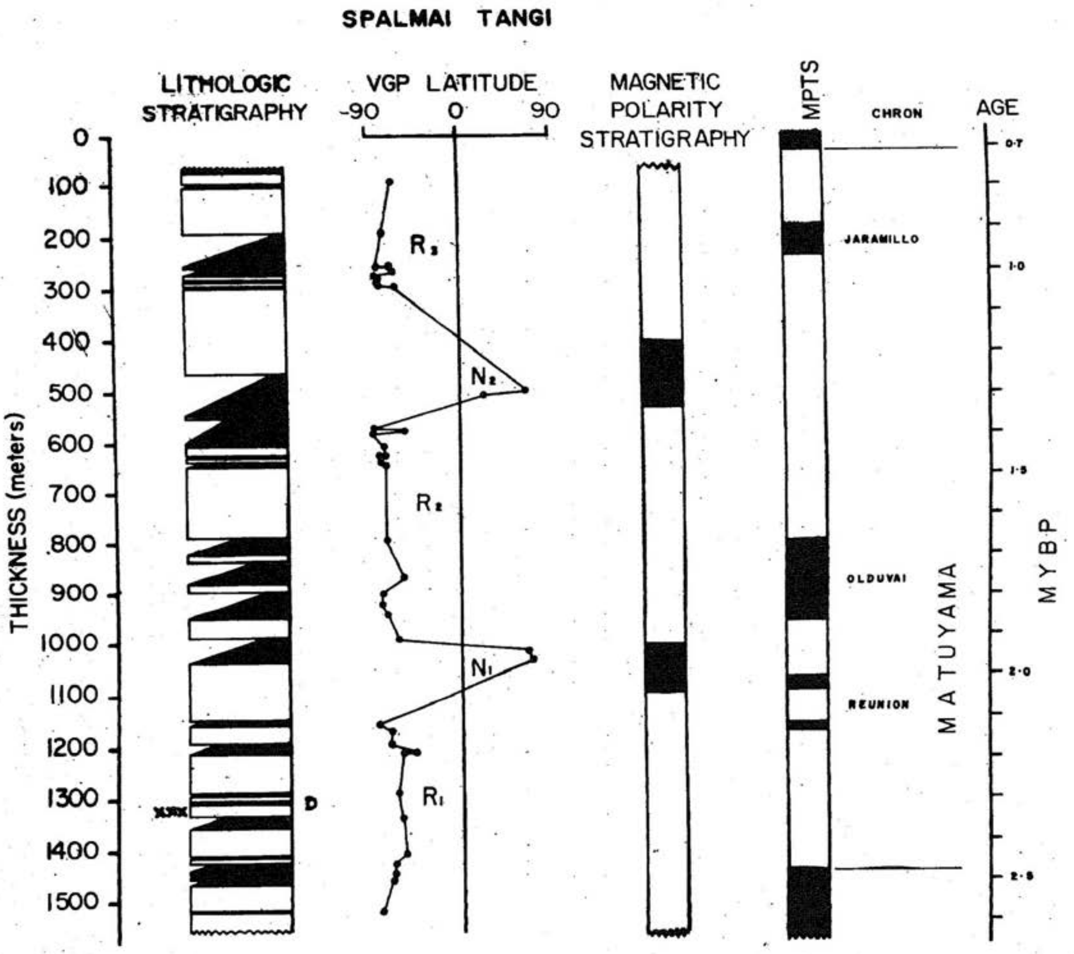

Figure 4. Plot of VGP latitudes versus stratigraphic thickness for Spalmai Tangi site in Shinghar range. Plotting conventions same as fig.. 3.

ORIGIN

Genetic differentiation between diamict deposits of various origins is well known to be a difficult task (Madole, 1981; Shroder and Sewell, 1981, and in press). Discrimination between deposits of varying antiquity is continuously attempted in Pakistan and many other places, with varying degrees of success (Derbyshire, 1984; Li Jijun and others, 1984). Processes prodcuing diamicts include glaciers, periglacial gelifluction, debris slide and flow, mud-rock flow, volcanic-lahar flow, and underwater turbidity currents. Methods attempted for differentiation include analysis of clast size and texture (scanning electron microscope), fabric, presence or absence of sedimentary structures, composition, paleomagnetism, and geomorphic context. The latter is commonly the most diagnostic if landforms survive, although some of the other parameters may be revealing in certain cases.

Many scientists of the late 19th and early 20th centuries commonly suggested a glacial origin for unsorted, unstratified deposits that were too widespread to be landslips, or not directly associated with volcanics. Although Morris (1938) assigned a non-genetic name to the "Bain Boulder-bed", he concluded that it was a tillite. The observations that led him to invoke a glacial origin were: (1) large variety of clasts; (2) absence of any sign of internal bedding; (3) absence of any sign of turbulent conditions of deposition, within and at the base; (4) occurrence of a few scratched boulders within the unit.

Although these features can be common to glacial deposits, they are by no means diagnostic. Similar features occur in debris-flow diamicts. Johnson (1965) reported the random orientation of clasts in a fine-grained matrix as an important feature of a modern debris-flow deposit. Johnson (1970) and Hampton (1972) suggested that within most debris flows laminar conditions prevail but orientation of clasts are random. Laminar flow is also indicated by the preservation of soft shale and clasts with fractured boundaries (Johnson, 1970). The preservation of soft and fissle fragments of mudstone, shale, slate and fractured boulders of limestone in the Bain diamictite is clearly the result of nonturbulent flow in a subaerial debris flow. An absence of scour marks is also characteristic of debris flows (Middleton and Hampton, 1973); no sign of scouring has been observed beneath the Bain diamictite.

Furthermore, there are other good reasons for believing that the Bain diamictite cannot be a tillite. Gansser (1964 p. 49–50) first suggested that the Bain deposits were more likely to be the product of cloud-burst generated, desert debris flow. He pointed out in particular that acceptance of the Bain diamictite as a tillite would indicate an early glaciation prior to the Siwalik orogeny. This would be before the main Himalayan uplift; a fact most difficult to explain, given the necessity of having a nearby glacierized upland to push a glacier down to the lowlands at about 500m altitude where the Bain deposits are located. The observations discussed above therefore suggest that the Bain diamictite throughout its extent is a debris-flow type of deposit. A special case of debris flows that has not been considered, heretofore, is the volcanic lahar. Evidence of a volcanic source is abundant, and includes fresh volcanic clasts, such as the largest boulders, and basal stringers of ash in a few places. Where uneroded, the top of the deposit shows a crude prismatic or columnar jointing that resembles the pattern produced on the surface of cooling and drying volcanoclastic deposits observed elsewhere. A number of other bentonitic ashes and a sandy tuff occur lower down in the section, testifying to explosive volcanism in the area. Further consideration of the characteristics of lahar types of deposition is therefore necessary.

Lahars originate in five main ways (Crandell, 1971): (1) displacement of crater or caldera lakes; (2) direct ejection of mud from a volcano; (3) avalanche of rock debris and temporary blockage of a river; (4) eruption of hot material beneath glaciers and snowfields on a volcano, or over extensive snowfields and ice adjacent to a volcano; (5) mobilization of loose pyroclastics by torrential rains generated from atmospheric instability associated with eruption clouds. Features commonly, but not everywhere, occurring in lahars are lack of internal stratification, crude size gradation from coarse to fine upward in places, irregular-shaped small air spaces in matrix, and propensity to flow as massive thick lobes down valleys without leaving much behind except as a thin veneer. Velocities may be as much as 85km/hr (Crandell and Mullineaux, 1978), although in the exceptional case of the lateral blast in 1980 that generated lahars at Mount St. Helens, Washington, supersonic initial velocities of 100m/sec occurred (Kieffer, 1981).

The lithology and sedimentologic relationships of the Bain diamictite are thus compatible with a lahar origin; the main remaining questions would be the possible volcanic source, and the probable exceptional size of the deposit. Recent work by French, German, and Russian geologists (Shroder, 1983) has delineated the large Dasht-i-Nawar caldera in nearby Afghanistan, which seems the most likely source in an otherwise nonvolcanic area, and it is known to have been active in Plio-Pleistocene time when the Bain diamictite was deposited.

The distance from the caldera across the Ghazni-Gardez plains and down the large Kurram river valley to the distal end of the Bain deposit is about 400km (Fig. 1). A more direct route through small breaks in the hills past Urgun and down the Tochi valley is about 300km. Of course, the topography at the time of deposition was likely to be much less tectonically disturbed, uplifted and eroded than now. The flow therefore may have been less impeded than would be the case today. In comparison with the probable distance of transport, one of the world's largest other known lahars, the Osceola from Mount Rainier, Washington, travelled about 100km.

At their proximal end near their volcano source, lahars erode and incorporate much loose material. Some lahars 60–80km from the source are over 50% other rocks picked up in transit. At their distal ends, however, lahars do not erode much at their base where they move mostly by laminar flow; shear is concentrated at the bottom with plugflow above. Crandell (1971) noted that it is as if lahars move forward as a rug is unrolled; the immobilized layer (the rug) then acts as a buffer zone immediately above the underlying surface to protect it from erosion. As noted above, the Bain diamictite exhibits these characteristics.

In some cases lahars are known to have a basal zone less than 30cm thick of vaguely stratified fine to coarse sand (Schmincke, 1967). Crandell (1971) noted beds of sand beneath many lahars but thought the beds were genetically related to the underlying sequence of fluvial deposits rather than to the lahar. The underlying pebble bed and basal less indurated part of the Bain unit seem to resemble these descriptions.

Comparison of other factors of the previously mentioned Osceola lahar to the Bain diamictite is also useful. The Osceola lahar covered an area of about 256km^2 with an average thickness of about 6m to produce a volume of about 2x10^9 m^3. In contrast, if we assume the ends of the Bain outcrop to be connected in the subsurface (dashed lines in Fig. 2), the area is about 2x10^9 m^2. With an average thickness of 15m, this gives a volume of about 30x10^9 m^3 or 15 times bigger than the Osceola deposit, and therefore perhaps the largest known lahar deposit in the world. Lest this seem an excessive estimate in comparison with the Mount Rainier example, it should be borne in mind that fundamental size differences occur between Rainier and Dasht-i-Nawar. For example, Rainier is a stratovolcano about 60km in basal diameter with a summit-crater source less than a kilometer in diameter, and smaller side vents, whereas Dasht-i-Nawar caldera itself is nearly the same size as the whole of Rainier. Also the Rainier summit is 439km altitude, and six of the many rim mountains of the caldera are over 4000m ,indicating that the original summit may have been much higher.

The roughly rectangular Dasht-i-Nawar caldera is about 35km EW and 70km NS, or about 2450km^2 in area. The floor of the caldera at about 3000m altitude is about 1000m below the surrounding peaks. Assuming an unlikely flat surface from peak to peak, the volume of space in the caldera now is about 2.5x10^9 m^3. This volume is about 12 times less than the suspected volume of the Bain deposit, but neglects considerable subsequent sedimentation into the closed basin of the caldera, and it also neglects a probable higher peak area. Volume expansion of the original bedrock and subsequent incorporation of material in transport have also been disregarded in the calculation. Adding only another 1000m altitude to the rim mountains of Dasht-i-Nawar produces a volume of about 25x10^9 m^3, in the same range as the possible volume of the Bain diamictite. If the deposit were not to be considered a lahar in spite of the evidence presented above, then one is faced with the more formidable task of explaining such a massive deposit as resulting from a cloud-burst generated debris flow.

CONCLUSION

The Bain diamictite thus appears to be the result of a catastrophic lahar event from Dasht-i-Nawar caldera in Afghanistan. Reasons for this conclusion can be divided into four categories with evidence of: (1) a debris- or lahar-flow origin; (2) a volcanic source; (3) a transport direction from WNW; and (4) the source as Dasht-i-Nawar in Afghanistan. The debris- or lahar-flow mechanics of transport are indicated by lack of basal scour, absence of internal sedimentary structure, some vertical size gradation with large boulders near the base, general lack of sorting or stratification, and possible drying cracks on the surface. The volcanic source is indicated by the basal ash stringers, the pumice clasts, and the possible cooling cracks. A transport direction from the WNW is indicated because of the rocks and regional slope down from Afghanistan, the ESE-oriented lobate shape of the deposit, and its abrupt termination before the Marwat Range to the SE. Finally, the Dasht-i-Nawar area is indicated as the only feasible volcanic source close enough and active at the right time to produce the deposit. Considerations of required volume relationships, sketchy as is the actual size of the Bain diamictite, are also about right.

Further work may provide even more definitive answers to the origin of the Bain diamictite. For example, scanning-electron microscopy may show fabric or grain textures and ash shards typical of lahars; comparison of clasts can be attempted with specimens known to have been collected at Dasht-i-Nawar by French geologists; and paleomagnetic analysis can be tried to determine whether the deposits was emplaced as a hot lahar above the Curie temperature, in which case the magnetism may be oriented rather than random as in the case of many other diamicts.

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