

The Talya Conglomerate: an Archean (~2.7 Ga) Glaciomarine Formation, Western Dharwar Craton, Southern India

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The ~2700 Ma Talya Conglomerate is comprised of 15 diamictites (i.e. matrix-supported conglomerates) interbedded with mudstone and sandstone units, and is interpreted as a glaciomarine deposit. The entire thickness of this conglomeratic member within the Vanivilas Formation, the lowest formation of the Chitradurga Group of the Neoproterozoic Dharwar Supergroup, is exposed in a 543 m-thick measured section. It is in a sub-vertical attitude, is highly sheared, and has undergone greenschist facies metamorphism. The diamictites had an original matrix of laminated mud/silt and fine sand. While including diamictites throughout, the Talya is a fining-upward sequence with intercalated sandstones dominant in its lower portion and mudstones dominant in its upper portion. We interpret that the Talya Conglomerate was deposited in a marine environment, with diamictites composed of ice-rafted detritus (IRD) deposited from icebergs calved from tidewater glacier tongues and/or possibly from ice shelves. In these ‘rainout diamictites’,

the larger clasts were dropped into fine-grained bottom sediment deposited by sediment plumes and currents. The source ice sheet was located to the west and southwest on a land mass that included the older than 2720 Ma Bababudan Group of quartzites and mafic volcanics and older than 3000 Ma basement of granitic/gneissic rocks. Application of Walther’s law indicates that the mudstone-bearing portion of the Talya was deposited upon the sandstone-bearing portion as the sea further inundated the land mass due to glacial retreat and a decrease in glacial mass, thereby resulting in the fining-upward nature of the Talya Conglomerate. We also interpret the lower portion of the Kaldurga Conglomerate, located 50–75 km to the southwest of the Talya, to be equivalent with the Talya. The Kaldurga contains mostly granitic basement detritus, perhaps exposed due to basement uplift related to isostatic rebound caused by glacial melting or due to tectonism related to westward subduction.

Keywords: Archean, diamictites, dropstones, Dharwar craton, glaciomarine deposit.

THERE is a dearth of evidence for glacial activity in the Archean rock record. There are only three documented Archean occurrences that include the association of diamictites and dropstone units, considered as essential field evidence for glacial deposits^{1,2}. One is in the ~2900 Ma Pongola Supergroup of South Africa³. Diamictites interpreted as possible glacial deposits in the likely correlative Witwatersrand Supergroup have been described by several workers^{4–9}, but without documented dropstone units. A second glaciogenic unit, based on the presence of both diamictites and dropstones, is in the footwall of the 2700–2710 Ma Stillwater Complex in Montana, USA^{10–13}. The third is ~2700 Ma diamictites with dropstones in the basal Chitradurga Group in the supracrustal belts on the Dharwar Craton, proposed as

glaciogenic by Srikantia¹⁴, and which are the subject of this study. A glaciogenic origin for a 2780 Ma volcanogenic sedimentary sequence in the Nnywane Formation in Botswana was proposed by Modie¹⁵, but because it is a thin volcanoclastic unit within a thick sequence of volcanic rocks, and because the dropstones are volcanic clasts, we think a glacial origin needs further study.

We re-examined the conglomerates that were studied by Srikantia¹⁴, who proposed a glaciomarine origin for the Talya and some other conglomerates (Figure 1). Indeed, our work found convincing evidence of a glaciomarine origin. In this article, we provide data for the Talya Conglomerate and the lower portion of the Kaldurga Conglomerate, which we consider as equivalent because of a similarity in depositional style. In a later paper, we will integrate these data with additional information on conglomeratic rock units of other supracrustal belts of the Dharwar Craton. The findings recorded here from the Talya Conglomerate assume major significance, as they document another glacial episode on the Earth between

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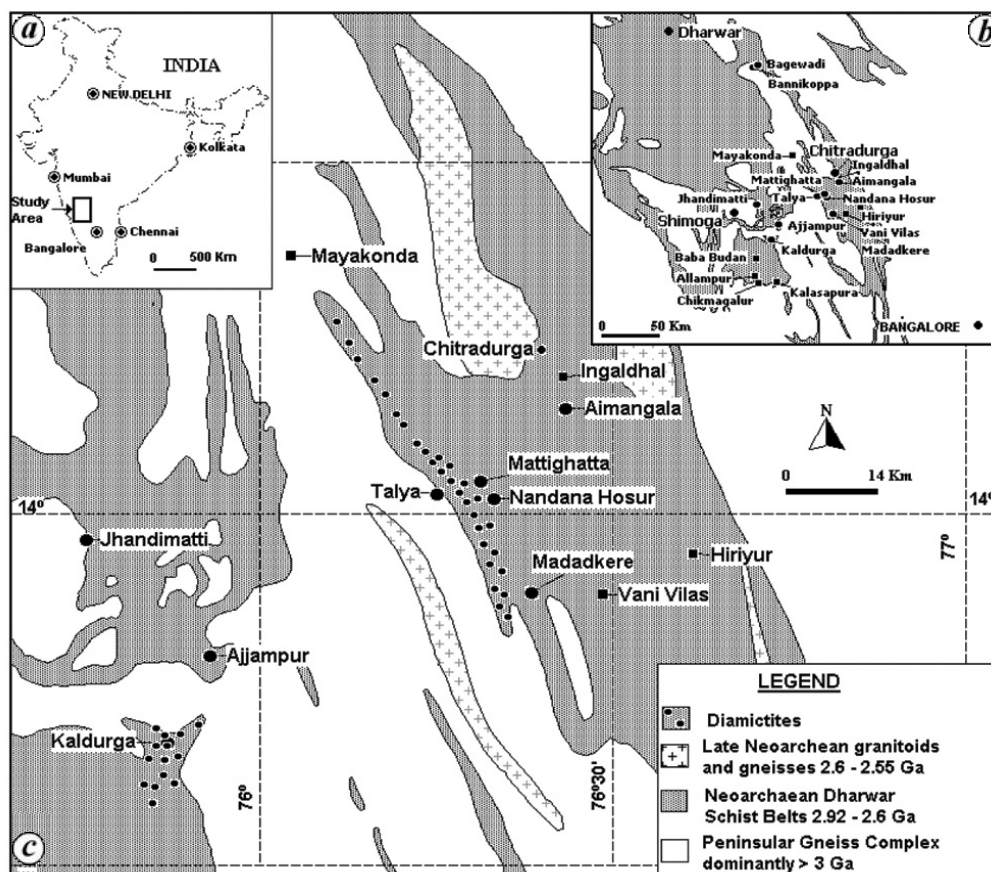


Figure 1. Map of the Western Dharwar Craton showing the Talya and Kaldurga conglomerates. *a*, Location of the Western Dharwar Craton in India. *b*, The Bababudan, Dharwar, Shimoga and Chitradurga schist belts in which the glacial diamictites occur. *c*, Distribution of Talya Conglomerate close to the western margin of Chitradurga schist belt between Mayakonda and Madakkere. Detailed observations were done west of Mattighatta and Nandana Hosur; the measured section shown in Figure 2 is to the west of Nandana Hosur.

the presently known ~2900 Ma Pongola and ~2400 Ma Huronian glaciations.

Regional geology

In the Dharwar Craton of the southern Indian shield, a 2910–2610 Ma Neoproterozoic volcano-sedimentary sequence constituting the Dharwar Supergroup (SG) accumulated on 3360–3000 Ma tonalite gneiss–granodiorite basement. The Dharwar SG was invaded by 2600–2500 Ma granitoids^{16–19}.

The craton consists of two parts – the Western Dharwar Craton (WDC) and the Eastern Dharwar Craton (EDC). The basement for the Dharwar SG is preserved in several places in WDC. However, due to juvenile granitic intrusions and strong reworking of the basement between 2600 and 2500 Ma, the basement–cover relationships between the Mesoproterozoic gneiss–granite basement and the Neoproterozoic Dharwar volcanic and metasedimentary rocks have been erased in the EDC.

The Dharwar SG is divided into the Bababudan Group and the younger Chitradurga Group²⁰. A simplified

lithostratigraphy is shown in Table 1. Volcano-sedimentary sequences of both the Bababudan and Chitradurga groups are preserved in the supracrustal belts of WDC. The age of the Bababudan Group is constrained by the 2910 Ma Sm–Nd isotopic age of metabasalts of the Kalasapura Formation close to the base of the Group²¹ and a 2720 Ma U–Pb SHRIMP zircon age from felsic volcanoclastic rocks that are interlayered with BIF of the Mulaingiri Formation at the top of the group²².

The maximum age for the Chitradurga Group that overlies the Bababudan Group is not known because there are no age determinations for the oldest unit, the Vanivilas Formation, which includes the conglomerates of this study. The metabasalts of the middle unit – the Ingaldhal Formation – have yielded a Sm–Nd isochron age of 2750 Ma (ref. 21), and felsic volcanics of the same formation yielded a 2610 Ma SHRIMP U–Pb zircon age²³. The Dharwar SG was invaded by 2600–2500 Ma granitoids (Chardon *et al.*¹⁸ and references therein). Thus, the age of the Talya and the other conglomerate members of the Vanivilas Formation is between 2720 and 2610 Ma.

Table 1. Generalized stratigraphic column of the Western Dharwar Craton. Note that the Talya and Kaldurga conglomerates are basal members of the Vanivilas Formation of the Chitradurga Group

		Younger gneisses and granitoids (2.6–2.5 Ga)
Dharwar Supergroup Chitradurga Group	Hiriyur Formation	BIF Greywacke, interbedded volcanic tuff
	Ingaldhal Formation (2.75–2.61 Ga)	BIF, largely sulphidic Intermedite to felsic volcanic rocks and tuff Pillow basalt
	Vanivilas Formation	Stromatolitic cherty dolomite, limestone, shale BIF/BMF Polymictic conglomerate*
	Mulaingiri Formation (2.72 Ga)	Disconformity BIF interbedded with felsic tuff near the base, graphitic schist
	Santaveri Formation	Rhyodacite Basalt
Bababudan Group	Allampur Formation	Quartz arenite Gabbro, pyroxenite, basalt
	Kalasapura Formation (2.91 Ga)	Quartz arenite interbedded with amygdaloidal basalt Quartz arenite Quartz-pebble conglomerate
		Nonconformity Gneisses and granitoids with some older supra-crustal rock inclusions (3.0–3.36 Ga, possibly older than 3.5 Ga)

*The Talya and Kaldurga conglomerates belong to this stratigraphic horizon.

Previous work

At the base of the Bababudan Group, there are quartz-pebble conglomerates and quartz arenites that have been interpreted as (reworked?) braided fluvial plain deposits that accumulated *ca.* 3000–2900 Ma on 3360–3000 Ma peneplaned gneiss–granite basement²⁴.

At the base of the Chitradurga Group is a suite of polymictic conglomerates, the origin of which has long been debated. These conglomerates in the supracrustal belts of both WDC and EDC are shown in Figure 1. Smeeth²⁵ considered them to be autoclastic. Pichamuthu²⁶ and Rama Rao²⁷ proved their sedimentary origin, based on sedimentary structures including cross-bedding and graded bedding. Pichamuthu²⁶ suspected that the Kaldurga Conglomerate might be a glaciofluvial deposit. Nautiyal²⁸ proposed that they are tilloids. Srinivasan and Sreenivas²⁹, Naqvi *et al.*³⁰, and Srinivasan and Naha³¹ considered them to be greywacke conglomerates deposited in a geosynclinal environment. Ziauddin^{32,33} considered most of these conglomerates to be volcanic agglomerates. Chadwick *et al.*^{34–36} considered them to be submarine debris flow deposits.

Srikantia¹⁴ interpreted the Talya and some other units as glaciomarine diamictites. His suggestion did not receive general acceptance, as evidenced from the following sentence in Ramakrishnan and Vaidyanathan³⁷: ‘There were intermittent suggestions that the conglomerates may be glacial or fluvio-glacial in origin, but substantial proof is yet to come’. His paper is not referred to, nor are other papers that he cites alluding to a glacial origin. Mishima *et al.*³⁸ suggested a possible glacial origin for the Talya, but provided no evidence.

Field observations

The Talya Conglomerate in our measured section at Nandana Hosur encompasses the entire unit and consists of 543 m of rock plus a 42 m covered interval (Figures 1 and 2). The section was exposed during construction of an access road to wind turbines on an adjacent ridge; the road is roughly perpendicular to the strike of the Talya Conglomerate. It includes 15 diamictites (i.e. pebbly mudstones) ranging in thickness from 1 to 57 m (average 13.4 m) and which constitute 37% of the rock column (Figures 2 and 3).

The lower 234 m of the measured section includes seven diamictites separated by sandy/silty units (Figure 4), whereas the upper portion includes eight diamictites generally intercalated with muddy/silty units; the transition is usually gradational. Ten fine-grained sandy/silty units range in thickness from 2 to 37 m (average 11 m) and constitute 20% of the rock column. Eleven muddy/silty units (prior to metamorphism) range in thickness from 2 to 87 m (average 21 m) and constitute 43% of the column. These three major lithologies, upon close inspection, contain laminations of sand, silt and mud (Figure 5).

The Talya Conglomerate can be traced over a strike distance of about 55 km from Mayakonda in the north to Madadkere in the south (Figure 1). Because of its near-vertical dip, the width of outcrop approximates its apparent post-tectonic thickness.

We see no evidence in the Talya of either nearshore or slope deposits, such as debris flow noses, rafts of slumped sediment, tunnel valleys, eroded channels, gravelly beds, turbidite sequences, striated boulder pavements, bioturbation, hummocky cross-stratification, or pebble lags due to

winning. That is, we do not find a complex of variable sedimentary features that would indicate a grounding line of a floating glacier or the nearshore zone of tidewater glaciers. In our measured section, we saw no graded beds and only two cross-bedded sandstone beds.

There are several glacial indicators present in geologically younger undeformed sequences that would not be recognizable in the tectonized Talya. These include bullet-shaped boulders, gouges created by iceberg grounding (iceberg turbation), primary clast orientation (e.g. vertical clasts), convoluted beds and soft-sediment deformation features such as flame structures, water-escape

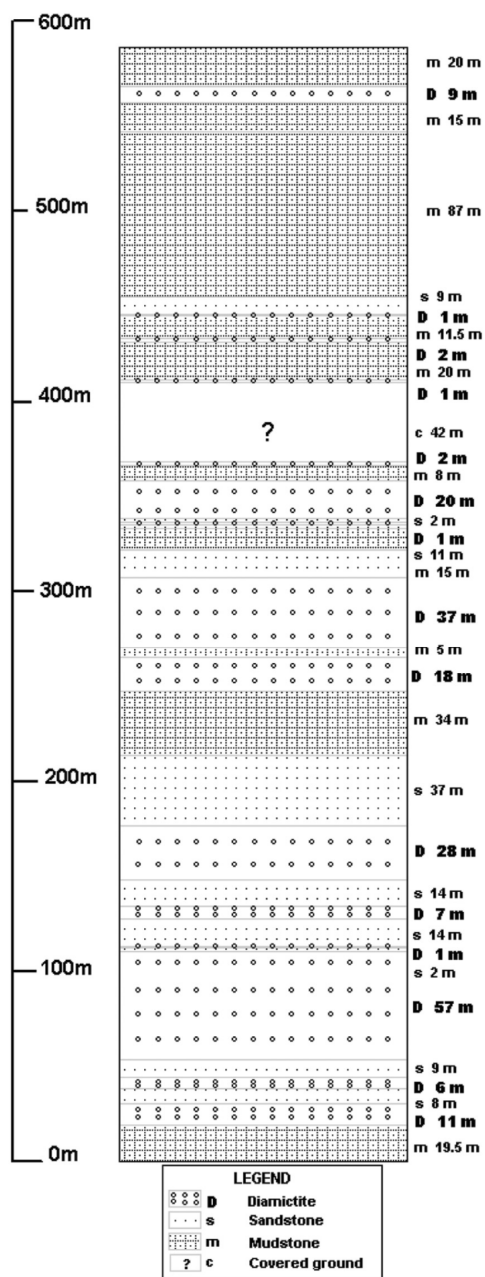


Figure 2. Composite measured lithologic column at Nandana Hosur. Three lithologies are present – diamictites (circles), sandy units (dots), and muddy units (squares with dots in the centre).

structures, rip-ups or clastic dikes. However, a few pebble nests (clast clusters) that likely originated by sediment dumps from overturned icebergs are still clearly visible (Figure 6).

Petrography

Field counts and measurements of clast size and lithology and the amount of matrix between clasts in two Talya diamictites and three lower Kaldurga diamictites were made by making a series of chalked line traverses a set distance apart on the outcrops, perpendicular to the bedding (Table 2). A total of 549 clasts were counted in 46 m of traverses. Note that quartzite is the dominant clast lithology in the Talya (~100% of clasts at Nandana Hosur, our measured section), whereas granite is dominant in the upper Kaldurga. Also present as rare clasts that were not intersected by the traverse lines are quartz-pebble conglomerate, dolomite, black chert, gneiss, pegmatite, banded iron-formation, mafic schist and vein quartz.



Figure 3. Typical diamictite. Location: Nandana Hosur measured section.



Figure 4. Sandstone unit gradational with overlying diamictite. Location: Nandana Hosur measured section.

Table 2. Abundance of clast lithologies and matrix

	Talya			Kaldurga	
	Nandana Hosur	Mattighatta	Shivapura	Mundre	Gollarahalli
Quartzite (%)	25	5	0	7	0
Granite (%)	0	4	31	25	19
Mafics (%)	0	0	5	3	0
Felsics (%)	0	4	0	0	0
Matrix (%)	75	87	64	65	81
Clast percentage of all clasts					
Quartzite	100	38	0	20	0
Granite	0	33	86	73	100
Mafic volcanics	0	0	14	7	0
Felsic volcanics	0	29	0	0	0

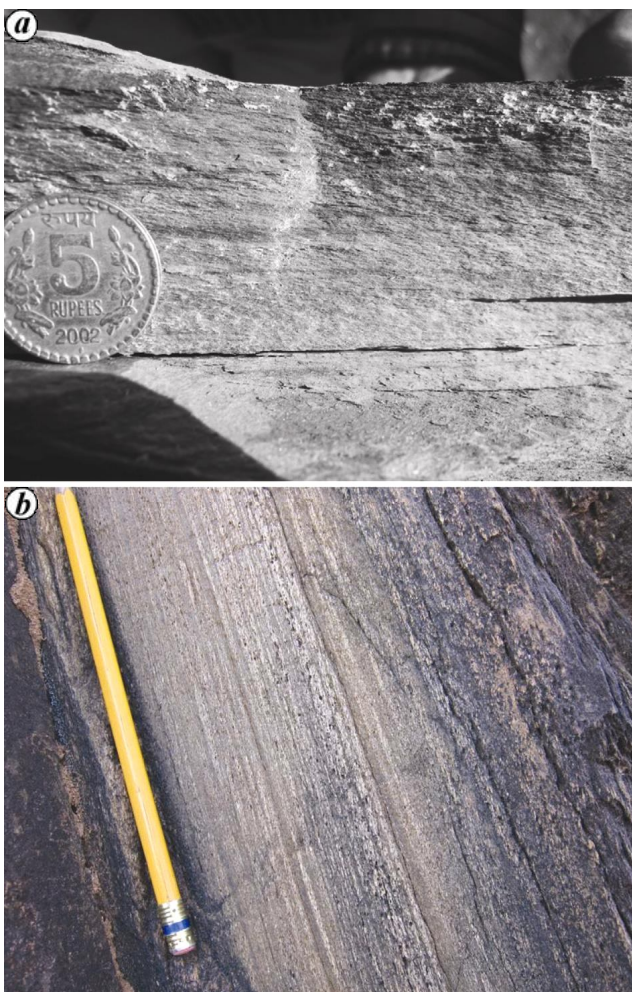


Figure 5. Intercalated muddy (dark) and sandy (light) laminae. Note in *a* that bedding/laminae are preserved in spite of superimposition of cleavage. Location: Nandana Hosur measured section.

Twelve thin sections of diamictite matrices, four of sandstone beds and two of mudstone beds were studied. The matrix samples are composed of mud laminae inter-

calated with laminae of silt and/or sand. The original clayey fractions have been metamorphosed to muscovite, biotite and chlorite. The silt-sand fractions are predominantly quartz; also present are minor plagioclase, chert, intermediate volcanic fragments and greenstone rock fragments. One sandstone bed in the Talya is an arkose with abundant K-feldspar; the other three are quartzose arenites with some volcanic quartz grains and volcanic rock fragments. Minor carbonate is present in most samples.

Geochemistry

Nesbitt and Young^{39,40} defined the chemical index of alteration (CIA) using molecular proportions as follows

$$\text{Al}_2\text{O}_3 / (\text{Al}_2\text{O}_3 + \text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O}) \times 100. \quad (1)$$

If the CIA values are low (e.g. less than 55, similar to unaltered bedrock), they indicate little removal of the labile oxides and therefore little chemical weathering. If the values are high, as in the 80s or 90s, they indicate the removal of labile oxides, probably during subtropical/tropical weathering. The CIA values for seven samples of the Talya and the lower Kaldurga range between 45 and 67, indicative of glacial flour in a cold climate. Sands generally show lower CIAs than associated shales, and a grain-size control on CIA is therefore evident. If sediment has had a previous history of weathering and fluvial transportation before it was transported by glaciers, the glacial deposits may have somewhat higher CIA values. Post-depositional K-metasomatism during diagenesis or metamorphism will bring down the CIA values relative to the pre-metasomatic CIA values⁴¹. We examined the CIA values of schistose (metamorphosed muddy) and granular (metamorphosed sandy) matrices of the Talya and Kaldurga conglomerates, and interbedded sandstones and mudstones as well, keeping in mind these restraints. There is a depletion of calcium and sodium, but K₂O

contents of 3.4–5.3% in some samples result in lower CIA values and indicate post-depositional metasomatism. We attribute the higher CIA values to the recycling history of Bababudan Group sedimentary rocks and also to pre-glacial weathering and fluvial transport. Therefore, while applying the CIA as a criterion for glacially deposited lithologies, one has to exercise considerable caution.

The dominance of quartzite clasts in the Talya and the lower Kaldurga shows derivation from a pre-existing supracrustal cover, whereas derivation of sediment from a basement granitoid source (TTG) is indicated for the upper sections of the Talya and especially of the upper Kaldurga.

Tectonic and metamorphic overprint

Identifying primary sedimentary features characteristic of glacial deposits (e.g. dropstones and polished and striated



Figure 6. Pebble nest (clast cluster) in a sandstone unit beneath a diamictite unit. Tip of walking stick for scale. Location: Nandana Hosur measured section.



Figure 7. Quartzite dropstone in diamictite. Stratigraphic top is upward in the photograph. Location: Nandana Hosur measured section.

surfaces on faceted clasts) obviously requires great care in deformed and metamorphosed sequences such as the Talya. Clasts of different rigidities and aspect ratios set in a ductile matrix may exhibit different senses of rotation and the schistose matrix may have flowed around the clasts, mimicking dropstone-like features. Slickensides on clasts may be misinterpreted as glacial striations and tectonic polishing may mimic glacial polish.

The conglomeratic formations at the base of the Chitradurga Group of the Dharwar SG have been affected by regional, open to isoclinal folding and greenschist facies metamorphism, and in some places, strong shearing as well^{16,42}. However, we are confident that our measured section of the Talya Conglomerate, although sheared, does not include any repetition of the section; only rare minor folds were observed. Tectonism has obviously compressed the formation; we estimate that ‘shortening’ could be 50% or more. This emphasizes the point that this is a very thick unit of diamictites with interbedded mudstones and fine-grained sandstones.

The Talya is exposed close to the western margin of the Chitradurga schist belt and constitutes the long limb of an S-shaped fold with a N–S to NNW–SSE axial plane trace (Figure 1). The hinge zone exposed north of Madadkere shows axial plane foliations at right angles to bedding. Axial plane foliation in the Talya is defined by muscovite, biotite and chlorite. Lineation is defined by stretched pebbles and schistose striping. The foliation in schistose matrix swerves around the pebbles and boulders. In some places where the aspect ratios of the boulders are large and where the boulders are at a high angle to the foliation, even the boulders and pebbles have been somewhat folded. Development of fibrous quartz and chlorite in the pressure shadow areas of deformed pebbles is locally observed. A major sinistral shear close to the western margin of the Chitradurga schist belt, designated as the Mayakonda shear, has also affected the conglomerate.

We have closely examined the Talya for glacial aspects, fully aware of the limitations imposed by the above difficulties. In spite of the deformation and metamorphism, most of the exposures preserve primary laminae of intercalated mud/silt and fine sand (Figures 5 and 6). Most clasts could be called lonestones. The pervasive shearing commonly made it difficult to ascertain whether these clasts are true dropstones, with a penetration or bowing down of the underlying sedimentary laminae and a draping upward of the overlying laminae. Therefore, in the identification of true dropstones, we tried to make sure that we were looking at primary laminations and not ‘pseudo-laminations’ or ‘shear banding’ generated by the schistosity. We identified several authentic dropstones in every exposure (Figures 7–9).

Many cobbles and boulders are tectonically striated. Whenever we observed rare striated clasts with obviously different orientations of striations compared to those in nearby clasts, we assumed they could be glacial striations.

We then measured tectonic lineations at those exact spots to make sure that the striations were indeed not parallel to the prevalent tectonic lineations (Figure 10). Some clasts are faceted. The recognition of faceted clasts requires 3D observations; flat surfaces seen only in profile may simply represent original fractures.

Evidence for glaciomarine deposition: comparisons from the literature

We did a modestly comprehensive search of the literature on glacial and glaciomarine deposits and their attributes. Especially useful reviews were those by Crowell², Molnia⁴³, Anderson and Ashley⁴⁴, Eyles *et al.*⁴⁵, and Eyles and Eyles⁴⁶.

The present-day glaciers of Antarctica do not provide a valid comparison for the Talya glaciation, as cold-based (polar) glaciers and their generally clean icebergs do not yield much detritus due to the lack of a basal meltwater

(i.e. warm-based) system^{47,48}. Hambrey and Harland⁴⁹ emphasized that deposition from tidewater glaciers is more important than from ice shelves, which largely record the accumulation of snowfall.

In contrast, sub-Arctic glaciomarine sediment in the Gulf of Alaska is voluminous^{50,51}. The average Holocene sedimentation rate of clayey-silt (rock flour) in the Gulf of Alaska is 4.5 mm/year; most is deposited by suspended sediment plumes on the mid- to outer-shelf, but some is deposited beyond the continental margin⁴⁸. The overall sedimentation rate is highest during deposition by underflow currents or grain flows (depositing silty sand), whereas flocculation and settling from turbid overflow and/or interflow plumes deposit the muddier sediment. A decrease in the abundance of silty sand can be related to diminished meltwater due to a receding ice front⁵².

Today, no icebergs are found beyond the fjord mouths of Alaskan tidewater glaciers, but studies of sediment on the modern floor of the northwestern Pacific show that IRD was transported for distances as far as 2500 km from the source tidewater glaciers, and much is deposited within 1000 km (refs 53, 48). Pulses of IRD found in short cores in the North Atlantic ('Heinrich events') are attributed to periods of iceberg development due to pulsating glaciers of northeastern North America during the past 130,000 years^{54,55}. MacAyaal⁵⁶ referred to this as the 'binge-purge model' (i.e. build up and destabilization) of the Laurentide ice sheet. In general, the coarser sediments in Heinrich layers are much finer-grained than those in the Talya, but that is likely related to the small diameter of the studied North Atlantic cores.

The glaciomarine Late Cenozoic Yakataga Formation deposited over the last 20 m.y. along the Gulf of Alaska is a good analogue for the Talya. Onshore and beneath the Holocene sediment of the Pacific floor off Alaska, the 5-km thick formation is largely comprised of a compacted

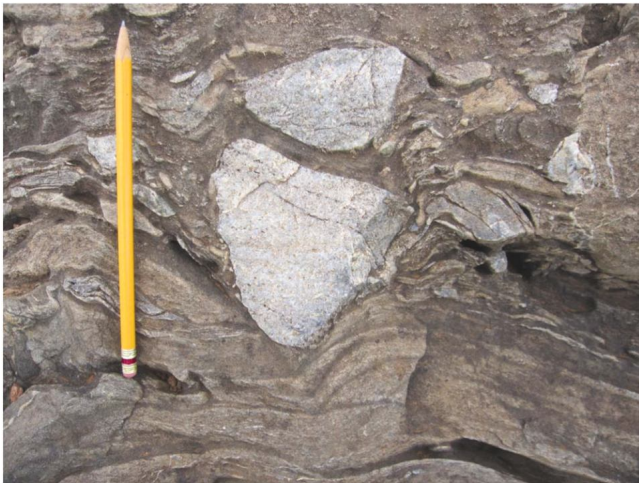


Figure 8. Quartzite dropstone in diamictite. Stratigraphic top is upward in the photograph. Location: Nandana Hosur measured section.



Figure 9. Quartzite dropstone in diamictite. Stratigraphic top is upward in the photograph. Location: Nandana Hosur measured section.



Figure 10. Glacially striated granitic clast beneath the lower pencil. The lower pencil is parallel to the striations, whereas the upper pencil is parallel to the steeply plunging tectonic lineation. Location: Nandana Hosur measured section.

sequence of clayey-silty sediment with interbedded diamictites^{48,57}. The blanket-type diamictites (with angular to rounded IRD constituting 5–20% by volume) are as thick as 200 m, but are commonly only tens of metres thick. They constitute as much as 86% of a measured section on Middleton Island⁵⁷. A total of 35 diamictites were documented in a 1.25 km-thick section on Middleton Island, Alaska⁴⁵. Coarse sediment, other than IRD, was deposited near fjord outlets. The Yakataga was deposited in a convergent plate margin setting.

Another good analogue is the Neoproterozoic Port Askaig Formation of Scotland and Ireland. It is as thick as 850 m, can be traced for 700 km, contains 47 diamictites and has been interpreted as representing 17 glaciations⁵⁸. The Neoproterozoic Mineral Fork Tillite of Utah contains 28 diamictites of both terrestrial and glaciomarine origin in a 900 m-thick column⁵⁹. The Paleoproterozoic Ukkavaara Formation in the Jatulian Supergroup of Finland⁶⁰, the Late Paleozoic Whiteout Conglomerate of the Ellsworth Range, Antarctica⁶¹ and the Late Paleozoic Buckeye Formation in the Ohio Range of Antarctica's Transantarctic Mountains⁶² also provided useful analogues and contrasts.

Discussion

Glaciomarine sequences on modern high-latitude continental shelves are typically thick, in excess of a kilometre⁴⁷. The Talya, while not that thick, nevertheless totals >500 m after tectonic compression. Thick glaciomarine deposits are best preserved along subsiding coastlines, or perhaps in subsiding intra-cratonic basins. Logically, preservation is more likely in deeper parts of a glaciomarine environment.

The Talya has a uniform lithofacies along its entire 55 km lateral trace, suggesting a fairly widespread area of uniform sedimentation. The correlative lower portion of the Kaldurga Conglomerate that is present 50–75 km to the southwest of the Talya, is similar to the Talya. This indicates that the area of glaciomarine diamictite deposition was quite broad.

Do the 15 diamictites each represent a distinct glaciation event, or simply minor fluctuations in the basinward advances of ice tongues and associated calving of icebergs? Clearly, the numerous sandy and muddy units intercalated with the diamictites reflect variable intervals of a reduced supply of IRD. Similarly, do the thicker non-diamictite sandy and muddy units represent actual interglacial epochs?

How many years of glaciomarine sedimentation does the Talya represent? We can only arrive at a *very* crude estimate by making a comparison with modern/Holocene average depositional rates of rock flour in the Gulf of Alaska, using the average rate of 4.5 mm/year reported by Molnia⁴³. Using the present thickness of the Talya in

our measured section – 543 m – gives a duration of about 118,000 years. If we assume the original pre-deformational thickness was twice what it is today, that number obviously doubles to ~236,000 years. This is roughly comparable to the combined Illinoian–Wisconsinian, the last two glacial advances of the Pleistocene in North America. A study of DSDP cores from Site 178 in the Gulf of Alaska southeast of Kodiak Island showed that the top 270 m consists of grey mud with ice-rafted erratics as large as 20 cm (ref. 63). The rate of sedimentation in the portion of the core younger than 1 m.y. (dated by diatoms and foraminifera) is 70–180 m/m.y. and for the lower portion (between early Pleistocene and earliest Miocene) it is 30 m/m.y. Based on these figures, and assuming the Talya was originally ~1000 m thick, the duration of Talya deposition may have been as long as 3–14 m.y.

We cannot speculate on the relative importance of glacio-isostatic and glacio-eustatic sea-level changes. The fining-upward nature of the sequence could be due to glacial retreat and therefore less access to coarser sediment. A glacial retreat might cause post-glacial rebound (isostatic emergence) in the source region and thus a seaward movement of the shoreline and access to coarser sediment. It seems likely that the Talya was deposited in a more distal, seaward location where a retreat of an ice sheet would not cause an influx of coarser sediment.

Conclusions

1. The Talya Conglomerate and the lower Kaldurga are interpreted as a glaciomarine unit deposited on a marine shelf (or possibly on the slope/abyssal plain) by rainout of iceberg-rafted coarse detritus (the IBRD of Powell⁵¹) and suspension settling of fine sediment, all derived from tidewater, wet-based glaciers likely emanating from a continental ice sheet. A mountain glacier source, as suggested by Srikantia¹⁴, is also a distinct possibility, with Holocene glaciation of Alaska as a comparative example.

2. Much erosion occurred in the source areas and unconsolidated glacially eroded sediment was likely derived from older stream deposits of rounded clasts. This coarse fraction, as well as rock flour generated by glacial scouring, was transported by glaciers to the shoreline of the marine basin. The fine sediments were then transported seaward by plumes of suspended sediment and bottom currents. Laminations resulted from episodic bottom currents, but where such currents were absent, the result was more massive beds.

3. The Talya is a fining-upward sequence, in that the sedimentary units between diamictites in the lower portion of the units are mainly fine-grained sandstones, whereas in the upper portion they are dominantly mudstones. Application of Walther's law suggests that the mudstone-bearing portion of the upper Talya was

deposited upon the sandstone-bearing portion as the sea further inundated the land mass due to glacial retreat and a decrease in glacial mass. This resulted in deposition of muddy sediment farther out to sea and the fining-upward sequence.

4. The considerable thickness of the Talya may indicate that it was deposited near an area of maximum crustal depression (i.e. relatively near the centre of ice accumulation).

5. Repeated calving cycles from tidewater glaciers as the ice sheet advanced seaward likely produced repeated increases in the abundance of icebergs and IRD. Changes in current or wind directions could also have affected the local abundance of icebergs and IRD.

6. Because of the considerable thickness of the Talya (>500 m), we favour the probability of a marine rather than a lacustrine environment of deposition.

7. Due to the abundance of coarse IRD-rich units throughout the Talya, shore ice was ruled out as a significant depositional agent.

8. The Allampura Formation of the Bababudan Group was the source of the abundant quartzite clasts and less common mafic clasts; the Kalasapura Formation of the Bababudan Group provided few clasts of quartz-pebble conglomerate, and the basement complex provided the granitic clasts of the Kaldurga Conglomerate, as noted by Srikantia¹⁴. Erosion of granitic basement detritus could be the result of basement uplift related to isostatic rebound caused by glacial melting, or perhaps by tectonism related to subduction.

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