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Glacigenic Diamictons – A Rationale for Study

The Glacial Drifts … are known to us all but too well. We cannot escape them; their clays, their sands and gravels confront us at every turn, so masking the underlying rock that they are a positive curse to the 'solid' geologist.

Carruthers (1947–48, p. 43)

The process sedimentology of tills is crucial to the understanding of the glacier ice–bed interface as a complex depositional, erosional and shear boundary layer. Consequently, it also plays a central role in deciphering the genesis of enigmatic subglacial bedforms such as drumlins, flutings and ribbed terrain. Yet, unlike the study of other boundary layers such as those that operate at the bed of fluvial, aeolian and deep water systems, our knowledge of subglacial process–form relationships is relatively impoverished, largely due to the inaccessibility of glacier and ice sheet beds. Notwithstanding the important contributions now being made to this research problem by remotely sensed and localised borehole observations as well as reductionist laboratory experiments, it is critical that glacial scientists continue to refine their interpretations of ancient archives of subglacial processes, specifically those that are represented by tills and associated deposits, as these archives form the most widespread and accessible record of processes at the ice–bed interface (Figure 1.1).

Such an inductive approach to the reconstruction of former subglacial processes has some considerable shortcomings, largely because it relies on actualist principles that are in turn based on process–form relationships that we cannot as yet unequivocally validate. This often has been compounded by the glacial geomorphology literature, wherein the traditional, uncritical acceptance of thick sequences of diamicton as 'lodgement tills' has assumed a definitive knowledge of process–form relationships even though that knowledge base is far from definitive. This has been exposed more recently in the apparent incompatibility between modern process measurements (indicating thin subglacial deformation/till construction) and ancient glacigenic sequences interpreted to contain often very thick subglacial tills. Moreover, the existence of ambiguous diagnostic criteria for identifying processes of subglacial sedimentation in ancient diamictons does not inspire confidence in the glacial research community when turning to till sedimentology for some guidance!

What we can now be confident in espousing are the concepts of debris entrainment and transport pathways together with concomitant clast modification within the glacial debris cascade (Figure 1.2). Till sedimentology should reflect the nature of the debris cascade, or more specifically: (1) the entrainment and transport history; (2) the continuum of clast modification during various phases or repeat cycles of transport and deposition; (3) the debris release processes and (4) any secondary displacement processes such as deformation. Glacial systems are complex in that these three aspects of the

Till: A Glacial Process Sedimentology, First Edition. David J A Evans.

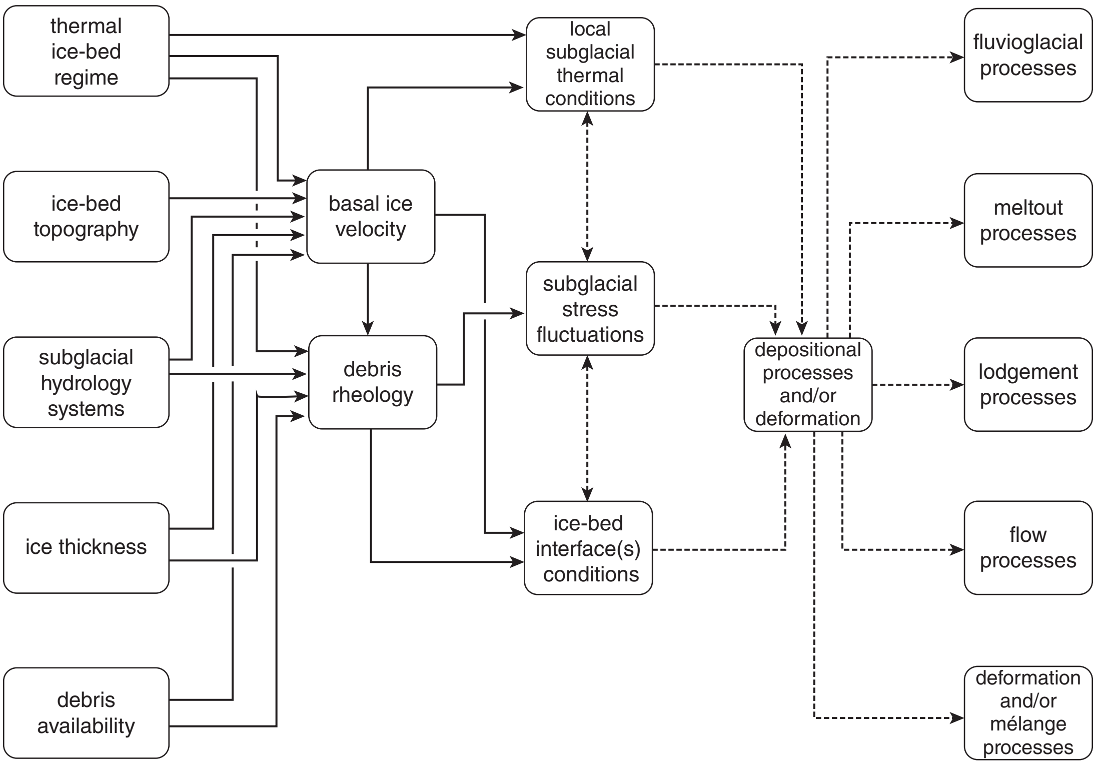
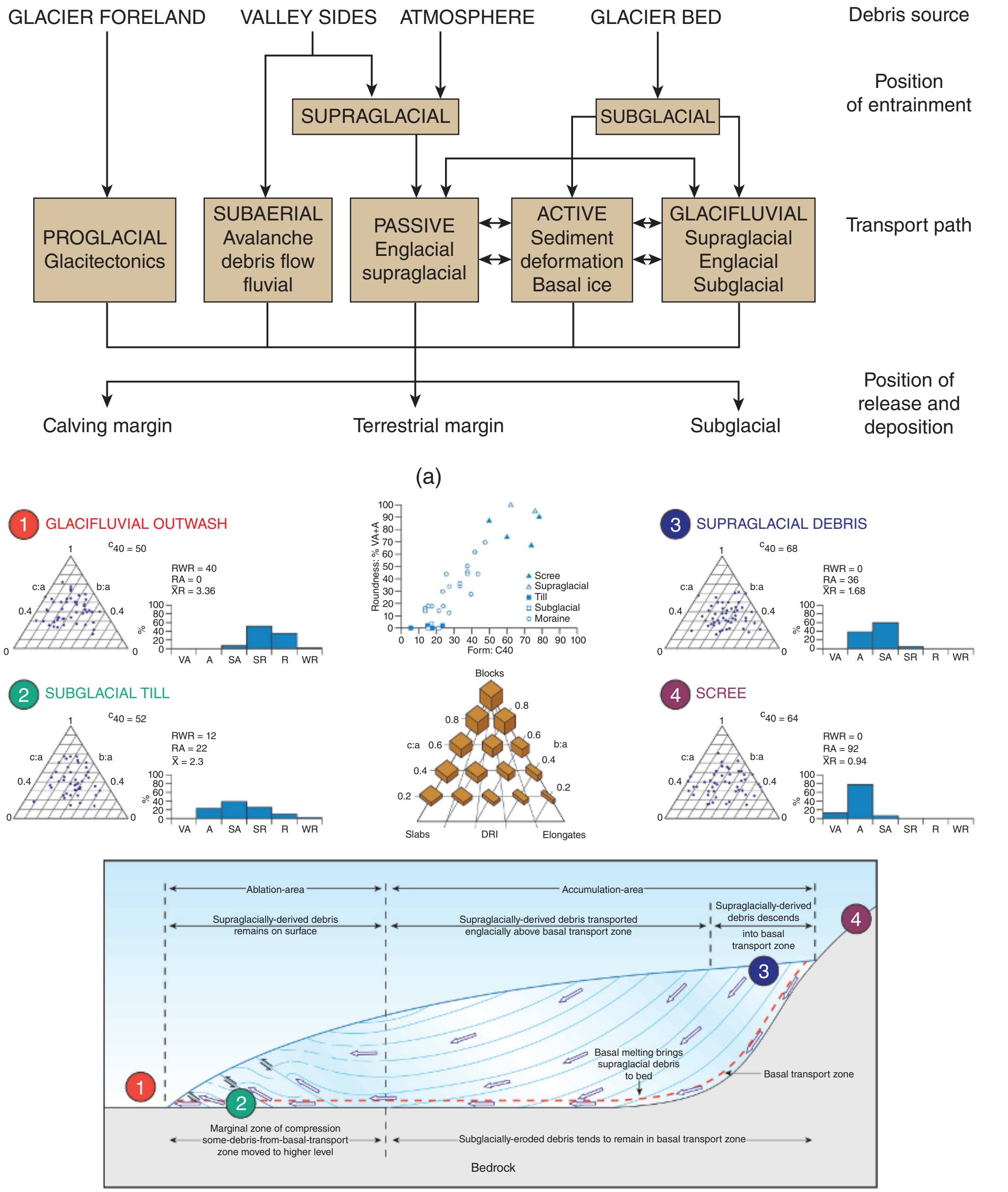


Figure 1.1 Flow diagram to illustrate the inter-relationships between the main glaciological and sedimentological processes associated with the subglacial environment (modified from Menzies and Shilts (1996) to acknowledge glacitectonic processes as deformational rather than depositional).

debris cascade are juxtaposed in a contemporaneous process–form regime. The result is a temporal and spatial mosaic of process operation that can be shut down at any stage of development once a landscape undergoes deglaciation. This temporal and spatial mosaic is a recurring theme throughout this book, because it allows us to visualise the till forming environment more appropriately as a process–form hierarchy more akin to the principles of sequence stratigraphy as they are applied to other geomorphological systems.

Given the ambiguity of the diagnostic criteria that have been proposed as interpretive aids in the study of tills, it is not surprising that controversy abounds and is manifest in some surprisingly contradictory alternative explanations of glacigenic sediment genesis. This is nowhere better illustrated than with glacigenic diamictons and the sediments that are stratigraphically and genetically associated with them (Figure 1.3), all of which lie at the heart of some significant debates in reconstructions of glacial depositional environments pertaining to the whole range of the geological timescale. The crux of these debates commonly can be distilled into disagreements over the subaqueous and/or mass flowage versus subglacial (till) origins of diamictons (e.g. Visser *et al.*, 1984; Eyles, 1987; C.H. Eyles *et al.*, 1985; Eyles *et al.*, 1987, 1988a, b, 1990; Shaw, 1988). Some high-profile examples of such dichotomies include the deposits of the Late Proterozoic Snowball Earth (e.g. Spencer, 1971; Schermerhorn, 1974; Eyles and Eyles, 1983a; Hoffman *et al.*, 1998; Hoffman and Schrag, 2000, 2002; Benn and Prave, 2006; van Loon, 2008; Carto and Eyles, 2012a, b) and the Pleistocene glaciated basins of the Great Lakes (e.g. Eyles and Eyles, 1983b, 1984a; Dreimanis, 1984), North Sea (e.g. Eyles *et al.*, 1989,



(b)

Figure 1.2 The glacial debris cascade and transport pathways: (a) the glacial debris cascade (from Benn and Evans, 2010); (b) simplified diagram to show the main debris transport pathways through a simple valley glacier, indicating that some debris may bypass the subglacial traction zone and follow a passive transport route (after Boulton, 1978). The impacts of various transport routes on clast form signatures are illustrated using: (1) glacifluvial outwash, (2) subglacial till, (3) supraglacial debris and (4) scree. Clast form data is depicted in the commonly used graphics of ternary diagrams (depicting clast shape based upon principle A – long, B – intermediate and C – short axes), histograms (depicting roundness, VA-WR or 0–5) and co-variance graph (plotting RA roundness or VA+A% against C40 form or % clasts below 0.4 c:a axial ratio). Other statistics are RWR = R+WR% and ẊR = average roundness.

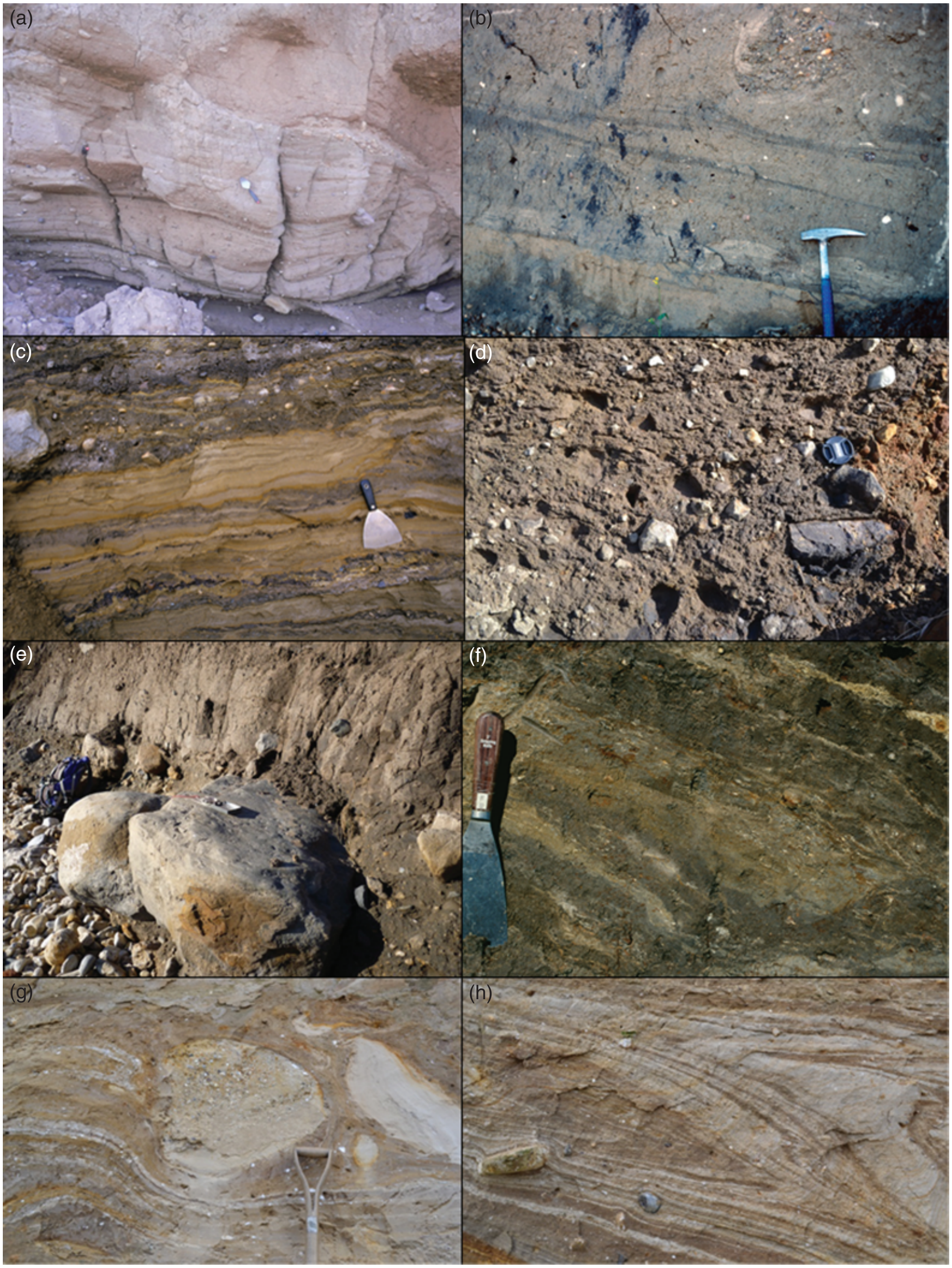


Figure 1.3 Examples of the range of deposits generally referred to as *glacigenic diamictons* (including tills) and sediments that are stratigraphically and genetically related to them: (a) stratified diamicton, Filey Bay, eastern England; (b) pseudo-laminated diamicton with gravel clot/intraclast, Red Deer Lake, Alberta, Canada; (c) stratified diamicton and horizontally bedded interbeds, Drayton Valley, Alberta, Canada; (d) fissile, clast-rich diamicton, Glen Varragill, Isle of Skye, Scotland; (e) discontinuous boulder pavement beneath massive, matrix-rich diamicton, Whitburn, northeast England; (f) heterogeneous, tectonically laminated and shale-rich diamicton, near Kinsella, Alberta, Canada; (g) mélange of stratified sands and gravels, pseudo stratified diamictons and sand and gravel intraclasts (rafts), West Runton, East Anglia, England; and (h) heavily deformed and attenuated stratified diamicton, Sheringham, East Anglia, England.

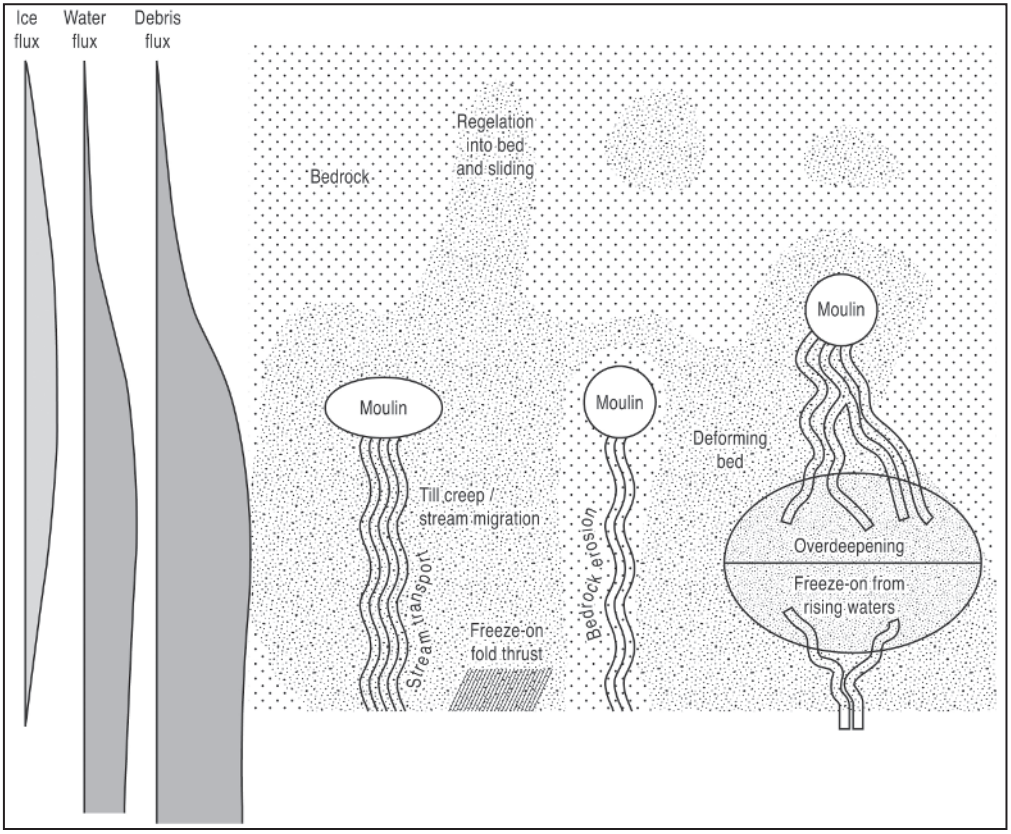


Figure 1.4 Summary schematic diagram showing the range of subglacial sediment transport mechanisms that can operate near the sub-marginal zone of an ice sheet or glacier (from Alley *et al*., 1997). The debris flux and its typical relationships with ice and meltwater flux are also depicted.

1994; Hart and Roberts, 1994; Lunkka, 1994) and Irish Sea Basin (e.g. Eyles and Eyles, 1984b; Eyles and McCabe, 1989a, b, 1991; Wingfield, 1992; McCarroll, 2001; Ó Cofaigh and Evans, 2001a, b; Scourse and Furze, 2001; Evans and Ó Cofaigh, 2003). Additionally, parallel debates have ensued over the precise origins of subglacial tills, focussed on the relative roles of lodgement, melt-out, deformation and meltwater (c.f. Paul and Eyles, 1990; Piotrowski and Tulaczyk, 1999; Munro-Stasiuk, 2000; Boulton *et al*., 2001; Piotrowski *et al*., 2001, 2002, 2004; Ruszczynska-Sjenach, 2001; Evans *et al*., 2006a).

In summary, despite a long history of investigation and a plethora of process-based nomenclature, it is clear that glacial sedimentologists have yet to reach a consensus on the diagnostic criteria for identifying till genesis in the geological record. More than 30 years after Dreimanis and Lundqvist (1984) posed the question '*What should be called Till?*', this book attempts to ask and answer the same query. In the interim, advances in physical glaciology (see Alley *et al*., 1997) have clarified the nature of ice–bed interactions as they pertain to the entrainment and transport history in the glacial debris cascade (Figure 1.4), highlighting the spatial patterns of regelation, meltwater drainage, bed deformation, marginal freeze-on and supercooling, and englacial folding and thrusting. Other aspects of the debris cascade, particularly debris release processes and deformation signatures, have similarly received concerted attention from glacial geomorphologists who have elucidated on the depositional and structural impacts of such aspects, but the accumulated knowledge has yet to fully permeate the realm of glacial sedimentology or at least to be systematically assimilated into clear diagnostic criteria for the reading of the glacial depositional record. This book addresses these issues through critical reviews of the till literature, laboratory- and experiment-based assessments of subglacial processes, and the theoretical constructs that have emerged from process sedimentology. These deliberations are then employed in the erection of a contemporary till nomenclature in which process–form relationships are founded on a coherent synthesis of a wide range of knowledge bases.