Chapter 8 The Pleistocene history of the Gordano Valley

8.1 Introduction

In this chapter the depositional and post-depositional environments identified in Chapter 7 are integrated to provide a palaeoenvironmental history for each core. Timing of the deposition of the sediments is constrained by the radiocarbon date of 13430 to 13190 Cal BP obtained for NR15 and 22200-22000 Cal BP obtained for CGA6, by correlation of TG8 through AAR geochronology with late MIS 7, and by OSL dates which indicate sediment deposition between 107 ka and 48 ka for core TG-OSL. The palaeoenvironmental interpretations are then summarised to produce overarching depositional and post-depositional histories. Various models for their palaeoenvironmental reconstruction are then discussed and valley-wide Pleistocene palaeoenvironments for the Gordano Valley are reconstructed.

8.2 Palaeoenvironmental history of core GV

Fluvial gravel GV2 was deposited onto the weathered bedrock surface of GV1 from a muddy river. The resulting deposit is well-consolidated, and the gravel is highly or moderately weathered, so the age of this event is uncertain; it may pre-date the Pleistocene. Subsequent deposits are all poorly consolidated and are therefore probably Pleistocene, although no dates are available.

GV3, GV4 and GV5 were deposited in a gravel-bedded river under turbulent discharge conditions; fluvial deposition is supported by the presence of freshwater molluscs in GV3 and GV5. Subsequent lower fluvial competence removed the fine component of GV3 leaving a lag deposit in a gravel-bedded river. After deposition, GV3 and GV4 underwent short periods of sub-aerial exposure in a semi-arid climate regime. Following deposition of GV5 the climate became cool and wet, although vegetation remained sparse, and the gravel was sub-aerially exposed for a longer period.

Inability to cope with rapid inundation resulted in deposition of GV6 in a braided stream channel. Following deposition, the climate was cool and wet and vegetation cover was sparse. Reactivation of braided stream flow resulted in deposition of GV7; a period of landscape stability then ensued, during which pedogenesis took place in locally deposited river silt under a temperate, humid climate regime. This pedogenic material was subsequently eroded was deposited from a muddy river as GV8. Later, GV9 and GV10 were deposited in a sand-bedded river channel during discrete periods of fluvial activity. GV10 was subjected to sub-aerial exposure during a subsequent period of semi-aridity with sparse vegetation. Subsequently, GV11 was deposited from turbulent flow in the channel of a gravel-bedded river. Lower fluvial competence resulted in a lag deposit which underwent a period of sub-aerial exposure under low flow conditions. Deposition was followed by a semi-arid climate regime.

The stratigraphy, description, and inferred depositional and post-depositional environments of core GV are summarised in Table 8.1.

Table 8.1: Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core GV

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
GV11 (0.77 to 1.22)	Pink poorly sorted gravel of highly weathered, platy, sub-angular limestone clasts. Very low clay content. Contains reed leaves and stems, roots, twigs, and shell fragments. Sharp, planar basal contact.	Turbulent gravel-bedded river channel	
GV10 (0.62 to 0.77)	Reddish brown very poorly sorted gravelly silty sand. Calcareous, with low clay and organic content. Contains organic detritus and shell fragments. Sharp, planar basal contact.	Sand-bedded river channel	Semi-arid; sparse vegetation
GV9 (0.47 to 0.62)	Brown very poorly sorted gravelly silty sand. Calcareous, with low clay and organic content. Contains organic detritus and shell fragments. Sharp, planar basal contact.	Sand-bedded river channel	Semi-arid; sparse vegetation; damp, disturbed ground, near freshwater
GV8 (0.37 to 0.47)	Reddish brown very poorly sorted gravelly silt. Calcareous with very high clay and low organic content. Contains very fine organic detritus. Sharp, planar basal contact.	Muddy river	Semi-arid; sparse vegetation; damp, disturbed ground, near freshwater

Table 8.1(continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core GV

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
GV7 (0.22 to 0.37)	Reddish brown very poorly sorted slightly gravelly sandy silt. Slightly calcareous, with very high clay and moderate organic content. Contains very fine organic detritus and reed fragments. Sharp, planar basal contact.	Braided stream	Temperate, humid; landscape stability; pedogenesis; damp, disturbed ground, near freshwater
GV6 (-0.08 to 0.22)	Brown very poorly sorted slightly gravelly silty sand. Slightly calcareous, with moderate clay and low organic content. Few, very fine detrital organic remains. Sharp, planar basal contact.	Braided stream	Cool, wet; sparse vegetation
GV5 (-0.18 to -0.08)	Brown very poorly sorted silty gravel of highly- to slightly-weathered, bladed, sub-round and round limestone clasts. Slightly calcareous, with very low clay and low organic content. Contains a single gastropod shell and few very fine detrital organic remains. Sharp, planar basal contact.	Turbulent gravel-bedded river channel	Cool, wet; sparse vegetation
GV4 (-0.28 to -0.18)	Strong brown very poorly sorted gravel of slightly weathered bladed and elongate, sub-angular limestone clasts. Very calcareous, with very low clay and low organic content. Few very fine detrital organic remains and shell fragments. Sharp, planar basal contact.	Turbulent gravel-bedded river channel	Semi-arid; sparse vegetation
GV3 (-0.58 to -0.28)	Yellowish brown very poorly sorted gravel of slightly weathered, bladed, sub-angular limestone clasts. Very calcareous, with very low clay and low organic content. Contains shell fragments and a single gastropod shell. Sharp, planar basal contact.	Turbulent gravel-bedded river channel	Semi-arid; sparse vegetation

Table 8.1(continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core GV

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
GV2 (-0.78 to -0.58)	Reddish brown extremely poorly sorted silty gravel of highly and moderately weathered, angular brown sandstone clasts. Very calcareous, with very high clay and moderate organic content. Sharp, planar basal contact.	Muddy river	Warm, temperate; landscape stability
GV1 (-1.18 to -0.78)	Weak red very poorly sorted gravelly silt. Very calcareous, with very high clay and low organic content. Bedrock (Mercia Mudstone Group).	Bedrock	Semi-arid; sparse vegetation

8.3 Palaeoenvironmental history of core PG

PG1 was deposited in a river channel under flow conditions turbulent enough to erode a rip-up clast from the stream bed or bank. A subsequent erosional episode resulted in an irregular surface on which PG2 was deposited from a muddy river. This was followed by a period of sub-aerial exposure prior to deposition of PG3, also from a muddy river. The surface of PG3 was subsequently exposed to sub-aerial processes and a desiccation crack formed in the water-saturated sediment surface, possibly of a drying-out pond, lake or abandoned river channel. Subsurface water levels fluctuated, resulting in orange mottling associated with a wood fragment. Subsequently soil formation commenced during a period of landscape stability. The desiccation crack was later infilled by sand from the river channel of PG4.

PG5 was deposited from a muddy river. As water levels fell, a period of landscape stability ensued and either soil formation was initiated in the already swampy ground or alternatively the ground was submerged by a rising water table once soil formation had commenced. A fluctuating shallow water table prevented the sediment from completely drying out. PG6 was deposited from a high competence muddy river. Subsequent shallow groundwater conditions facilitated precipitation of carbonate deposits onto the gravel clasts. Later, PG7 was deposited from locally available glacial deposits during high-energy flow in a gravel-bedded river which originated within the valley. Subsequent lower fluvial competence resulted in a lag deposit. Diminished flow and a shallow water table resulted in precipitation of carbonate onto the gravel clasts. PG8 was subsequently deposited in a sand-bedded river. Deposition of PG7 and PG8 was followed by semi-arid conditions with sparse vegetation.

The stratigraphy, description, and inferred depositional and post-depositional environments of core PG are summarised in Table 8.2.

Table 8.2: Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core PG

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
PG8 (2.10 to 2.55)	Brown very poorly sorted gravelly silty sand. Calcareous, with low clay and organic content. Sharp, planar basal contact.	Sand-bedded river channel	Semi-arid; sparse vegetation
PG7 (1.89 to 2.10)	Reddish brown very poorly sorted matrix-supported gravel comprising slightly weathered, platy and bladed, sub-angular large pebble to granule-size clasts of brown sandstone in a silty sandy matrix. Contains very small shell fragments and organic fragments. Calcareous, with low clay and organic content. Sharp, planar basal contact.	High-energy gravel-bedded river	Semi-arid; sparse vegetation; shallow water table
PG6 (1.77 to 1.89)	Brown extremely poorly sorted silty gravel with reddish brown sand inclusion. The gravel comprises slightly weathered, compact, sub-angular large pebble to granule-size clasts of brown sandstone and includes tufa clasts. Slightly calcareous, with high clay content and moderate organic content. Basal contact is unclear due to disturbance of sediments.	Muddy river	Shallow water table
PG5 (1.51 to 1.77)	Greenish grey very poorly sorted gravelly silt. Contains organic fragment. Calcareous, with high clay and moderate organic content. Basal contact coincides with the base of the core section and is uncertain.	Muddy river	Hydromorphic soil formation; fluctuating water table; landscape stability

Table 8.2 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core PG

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
PG4 (1.19 to 1.51)	Yellowish brown very poorly sorted gravelly silty sand. Contains very small shell fragments and detrital organic remains. Calcareous, with low clay and organic content. Sharp, irregular lower boundary with sand filled crack.	Sand-bedded river channel	
PG3 (0.82 to 1.19)	Light yellowish brown very poorly sorted gravelly silt. Infill of sand behind the silt thins out towards the base of the unit. There is strong brown mottling associated with wood fragments. Calcareous, with high clay and moderate organic content. Sharp, planar basal contact.	Muddy river	Weak pedogenesis on recently exposed surface; fluctuating water table; landscape stability
PG2 (0.67 to 0.82)	Light reddish brown very poorly sorted gravelly silt. Calcareous, with high clay and low organic content. Sharp, irregular lower boundary dips at 100°.	Muddy river	
PG1 (0.43 to 0.67)	Light yellowish brown very poorly sorted gravelly silty sand with 2 cm thick yellowish red fine sand inclusion which thins towards base of core. A further light yellowish brown silt structure is folded into the sand inclusion and both continue below the base of the core. Contains part of a fossilised burrow or root, approximately 10 mm in length and 1 mm wide. Calcareous, with moderate clay and low organic content.	Turbulent sand-bedded river channel	

8.4 Palaeoenvironmental history of core PGA

PGA1 was deposited in a sand-bedded river channel. Deposition was followed by sub-aerial exposure and a period of non-deposition or erosion resulted in a sharp boundary with PGA2. Subsequent channel reactivation resulted in deposition of PGA2 in a gravel-bedded river. Following deposition, sub-aerial exposure and a period of non-deposition or erosion resulted in a sharp boundary with PGA3. Further channel reactivation resulted in the deposition of PGA3, again in a gravel-bedded river channel. The channel was again abandoned, followed by sub-aerial exposure and a period of erosion or non-deposition. Post-depositional conditions for PGA1, PGA2 and PGA3 were semi-arid with sparse vegetation cover.

PGA4 was later deposited from a braided stream during rapid fluvial inundation. Deposition was followed by sub-aerial exposure under conditions of semi-aridity with sparse vegetation. The sharp, irregular upper surface indicates an erosion surface onto which the muddy river sediments of PGA5 were later deposited. This was followed by sub-aerial exposure and weak pedogenesis during a long period of non-deposition. Groundwater carbonate nodules formed under semi-arid conditions around a near-surface, possibly seasonally fluctuating, water table. Surface erosion occurred prior to rapid inundation by a braided stream which deposited PGA6 under waning flow conditions. The boundary between PGA6 and PGA7 is irregular and dipping, suggesting a scoured surface. PGA7 was deposited in a river channel followed by a period of erosion or non-deposition under semi-arid climatic conditions with sparse vegetation. PGA8 was subsequently deposited from a braided stream and was subjected to periodic waterlogging.

This was followed by a series of deposits from muddy rivers, interspersed with a mudflow. PGA9 is the first muddy river deposit, followed by PGA10 and PGA11. Post-depositional conditions for PGA9 and 10 were semi-arid with sparse vegetation cover, with periodic waterlogging and weak pedogenesis in PGA10, whilst for PGA11 there were temperate climate conditions and a period of landscape stability during which the surface was sub-aerially exposed and soil formation and vegetation growth commenced and there was a near-surface water table. PGA12 was deposited from a mudflow, prior to deposition of PGA13 from a muddy river. After their deposition, PGA12 and PGA13 underwent sub-aerial exposure and weak pedogenesis under temperate climatic conditions, and following deposition of PGA13 there was water table fluctuation with periodic waterlogging.

A period of erosion ensued, followed by deposition of PGA14 from high-energy flow in a gravel-bedded river. Its deposition marks a change in gravel source from predominantly limestone (in PGA2 and PGA3) to predominantly brown sandstone. As discharge waned, lower fluvial competence resulted in a lag deposit; the surface underwent sub-aerial exposure as the shallow water table fluctuated in a semi-arid climate with sparse vegetation cover. Subsequent rapid inundation during flooding resulted in the deposition of

PGA15, PGA16 and PGA17 from braided streams; locally available pedogenic and organic material was incorporated into PGA16. These units underwent post-depositional waterlogging.

The stratigraphy, description, and inferred depositional and post-depositional environments of core PGA are summarised in Table 8.3.

Table 8.3: Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core PGA

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
PGA17 (2.47 to 2.51)	Grey poorly sorted slightly gravelly sand. Non-calcareous, with very low clay content and very low organic content. Sharp, planar basal contact.	Braided stream	Waterlogging
PGA16 (2.46 to 2.47)	Very dark greyish brown poorly sorted slightly gravelly sand containing darker, horizontally oriented detrital leaf and other organic fragments. Slightly calcareous, with very low clay content and very low organic content. Sharp, planar basal contact.	Braided stream	Waterlogging
PGA15 (2.32 to 2.46)	Grey poorly sorted slightly gravelly sand containing vertically oriented organic detritus. Slightly calcareous, with very low clay content and very low organic content. Sharp, planar basal contact.	Braided stream	Waterlogging
PGA14 (1.70 to 2.32)	Reddish brown to dark reddish brown very poorly sorted matrix-supported gravel, with strong brown mottling. The lower 5 cm is less stony and the lower 2 cm contains fragments of shell and organic material. The gravel comprises slightly weathered, bladed, angular, occasionally broken, large pebble to granule-size clasts of brown sandstone in a silty sandy matrix and includes tufa clasts. Calcareous, with low clay content and very low organic content. The contact with the underlying unit is uncertain.	High-energy gravel-bedded river	Semi-arid; sparse vegetation; fluctuating shallow water table

Table 8.3 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core PGA

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
PGA13 (1.64 to 1.70)	Grey very poorly sorted gravelly silt. There are occasional, very fine, unidentifiable, organic remains. Slightly calcareous, with high clay content and moderate organic content. The contact with the underlying unit is uncertain.	Muddy river	Temperate; weak pedogenesis; periodic waterlogging; fluctuating water table
PGA12 (1.52 to 1.64)	Yellowish brown very poorly sorted gravelly silt. The lower 1 cm displays a vertically oriented brown streak associated with the presence of possible organic remains. The sediment is calcareous, with high clay content and moderate organic content. Sharp, irregular basal contact dips at 23°.	Mudflow	Temperate climate; weak pedogenesis
PGA11 (1.40/1.48 to 1.52)	Red very poorly sorted gravelly silt containing granule-sized clasts. The unit is strongly associated with the presence of a root trace. Calcareous, with high clay content and moderate organic content. Sharp, irregular basal contact dips at 45°.	Muddy river	Temperate climate; landscape stability; low water table; weak pedogenesis; vegetation growth
PGA10 (1.20/1.28 to 1.40/1.48)	Olive yellow and brown Liesegang rings in very poorly sorted slightly gravelly sandy silt. The Liesegang rings are contorted, convex, and become fainter with increasing depth. Towards the base of the unit is a 5 cm thickness of strong brown mottling, below which convex olive yellow/brown Liesegang rings reappear. The lower 10 cm of the unit exhibits horizontal cracks. Calcareous, with high clay content and low organic content. Because of the difficulties experienced in recovering the core, the nature of the basal contact is uncertain, but it appears to dip at 67°.	Muddy river	Semi-arid; sparse vegetation; periodic waterlogging; fluctuating water table; weak pedogenesis

Table 8.3 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core PGA

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
PGA9 (1.04 to 1.20)	Brown very poorly sorted gravelly silt. Calcareous, with high clay content and low organic content. The nature of the basal contact is uncertain.	Muddy river	Semi-arid; sparse vegetation
PGA8 (1.00 to 1.04)	Light olive brown very poorly sorted gravelly silty sand. Calcareous, with low clay content and low organic content. Sharp, planar basal contact.	Braided stream	Periodic waterlogging
PGA7 (0.75 to 1.00)	Yellowish red very poorly sorted gravelly silty sand. There are inclusions of light yellowish brown silt, with a sharp boundary between the silt and the surrounding sand. The sand contains shell fragments of approximately 5 mm diameter. Calcareous, with moderate clay content and very low organic content. Sharp, irregular basal contact dips at 50°.	Sand-bedded river channel	Semi-arid; sparse vegetation
PGA6 (0.54 to 0.75)	Light yellowish brown very poorly sorted slightly gravelly sandy silt, with a yellowish red sand inclusion, probably from the overlying unit, folded into the silt. The silt displays horizontal cracks (maximum 3 mm wide) which become progressively finer with increasing depth. Wisps of brown silt are contorted and dip at 35°. Calcareous, with high clay content and very low organic content. Sharp, irregular, convex basal contact.	Braided stream	

Table 8.3 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core PGA

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
PGA5 (0.16 to 0.54)	Reddish brown poorly sorted slightly gravelly sandy silt with soft white carbonate nodules towards the base of the unit. The upper 10 cm is sheathed in material from the overlying unit; this sheath gradually thins with depth. The lower 12 cm contains small shell fragments and the number of soft white carbonate nodules increases. There are numerous fine (<1 mm wide) horizontal cracks throughout the unit. Slightly calcareous, with high clay content and low organic content. Sharp, irregular, convex basal contact.	Muddy river	Semi-arid; fluctuating water table; pedogenesis
PGA4 (0.14 to 0.16)	Yellowish red very poorly sorted slightly gravelly silty sand. Shell fragments are present and the sediment is calcareous, with moderate clay content and very low organic content. Sharp, planar basal contact.	Braided stream	Semi-arid; sparse vegetation
PGA3 (0.08 to 0.14)	Reddish brown very poorly sorted clast-supported gravel with a silty sandy matrix. The gravel comprises moderately weathered, angular, compact-elongate medium pebble-size limestone clasts and includes tufa clasts. Very calcareous, with low clay content and low organic content. Sharp, planar basal contact.	Gravel–bedded river channel	Semi-arid; sparse vegetation; shallow water table
PGA2 (0.06 to 0.08)	Yellowish brown very poorly sorted clast-supported gravel with a silty sandy matrix. The gravel comprises granules and moderately weathered, angular, bladed, small pebble-size limestone clasts. The sediment contains a high number of shell fragments and is very calcareous, with very low clay and organic content. Sharp, planar basal contact.	Gravel-bedded river channel	Semi-arid; sparse vegetation; shallow water table

Table 8.3 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core PGA

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
PGA1 (0.05 to 0.06)	Dusky red very poorly sorted gravelly silty sand. The gravel element comprises granules and small pebble-size clasts. The sediment contains small (<1 mm) fragments of shell, and is very calcareous, with very low clay and low organic content.	Sand-bedded river channel	Semi-arid; sparse vegetation

8.5 Palaeoenvironmental history of core CGA

CGA1 is a braided stream lag deposit. A subsequent period of semi-aridity and non-deposition or erosion resulted in a sharp boundary with CGA2, which was deposited from a muddy river, followed by low flow, which left CGA2 as a lag deposit. Subsequent sub-aerial exposure resulted in very weak pedogenesis under semi-arid conditions with sparse vegetation cover and was followed by a period of non-deposition or erosion resulting in a sharp boundary with CGA3. CGA3 accumulated in a sheltered topographic hollow from deflated local fluvial deposits. The surface was later subjected to sub-aerial exposure, again under semi-arid conditions with sparse vegetation cover and followed by a period of erosion, resulting in a sharp boundary with CGA4.

CGA4, CGA5 and CGA6 form an upward-fining sequence of deposits whose gradational contacts indicate continuous deposition. CGA4 was deposited during turbulent flow in the channel of a gravel-bedded river which reworked locally available deposits including some glacial material. Deposition was followed by a reduction in flow and competence which removed the fine component of CGA4 leaving a lag deposit. CGA5 and CGA6 were deposited in a river channel under a waning, but still vigorous, flow regime. There was gradual climate amelioration from semi-aridity with sparse vegetation for CGA4 to a wetter, temperate climate with increased organic productivity following deposition of CGA6. Channel flow then either decreased or the channel was abandoned; the water table fluctuated and a palaeosol formed on the recently exposed surface. Palaeosol formation ended with the onset of LGM cold conditions and an erosional event removed the uppermost (organic) soil horizons.

Later, CGA7, CGA8 and CGA9 were deposited from a muddy river. Subsequent lower fluvial competence left CGA7 as a lag deposit. Each depositional event was followed by a period of non-deposition or erosion, resulting in sharp intervening boundaries. A temperate climate prevailed following deposition of CGA7 and CGA8. CGA10 accumulated in a sheltered topographic hollow from deflated local fluvial deposits; deposition was followed by fluctuations in a shallow water table. CGA11 was deposited from a muddy river. Subsequent lower fluvial competence resulted in a lag deposit; water levels fell, groundwater levels fluctuated and soil formation commenced on the recently exposed surface under temperate climate conditions. This was followed by a period of erosion, resulting in a sharp boundary with CGA12. CGA12 was deposited in a river channel, followed by a reduction in fluvial competence, leaving a lag deposit. A further period of erosion followed, resulting in a sharp boundary with CGA13, also deposited in a river channel. A gradational boundary with the braided stream deposit CGA14 indicates continuous deposition. Subsequent lower fluvial competence left CGA14 as a lag deposit. Climate following deposition of CGA13 and CGA14 was cool and wet.

The stratigraphy, description, and inferred depositional and post-depositional environments of core CGA are summarised in Table 8.4.

Table 8:4: Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core CGA

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
CGA14 (3.16 to 3.18)	Yellowish brown poorly sorted sand. Non-calcareous with very low organic and clay content. Basal contact is gradational and planar.	Braided stream	Cool, wet
CGA13 (2.77 to 3.16)	Light yellowish brown to pale brown very poorly sorted gravelly silty sand. The middle part of the section is disturbed, but appears to be stonier, with highly weathered sub-angular small to medium pebbles. Iron mottling is visible over less than 10% of the surface area. Rare very small shell fragments are present. The sediment is slightly calcareous, with very low clay and organic content. Basal contact is sharp and irregular.	Sand-bedded river channel	Cool, wet
CGA12 (2.57 to 2.77)	Yellowish red very poorly sorted gravelly sand, with large pebbles both vertically and horizontally orientated. Two cracks are present: one is 1 mm wide and sub-horizontal; the other is 3 mm wide and horizontal. Iron mottling is focused around possible organic remains. The sediment is calcareous, with moderate clay content and very low organic content. Basal contact is sharp and planar.	Sand-bedded river channel	
CGA11 (2.31 to 2.57)	Yellowish brown very poorly sorted gravelly silt with brown vertical wisps. There are numerous fine horizontal and vertical cracks. Iron mottling is associated with a vertical root trace. The sediment is slightly calcareous, with high clay content and low organic content. Basal contact is unclear, but appears to be sharp, irregular and folded around the underlying unit.	Muddy river	Temperate climate; landscape stability; fluctuating water table; pedogenesis; vegetation growth

Table 8:4 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core CGA

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
CGA10 (2.14 to 2.31)	Yellowish red very poorly sorted gravelly silty sand. Strong brown iron mottling is associated with black streaks. The sediment is calcareous, with very low organic and moderate clay content. Basal contact is unclear, but appears to be gradational.	Aeolian; deflation of local fluvial deposits	Fluctuating water table
CGA9 (2.06 to 2.14)	Strong brown very poorly sorted slightly gravelly sandy silt, iron mottled over approximately 20% of the visible area. The sediment is calcareous with very low organic content and high clay content. Basal contact is sharp and planar.	Muddy river	
CGA8 (1.97 to 2.06)	Brown very poorly sorted gravelly silt, iron mottled over >50% of the visible area. The sediment is slightly calcareous, with high clay content and low organic content. Basal contact is sharp and irregular.	Muddy river	Temperate climate
CGA7 (1.83 to 1.97)	Strong brown very poorly sorted gravelly silt containing sub-angular to round large pebble to granules-size clasts. The lower 6 cm is stonier with streaks of iron mottling that are strongly associated with the larger pebbles. The sediment is slightly calcareous, with moderate clay and organic content. Basal contact is sharp and irregular.	Muddy river	Temperate climate
CGA6 (1.66 to 1.83)	Dark brown very poorly sorted gravelly silty sand with dark stained, dusky red, small, angular, highly weathered clasts cemented by manganese deposits. Dark mottling extends over 50% of the visible area. The sediment is calcareous, with low clay content and organic content is also low despite the presence of very fine fragments of organic remains. Basal contact is gradational.	Sand-bedded river channel	Temperate climate; landscape stability; low water table; vegetation growth; pedogenesis - cessation ^{14}C dated to 22280 to 21810 Cal BP

Table 8:4 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core CGA

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
CGA5 (1.46 to 1.66)	Strong brown very poorly sorted gravelly silty sand with highly weathered well round large pebble to granule-size clasts. Shell fragments throughout the unit. The sediment is calcareous, with low organic content and very low clay content. Basal contact is gradational.	Sand-bedded river channel	Climate amelioration
CGA4 (1.38 to 1.46)	Strong brown clast-supported very poorly sorted gravel of angular to sub-angular, platy or bladed, slightly to moderately weathered limestone clasts, some broken. The sediment is calcareous, with very low clay content and low organic content. Basal contact is sharp and planar.	Turbulent gravel-bedded river	Semi-arid; sparse vegetation
CGA3 (1.37 to 1.38)	Dark brown very poorly sorted gravelly silty very fine sand. The sediment is calcareous, with high clay content and low organic content. Basal contact is sharp and planar.	Aeolian; deflation of local fluvial deposits	Semi-arid; sparse vegetation
CGA2 (1.36 to 1.37)	Dark reddish brown very poorly sorted very dense gravelly silty sand, with a sequence of <1 mm thick rippled laminations. The sediment is calcareous, with low organic and clay content. Basal contact is sharp and planar.	Muddy river	Semi-arid; sparse vegetation; weak pedogenesis
CGA1 (1.35 to 1.36)	Brown very poorly sorted slightly gravelly silty sand. The sediment is calcareous, with low clay and very low organic content.	Braided stream	Semi-arid; sparse vegetation

8.6 Palaeoenvironmental history of core CGB

CGB1 was deposited from locally available glacial deposits in a high-energy gravel-bedded river. Subsequent lower fluvial competence left a lag deposit. The channel was subsequently abandoned and the surface exposed. This was followed by climatic cooling, conditions of semi-aridity, sparse vegetation cover and a shallow water table; a period of erosion or non-deposition ensued. Channel reactivation resulted in deposition of CGB2, again from locally available glacial sediment, in a gravel-bedded river. Climatic cooling and semi-aridity, with sparse vegetation cover and a shallow water table followed deposition. As flow waned, CGB3 was deposited in the river channel. This was followed by an erosional event, which left an irregular surface onto which CGB4 was deposited from deflation of local fluvial deposits which accumulated in a sheltered topographic hollow of a braid plain. Subsequent landscape stability led to the initiation of pedogenesis and organic productivity under a wetter temperate climate with a fluctuating water table. This was followed by a period of erosion or non-deposition.

Subsequent braided stream flow resulted in deposition of CGB5, followed by surface emergence, landscape stability weak pedogenesis and organic productivity under a wetter temperate climate, and a period of non-deposition or erosion. Later, CGB6 was also deposited from a braided stream. A semi-arid climate was established and vegetation cover decreased. An erosional event resulted in burial of CGB6 by CGB7, mobilised from locally available glacial sediment and deposited from high-energy flow in the channel of a gravel-bedded river. Subsequent lower fluvial competence resulted in a lag deposit.

This was followed by a series of river channel deposits, CGB8, CGB9, CGB10 and CGB11, with intervening periods of non-deposition or erosion. Deposition of CGB8 and CGB10 was followed by reduced fluvial competence, resulting in lag deposits. A change in the local source of gravel clasts occurred prior to deposition of CGB9. Post-depositional environments for CGB8 and CGB9 are characterised by continued semi-aridity, sparse vegetation and a fluctuating, shallow water table. Following deposition of CGB10 there was a period of landscape stability, surface exposure and weak pedogenesis. Deposition rates for CGB11 were initially low, but increased to rapidly overwhelm early vegetation growth. Deposition was followed by a prolonged period of landscape stability, sub-aerial exposure of the surface and soil formation. Carbonate nodules formed under conditions of semi-aridity and a fluctuating water table resulted in the formation of Liesegang rings.

An erosional event preceded deposition of CGB12 in a river channel. This was followed by reduction in fluvial competence, leaving a lag deposit. A period of landscape stability and weak pedogenesis ensued. A subsequent erosional event was followed by deposition of CGB13 from locally available glacial deposits in a gravel-bedded river.

Subsequent reduction in fluvial competence left a further lag deposit. A period of semi-aridity, sparse vegetation cover and fluctuating near-surface water table followed.

The stratigraphy, description, and inferred depositional and post-depositional environments of core CGB are summarised in Table 8.5.

Table 8.5: Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core CGB

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
CGB13 (2.77 to 3.04)	Brown extremely poorly sorted matrix-supported gravel comprising moderately weathered, angular, platy very large pebble to granule-size brown sandstone clasts in a silty sandy upward coarsening matrix. Iron mottling is visible towards the base of the unit. Calcareous, with very low clay and low organic content. Sharp, planar basal contact.	Gravel-bedded river	Semi-arid; sparse vegetation; fluctuating shallow water table
CGB12 (2.57 to 2.77)	Yellowish brown very poorly sorted gravelly silty sand. Slightly calcareous, with moderate clay and low organic content. Sharp, irregular, contorted and convex basal contact.	Sand-bedded river channel	Landscape stability; weak pedogenesis
CGB11 (2.17 to 2.57)	Brown very poorly sorted gravelly silty sand, becoming reddish brown with iron mottling, which increases with depth, and dark mottling with black manganese nodules; one manganese nodule lies proximal to a smooth-lined void in the sediment. Fine horizontal fractures (<1 mm thick) throughout the unit become more fissile towards the base. Liesegang rings are present; these become diffuse and wispy with increasing depth. In the lower part of the unit there is a large soft white carbonate nodule and many smaller nodules. Slightly calcareous, with high clay and low organic content. Sharp, planar basal contact.	Sand-bedded river channel	Semi-arid; sparse vegetation; fluctuating water table; landscape stability; pedogenesis

Table 8.5(continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core CGB

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
CGB10 (1.84 to 2.17)	Reddish brown to strong brown very poorly sorted gravelly silty sand. There are irregular horizontal fractures (~1 mm thick) associated with dark mottling and black nodules. Slightly calcareous, with low clay and organic content. Sharp, planar basal contact.	Sand-bedded river channel	Fluctuating water table; pedogenesis
CGB9 (1.79 to 1.84)	Dark brown very poorly sorted matrix-supported gravel comprising highly weathered, bladed and very bladed, sub-angular medium pebble to granule-size brown sandstone clasts in a dark mottled silty sandy matrix. Slightly calcareous, with very low clay and low organic content. Sharp, planar basal contact.	Gravel-bedded river channel	Semi-arid; sparse vegetation; fluctuating shallow water table
CGB8 (1.75 to 1.79)	Yellowish brown very poorly sorted gravelly silty sand with some darker mottling. Slightly calcareous, with very low clay and low organic content. Sharp, planar basal contact.	Sand-bedded river channel	Semi-arid; sparse vegetation; fluctuating water table
CGB7 (1.63 to 1.75)	Yellowish brown very poorly sorted silty sandy gravel comprising moderately weathered, angular to sub-angular, bladed large pebble to granule-size limestone clasts. Some larger clasts are blackened and appear to have a rind of black staining. Carbonate nodules are also present. Calcareous, with very low clay and low organic content. Sharp, planar basal contact.	High-energy gravel-bedded river	Semi-arid; sparse vegetation; seasonally fluctuating water table
CGB6 (1.58 to 1.63)	Strong brown very poorly sorted slightly gravelly silty sand, containing shell fragments <1 mm diameter. Calcareous, with low clay and moderate organic content. Sharp, irregular, convex basal contact.	Braided stream	Semi-arid; reduced vegetation cover

Table 8.5(continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core CGB

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
CGB5 (1.49 to 1.58)	Strong brown poorly sorted slightly gravelly silty sand. Slightly calcareous, with low clay and moderate organic content. Sharp, irregular, slightly convex basal contact, with 3 mm thick convex fracture just above the contact.	Braided stream	Temperate climate; landscape stability; weak pedogenesis; organic productivity
CGB4 (1.30 to 1.49)	Light brown very poorly sorted slightly gravelly silty sand. Many fine (<1 mm thick) horizontal fractures are present throughout. There is some dark mottling. Slightly calcareous, with high clay and moderate organic content. Sharp, irregular convoluted, unconformable basal contact dips at 50°.	Aeolian; deflation of local fluvial deposits	Temperate climate; landscape stability; fluctuating water table; weak pedogenesis; organic productivity
CGB3 (1.23 to 1.30)	Yellowish red very poorly sorted gravelly silty sand. Contains very small shell fragments. Calcareous, with very low clay and moderate organic content. Gradational, irregular basal contact.	Sand-bedded river channel	
CGB2 (1.21 to 1.23)	Reddish brown very poorly sorted clast-supported gravel with a silty sand matrix. The gravel comprises slightly weathered, bladed, angular, medium pebble to granule-size limestone clasts. Very calcareous, with very low clay and low organic content. Basal contact coincides with the top of the core 'plug' and is unclear but appears to be sharp and irregular.	Gravel-bedded river	Climatic cooling; semi-arid; sparse vegetation; shallow water table
CGB1 (1.15 to 1.21)	Weak red very poorly sorted silty sandy gravel comprising moderately weathered, bladed and elongate, angular to sub-angular large pebble to granule-size limestone clasts with some greenish completely weathered stone remnants. Very calcareous, with very low clay and moderate organic content.	Gravel-bedded river	Climatic cooling; semi-arid; sparse vegetation; shallow water table

8.7 Palaeoenvironmental history of core NR

NR1 was deposited from deflation of local fluvial deposits and accumulated in a sheltered topographic hollow of a braid plain. Later NR2 was deposited in a gravel-bedded river from high-energy transportation of a local sediment source. The surface subsequently underwent sub-aerial exposure and a period of landscape stability, with organic-rich soil and hydrological carbonate production from a shallow water table, ensued. An interval of non-deposition or erosion at the surface resulted in a sharp boundary with NR3, which was deposited in a river channel. A reduction in fluvial competence resulted in a lag deposit and eventual channel abandonment. The surface underwent sub-aerial exposure, with a shallow water table, increased aridity and a reduction in vegetation cover. A period of non-deposition or erosion followed before deposition under high-energy flow conditions in a gravel-bedded river channel of NR4, NR5 and NR6. All are from a local sediment source, the latter gravel from remobilised locally available glacial sediment. Following deposition of NR6, a reduction in fluvial competence resulted in a lag deposit. The sharp boundaries between NR4, NR5 and NR6 indicate intermittent deposition or deposition interrupted by periods of erosion or non-deposition. During subsequent intervals of semi-aridity, with sparse vegetation and a shallow water table, they underwent sub-aerial exposure.

NR7, NR8 and NR9 were deposited from a local sediment source in a river channel during a period of continuous deposition; NR7 was mobilised from locally available glacial sediment under conditions of turbulent flow and NR9 was deposited under high-energy flow conditions. After deposition of each unit fluvial competence was reduced, resulting in lag deposits. Subsequently there were intervals of semi-aridity, with sparse vegetation, a shallow, fluctuating water table and unstable landscape. Following deposition of NR9, there was a period of non-deposition or erosion which resulted in the sharp boundary with NR10.

NR10 was deposited from deflation of local fluvial deposits and accumulation in a sheltered topographic hollow of a braid plain. After deposition the surface of was exposed under an organically productive wet, temperate climatic regime; an interval of non-deposition or erosion resulted in a sharp boundary. NR11 was deposited in a braided stream, followed by period of sub-aerial exposure as climate deteriorated, becoming cool and wet with low organic productivity.

NR12 was deposited in a river channel. Deposition was followed by sub-aerial exposure as climate deteriorated, becoming cool and wet with low organic productivity.

NR13, NR14 and NR15 were deposited from a local sediment source in a gravel-bedded river, NR13 from locally available glacial sediment under high-energy flow conditions. After deposition of NR15, fluvial competence reduced, resulting in a lag deposit. Deposition was followed by a period of landscape stability in which there was organic-rich soil and hydrological carbonate production from a fluctuating water table. Soil formation was initiated at the surface of NR15 and temperatures were relatively warm. There was subsequent climatic cooling, reduction of vegetation cover and an erosional event which removed the upper A or O horizon and resulted in the sharp boundary with NR16 which was deposited onto the eroded surface sometime after *c*. 13430 Cal BP.

NR16 was deposited from locally available glacial sediment in a gravel-bedded river under turbulent flow conditions. Following deposition a reduction in fluvial competence resulted in a lag deposit and the channel was subsequently abandoned. This was followed by sub-aerial exposure of the surface during a period of semi-arid climate with a shallow water table, sparse vegetation. Later there was erosion of the sediment surface prior to deposition of NR17 in a gravel-bedded river. Again, following deposition reduced fluvial competence resulted in a lag deposit. Subsequently, there was sub-aerial exposure of the surface, a shallow water table with nearby shallow fresh or brackish water and organic productivity under a wetter, temperate climate. An interval of non-deposition or erosion at the surface resulted in a sharp boundary with NR18 which was subsequently deposited in a river channel. Deposition was followed by reduced fluvial competence, resulting in a lag deposit. A period of landscape stability, in which there was organic-rich soil and hydrological carbonate production from a shallow water table, followed.

Deposition of NR19 from a local source in a gravel-bedded river was followed by channel abandonment. The surface underwent sub-aerial exposure and there was a period of landscape stability, with organic-rich soil, hydrological carbonate production, nearby shallow fresh or brackish water and a shallow water table. An interval of non-deposition or erosion at the surface resulted in a sharp boundary with NR20, which was deposited from a muddy river. Deposition was followed by a period of organically productive, wetter, temperate climate with a fluctuating water table during which soil formation was initiated.

This was followed by an erosional event and NR21 was later deposited onto the eroded surface in a gravel-bedded river under high-energy conditions. Following deposition reduced fluvial competence resulted in a lag deposit. The surface subsequently underwent sub-aerial exposure under semi-arid conditions with a shallow water table, nearby shallow fresh or brackish water and sparse vegetation cover. A period of erosion or non-deposition ensued, followed by deposition of NR22, probably from a muddy river. As water levels fell the surface was exposed under an organically productive wet, temperate climatic regime. Deposition of NR23 followed reactivation of the river channel. Subsequently water levels fell, the channel was abandoned and the surface exposed. This was followed by conditions of semi-aridity with a shallow water table, nearby shallow fresh or brackish water and sparse vegetation cover. NR24 was deposited in a gravel-bedded river. Deposition was followed by sub-aerial exposure, increased aridity, decreased vegetation cover and a shallow, fluctuating water table. NR25 accumulated in a river channel; subsequent lower fluvial competence resulted in a lag deposit. Vertically oriented reed stems indicate that deposition may have been slow enough for vegetation growth to keep pace; however there are indications that this, and the overlying unit NR26, may have undergone anthropogenic disturbance. Deposition was followed by conditions of semi-aridity with a near-surface water table and sparse vegetation cover, although shallow fresh or brackish water was nearby.

Deflation of local fluvial deposits resulted in deposition of NR26 in a sheltered topographic hollow of a braid plain. Again, vertically oriented plant stems indicate deposition was slow enough for vegetation growth to keep pace. This was followed by a period of organically productive, wetter, temperate climate.

The stratigraphy, description, and inferred depositional and post-depositional environments of core NR are summarised in Table 8.6.

Table 8.6: Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core NR

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
NR26 (2.59 to 2.68)	Olive very poorly sorted slightly gravelly silty fine sand. There are vertically oriented organics and small shell fragments. Calcareous, with low organic and moderate clay content. Gradational, planar basal contact.	Aeolian; deflation of local fluvial deposits	Temperate, wet climate; organic productivity
NR25 (2.39 to 2.59)	Brown very poorly sorted gravelly silty sand. There are vertically oriented reed stems and roots throughout unit, with leaf fragments towards the base of the unit, very small shell fragments and carbonate nodules. Very calcareous, with very low organic and moderate clay content. Basal contact coincides with the base of the core section and is unclear but appears to be gradational.	Sand-bedded river channel	Semi-arid; sparse vegetation
NR24 (2.32 to 2.39)	Brown extremely poorly sorted silty sandy gravel comprising highly weathered, very angular, platy and bladed limestone clasts. The unit contains organic fragments, including reed stems, rare, very small, shell fragments and carbonate nodules. Calcareous, with low organic content and moderate clay content. Sharp, irregular basal contact.	Gravel-bedded river channel	Semi-arid; sparse vegetation; shallow, fluctuating, water table
NR23 (2.21 to 2.32)	Strong brown very poorly sorted gravelly silty sand. The unit contains organic fragments, including vertically oriented reed stems, and small shell fragments. Calcareous, with very low organic and moderate clay content. Sharp, irregular basal contact dips at 20°.	Sand-bedded river channel	Semi-arid; sparse vegetation; shallow water table

Table 8.6 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core NR

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
NR22 (2.13 to 2.21)	Brown very poorly sorted gravelly silt. There are small pebble-sized poorly consolidated carbonate nodules, and small (~ 3 mm) red flecks can be seen throughout the unit. The unit contains detrital organic fragments and is slightly calcareous with low organic and high clay content. Sharp, irregular basal contact.	Muddy river	Temperate, wet climate; organic productivity
NR21 (1.83 to 2.13)	Strong brown extremely poorly sorted gravel in a silty sandy matrix. The gravel comprises highly weathered, very angular, elongate limestone clasts. The unit contains very small shell fragments, vertically oriented reed stems and other detrital organic fragments. Calcareous, with low organic and moderate clay content. Sharp, planar, unconformable basal contact.	High-energy gravel-bedded river	Semi-arid; sparse vegetation; shallow water table
NR20 (1.47 to 1.83)	Reddish brown becoming brown very poorly sorted gravelly silt. There are fine horizontal fractures (<1 mm thick) and three irregular sub-horizontal fractures 2-4 mm thick at 8, 12 and 30 cm from top of unit and iron-staining 19 cm from top of unit and a lens of strong brown medium sand. There are very soft, chalk-like, carbonate nodules, red flecks, vertical black streaks and a single shell fragment 2 cm above base of unit. Slightly calcareous, with moderate organic content and very high clay content. Sharp, irregular basal contact.	Muddy river	Temperate, wet climate; organic productivity: fluctuating water table; pedogenesis

Table 8.6 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core NR

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
NR19 (1.39 to 1.47)	Brown very poorly sorted matrix-supported gravel comprising moderately weathered, angular and sub-angular, platy medium pebble to granule-sized limestone clasts in a silty sandy matrix. There is a vertically oriented root or stem running through the unit and organic detritus and shell fragments. Calcareous, with low organic and high clay content. Basal contact coincides with the base of the core section and is unclear but appears to be gradational.	Gravel-bedded river channel	Shallow water table; landscape stability
NR18 (1.27 to 1.39)	Reddish yellow to strong brown very poorly sorted gravelly silty sand. There are detrital organic fragments and rare shell fragments. Calcareous, with low organic and high clay content. Sharp, irregular basal contact.	Sand-bedded river channel	Landscape stability; organic productivity
NR17 (1.21 to 1.27)	Brown extremely poorly sorted silty gravel comprising highly weathered, platy, very platy or compact-elongate, very angular medium pebble to granule-size limestone clasts. There is a vertically oriented reed stem. Slightly calcareous, with low organic and moderate clay content. Sharp, irregular and unconformable basal contact.	Gravel-bedded river	Temperate, wet climate; organic productivity
NR16 (1.06 to 1.21)	Strong brown very poorly sorted matrix-supported gravel comprising moderately weathered, angular, bladed very large pebble to granule-size limestone clasts in a silty sandy matrix. There are organic fragments, including tangled fine roots. Calcareous, with low organic and very low clay content. Sharp, planar and unconformable basal contact.	Turbulent gravel-bedded river	Semi-arid; sparse vegetation; shallow water table

Table 8.6 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core NR

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
NR15 (1.04 to 1.06)	Dark yellowish brown very poorly sorted silty sandy gravel comprising moderately and slightly weathered, compact, angular large pebble to granule-size limestone clasts. Calcareous, with low organic and very low clay content. Gradational, planar basal contact.	Gravel-bedded river	Climatic cooling; reduced vegetation; fluctuating water table; pedogenesis - cessation ^{14}C dated to 13430 to 13190 Cal BP
NR14 (1.00 to 1.04)	Strong brown very poorly sorted silty sandy gravel comprising slightly weathered, compact-elongate, angular, medium pebble to granule-size limestone clasts. Contains very small shell fragments. Very calcareous, with moderate organic and very low clay content. Gradational, planar basal contact.	Gravel-bedded river	Temperate climate; landscape stability; shallow water table; organic productivity
NR13 (0.78 to 1.00)	Strong brown very poorly sorted matrix-supported gravel comprising moderately weathered, bladed, angular and sub-angular large pebble to granule-size limestone clasts in a silty sandy matrix. There are shell fragments throughout the unit and a fossil fruit or seed 12 cm below the top of unit. Very calcareous, with low organic and very low clay content. Gradational, planar basal contact.	High-energy gravel-bedded river channel	Temperate climate; landscape stability; shallow water table; organic productivity
NR12 (0.69 to 0.78)	Reddish yellow poorly sorted slightly gravelly silty sand. Slightly calcareous, with low organic and very low clay content. Gradational, planar basal contact.	Sand-bedded river channel	Cool, wet
NR11 (0.63 to 0.69)	Yellowish brown poorly sorted sand containing a few very small shell fragments. Slightly calcareous, with very low organic and low clay content. Sharp, planar basal contact.	Braided stream	Cool, wet

Table 8.6 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core NR

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
NR10 (0.59 to 0.63)	Strong brown poorly sorted slightly gravelly silty sand containing very small shell fragments. Calcareous, with low organic and moderate clay content. Sharp, irregular and unconformable basal contact.	Aeolian; deflation of local braid plain deposits	Temperate, wet climate; organic productivity
NR9 (0.39 to 0.59)	Strong brown to yellowish red very poorly sorted clast-supported silty sandy gravel comprising slightly weathered, bladed, angular large pebble to granule-size limestone clasts. Some pebbles are stained black or coated with a black precipitate. Contains shell fragments. Very calcareous, with low organic and very low clay content. Basal contact coincides with the base of the core section and is unclear, but appears to be gradational.	High-energy gravel-bedded river	Unstable landscape; fluctuating water table
NR8 (-0.01 to 0.39)	Strong brown very poorly sorted gravelly silty sand. There are detrital organic fragments including fragments of stem and leaf 6 cm from the top of the unit and very small shell fragments 14 cm from the top of the unit. Calcareous, with low organic and clay content. Gradational, planar basal contact.	Sand-bedded river channel	Unstable landscape semi-arid; sparse vegetation
NR7 (-0.17 to -0.01)	Strong brown very poorly sorted matrix-supported gravel comprising moderately and slightly weathered, bladed, angular, large pebble to granule-size limestone clasts in a silty sandy matrix. Contains small shell fragments. Very calcareous, with low organic content and very low clay content. Gradational, planar basal contact.	High-energy gravel-bedded river	Semi-arid; sparse vegetation; shallow water table

Table 8.6 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core NR

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
NR6 (-0.26 to -0.17)	Strong brown very poorly sorted clast-supported silty sandy gravel comprising moderately and slightly weathered, bladed, angular, medium pebble to granule-size limestone clasts. Contains small shell fragments. Very calcareous, with low organic and very low clay content. Sharp, planar basal contact.	High-energy gravel-bedded river	Semi-arid; sparse vegetation; shallow water table
NR5 (-0.28 to -0.26)	Reddish yellow very poorly sorted silty sandy gravel comprising slightly weathered, compact-bladed, angular limestone clasts. Very calcareous, with very low organic and clay content. Sharp, planar basal contact.	High-energy gravel-bedded river channel	Semi-arid; sparse vegetation; shallow water table
NR4 (-0.32 to -0.28)	Reddish yellow very poorly sorted clast-supported silty sandy gravel comprising horizontally oriented slightly weathered, bladed, angular, large pebble to granule-size limestone clasts. Contains small shell fragments. Very calcareous, with low organic and very low clay content. Sharp, planar basal contact.	Turbulent gravel-bedded river	Semi-arid; sparse vegetation; shallow water table
NR3 (-0.38 to -0.32)	Reddish yellow very poorly sorted gravelly sand containing shell fragments. Very calcareous, with very low organic and clay content. Sharp, planar basal contact.	Sand-bedded river channel	Semi-arid; sparse vegetation; shallow water table
NR2 (-0.61 to -0.38)	Reddish yellow very poorly sorted clast-supported gravel comprising slightly weathered, bladed, angular, large pebble to granule-size limestone clasts. Contains shell fragments. Very calcareous, with low organic and very low clay content. Basal contact coincides with the base of the core section and is unclear, but appears to be gradational.	High-energy gravel-bedded river channel	Shallow water table; landscape stability

Table 8.6 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core NR

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
NR1 (-0.67 to -0.61)	Strong brown poorly sorted slightly gravelly silty sand containing very small shell fragments and organic detritus. Very calcareous, with low organic and very low clay content.	Aeolian; deflation of local braid plain deposits	

8.8 Palaeoenvironmental history of core CM

CM1 was deposited in a slow-flowing muddy river. Subsequent emergence of the surface and more stable landscape conditions led to the initiation of pedogenesis with organic-rich soil and hydrological carbonate production under climatic conditions that were at least as warm as those pertaining today. This was followed by a period of erosion or non-deposition that resulted in a sharp boundary with CM2 which accumulated in a sheltered topographic hollow from deflated local fluvial deposits. Following deposition there was a period of erosion or non-deposition and the surface underwent sub-aerial exposure; vegetation cover was less extensive than after deposition of CM1 and the climate was increasingly arid.

CM3 was deposited under high-energy conditions from locally available glacial sediment in a gravel-bedded river. As flow waned, reduced fluvial competence left a lag deposit which was later subjected to limited sub-aerial exposure and weathering prior to burial by CM4 following channel reactivation. Again, waning flow and reduced fluvial competence left a lag deposit whose surface was later subjected to limited sub-aerial exposure and weathering. The very shallow water table fluctuated and the gravel was frequently waterlogged. Following this period there was landscape stability with organic-rich soil and hydrological carbonate production in a shallow water table.

CM5, CM6 and CM7 are discrete deposits from an intermittently flowing muddy river. Following deposition of CM5 there was a period of landscape stability, with sub-aerial exposure of the surface and a shallow water table, pedogenesis and plant growth were initiated and there was bioturbation of the sediment. Deposition of CM6, which includes material eroded from a nearby vegetated surface, was followed by sub-aerial exposure of the surface during a period of landscape stability. There was organic-rich, bioturbated, waterlogged soil and hydrological carbonate production around a very shallow water table. Following deposition of CM7 there was limited sub-aerial surface exposure, with a fluctuating, shallow water table, periodic waterlogging and initiation of hydromorphic soil formation. There was reduced vegetation cover and increasing aridity.

CM8 was deposited under high-energy conditions from locally available sediment in the channel of a gravel-bedded river. As flow waned, reduced fluvial competence left a lag deposit which was later subjected to sub-aerial exposure and weathering, with a shallow water table. Following deposition aridity increased, vegetation cover reduced and there was a period of erosion or non-deposition. Deposition of CM9 and CM10 in a river channel was followed by reduced fluvial competence, resulting in lag deposits. After deposition of CM9 there was a period of landscape stability, organic production and hydrological carbonate production, whereas CM10 was followed by climatic cooling, resulting in reduced vegetation cover and waterlogged sediment. Limited surface exposure of CM10 resulted in weak pedogenesis and bioturbation.

CM11 was deposited from a braided stream and was subsequently subjected to periodic waterlogging during a period of reduced vegetation cover and climatic cooling. Subsequently CM12 was deposited in a river channel under rapidly waning flow conditions, resulting in a lag deposit. Deposition was followed by periodic waterlogging. CM13 was deposited from a braided stream; subsequent reduction in fluvial competence resulted in a lag deposit. Following deposition there was stability of the land surface, although surface remained submerged for lengthy periods and weak pedogenesis and vegetation growth ensued in a wet, temperate climate.

The stratigraphy, description, and inferred depositional and post-depositional environments of core CM are summarised in Table 8.7.

Table 8.7: Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core CM

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
CM13 (1.53 to 1.70)	Bluish grey very poorly sorted slightly gravelly sandy silt. Vertically and sub-horizontally oriented reed stems are present throughout the unit. Slightly calcareous, with high clay and moderate organic content. Sharp, irregular basal contact.	Braided stream	Wet, temperate climate; landscape stability; waterlogging; hydromorphic soil formation; organic productivity
CM12 (1.37 to 1.53)	Bluish grey very poorly sorted gravelly silty sand. A black manganese concretion lies towards the base of the unit. Slightly calcareous, with moderate clay and low organic content, although detrital organic remains are present throughout the unit. Gradational, irregular basal contact.	Sand-bedded river channel	Waterlogging
CM11 (1.17 to 1.37)	Grey to pinkish grey poorly sorted slightly gravelly silty sand containing fine organic detritus and small shell fragments. At the top of the unit is a void with a smooth internal surface and stone below it. The void has light greenish grey base material that contains a shell fragment. Slightly calcareous, with low clay and organic content. Gradational basal contact.	Braided stream	Climatic cooling; waterlogging; reduced vegetation
CM10 (1.06 to 1.17)	Greyish brown very poorly sorted gravelly silty sand containing small shell fragments and detrital organic fragments. An irregular bioturbation trace of finer material with a nearby unconnected void runs vertically downwards towards the base of the unit,. Calcareous, with moderate clay and low organic content. Sharp, irregular basal contact with the underlying silt extending irregularly upwards.	Sand-bedded river channel	Climatic cooling; waterlogging; weak pedogenesis; reduced vegetation

Table 8.7: Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core CM

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
CM9 (0.98 to 1.06)	Greyish brown very poorly sorted gravelly silt with sand inclusion and a single shell fragment close to the base. Calcareous, with moderate clay and organic content. Sharp, planar basal contact.	Silt-bedded river channel	Landscape stability; waterlogging; organic productivity
CM8 (0.51 to 0.98)	Brown extremely poorly sorted matrix-supported gravel comprising slightly weathered, bladed and platy, angular large pebble to granule-size limestone clasts in a silty sandy matrix. Calcareous, with low clay and organic content. Gradational, planar basal contact.	High-energy gravel-bedded river	Increasing aridity; shallow water table; reduced vegetation;
CM7 (0.42 to 0.51)	Dark yellowish brown very poorly sorted gravelly silt with strong brown mottling. Calcareous, with high clay and moderate organic content. Underlying silt is folded into sharp, irregular basal contact, which dips at 30°.	Muddy river	Landscape stability; weak pedogenesis; fluctuating, shallow water table; waterlogging; reduced vegetation; increasing aridity
CM6 (0.20 to 0.42)	Reddish brown very poorly sorted gravelly silt increasingly stony with depth. There are greenish grey concretions and mottles over ~ 5% area. Vertically oriented reed stems, starting and terminating abruptly, run through the mid-part of the unit. Towards the top of the unit is an olive brown streak. A void with smooth inner surface lies mid-unit. A single shell fragment lies towards the base of the unit. Calcareous, with very high clay and high organic content. Sharp, irregular basal contact.	Muddy river	Landscape stability: shallow water table; waterlogging; organic productivity

Table 8.7: Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core CM

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
CM5 (-0.11 to 0.20)	Brown to greyish brown very poorly sorted gravelly silt. There are vertical and horizontal fine fractures, sub-mm to 1 mm thick. There are two voids with smooth internal surfaces. The upper void lies close to the upper boundary and has a single angular large pebble-sized clast underneath it. A smooth bioturbation trace lies below the void. The lower void is mid-unit and is surrounded by greenish grey flame-shaped haloes of sub-mm thickness. Occasional small shell fragments are found throughout the unit and black organic remains, possibly a reed stem, run vertically through the unit. Calcareous, with very high clay and moderate organic content. Sharp, irregular basal contact.	Muddy river	Landscape stability; weak pedogenesis; shallow water table; waterlogging; organic productivity
CM4 (-0.33 to -0.11)	Greenish grey to olive brown extremely poorly sorted matrix-supported gravel comprising moderately and slightly weathered, bladed, sub-angular large pebble to granule-size limestone clasts in a silty sandy matrix. A reddish brown silt inclusion contains a round medium pebble-sized clast. Black mottling covers ~ 10% of the surface area of the lower part of the unit. Contains occasional small shell fragments. Calcareous, with low clay and moderate organic content. Sharp, slightly irregular basal contact dips at 15°.	High-energy gravel-bedded river	Landscape stability; fluctuating shallow water table; waterlogging; organic productivity

Table 8.7: Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core CM

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
CM3 (-0.48 to -0.33)	Dark yellowish brown very poorly sorted matrix-supported gravel comprising moderately to slightly weathered, bladed, angular and sub-angular medium pebble to granule-size limestone clasts in a silty sandy matrix. A group of imbricated, round reddish brown clasts which dip at 28-37° lies mid-unit. Also mid-unit is a shell fragment and a fragment of organic material. Very calcareous, with very low clay and low organic content. Sharp, irregular basal contact.	High-energy gravel-bedded river	Landscape stability: shallow water table; organic productivity
CM2 (-0.52 to -0.48)	Strong brown very poorly sorted gravelly silty sand. Very calcareous, with low clay and organic content. Sharp, basal contact dips at 20° and is marked by a <1 mm thick dark zone; round pebbles cross the contact with the underlying unit.	Aeolian; deflation of local fluvial deposits	Less vegetation; more arid climate
CM1 (-0.95 to -0.52)	Reddish brown very poorly sorted slightly gravelly sandy silt with greenish grey and red concretions. There are very small shell fragments, detrital plant remains and a black streak of possibly organic remains. Calcareous, with high clay and organic content.	Muddy river	Temperate climate; landscape stability; weak pedogenesis; organic productivity

8.9 Palaeoenvironmental history of core TG

TG1 was deposited in a muddy river. After deposition it was subjected to sub-aerial exposure under organically productive wet, temperate climate conditions. Subsequently TG2 was deposited from turbulent flow in a gravel-bedded river channel; deposition was followed by sub-aerial exposure, with a shallow water table, increasing aridity and reduced vegetation cover. TG3 was also deposited from turbulent flow in a gravel-bedded river channel, followed by an interval of non-deposition or erosion and sub-aerial exposure, with a shallow water table, increasing aridity and reduced vegetation cover.

TG4, TG5, TG6 and TG7 are all braided stream deposits; waning flow and reduced fluvial competence after deposition of TG6 and TG7 resulted in lag deposits. Following deposition of TG4 there was landscape stability, organic productivity and hydrological carbonate production. Deposition of TG5 was followed by an interval of organic productivity in a wet temperate climate. Deposition of TG6 was followed by an interval of organic productivity during which soil formation was initiated in a wet, temperate climate. TG6 and TG7 are separated by a sharp boundary, formed by an algal mat composed of *Chara*. *Chara* indicate a fresh or brackish water environment, in which temperatures reached at least 10°C. TG7 molluscan evidence indicates accumulation in a small stagnant pool and the presence of a perennial small stream, with vegetation-rich shallow margins. Ostracod and foraminiferal evidence from TG7 indicates the presence of brackish coastal pools and estuary-marginal freshwater shallow streams with perennial flow, rich in aquatic vegetation. The area was open to occasional marine inundation which resulted in marine and exotic species being incorporated into the sediment. Alternatively, the estuarine, marine and exotic components may have been reworked from an earlier interglacial deposit. The coleopteran evidence is less clear because of its fragmentary nature. However, it does not preclude the interpretations from other evidence; *Staphylinidae* are known to feed on algae, especially on sandy beaches and stream-sides. An interglacial age is suggested for TG7.

Deposition of TG7 was followed by landscape stability, sub-aerial exposure and erosion or non-deposition at the surface, organic productivity and hydrological carbonate production around a fluctuating water table. TG8 was deposited in a river channel; deposition was followed by reduced fluvial competence, resulting in a lag deposit. Molluscan evidence indicates that deposition of TG8 was in a vegetation-free meandering stream channel, faster flow over sandy riffles and slow moving water in pools. *Pisidium obtusale*, *Radix balthica* and *Gyraulis laevis* indicate that stream margins were shallow, almost stagnant and vegetation-rich and the absence of land molluscs suggests a lack of surface flow to wash them into the channel (Lewis *et al*. 2006). Ostracod, foraminiferal and algal evidence indicates algal-rich littoral intertidal low marsh and estuary-marginal brackish water pools near a channel margin. The area was subject to frequent marine inundation which transported marine, estuarine and exotic species inland from the marine shelf, and these were incorporated into the sediment. Ostracod and foraminiferal evidence indicates an interglacial stage during which sea-level was close to that of the present day. This is consistent with AAR geochronology correlation with late MIS 7 or early MIS 5e, but a MIS 7 age is more likely (K.E. H. Penkman, 2010, Pers. comm.).

TG8 was later subjected to fluctuations in ground water level, with a periodically sub-aerially exposed surface. There was a reduction in vegetation cover, increased aridity, and a period of non-deposition or erosion ensued. TG9 was subsequently deposited in the channel of a gravel-bedded river under high-energy conditions which mobilised locally available sediment, including some glacial material. Deposition was followed by a reduction in vegetation cover and increased aridity, with a shallow water table and sub-aerial exposure of the surface.

TG10 and TG11 were deposited from a muddy river. TG10, which grades into TG11, was deposited as thin beds. Occasional rippling of the beds indicates deposition under flowing water and the iron-stained upper contact of some beds indicates sub-aerial exposure. Deposition of TG11 was followed by increased organic productivity and carbonate leaching in a wet, temperate climate. There was an erosional episode prior to deposition of TG12 in a river channel. This was followed by a reduction in fluvial competence, resulting in a lag deposit, increased aridity and decreased vegetation cover.

A subsequent period of erosion or non-deposition resulted in a sharp boundary with TG13, which was deposited in a gravel-bedded river under high-energy conditions which mobilised locally available sediment, including some glacial material. Following deposition there was a period of landscape stability, organic productivity and soil formation was initiated. A shallow water table facilitated hydrological carbonate deposition and the surface underwent sub-aerial exposure. Another interval of erosion or non-deposition resulted in a sharp boundary with TG14, which was deposited in a gravel-bedded river under turbulent flow conditions which again mobilised locally available sediment. Later the surface of TG14 underwent sub-aerial exposure and there was reduced vegetation cover, increased aridity and a low water table. This was followed by an erosional event, after which TG15 was deposited from a muddy river. Following deposition there was a period of landscape stability. The surface underwent sub-aerial exposure, soil formation was initiated and there was organic productivity.

TG16 to TG22 were subsequently deposited from a series of intermittently flowing braided streams. Carbonate nodules just below the surface of TG16 indicate a post-depositional period of aridity. TG18 is a thinly interbedded minerogenic/organic unit, which suggests repeated inwash of organic-rich sediment at the edge of a fluctuating body of water. During these depositional episodes, there was landscape instability with fluctuations in vegetation cover and hydrological carbonate production. There was a shallow, fluctuating water table with frequent waterlogging and a peaty pedogenic complex formed.

The stratigraphy, description, and inferred depositional and post-depositional environments of core TG are summarised in Table 8.8.

Table 8.8: Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core TG

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
TG22 (1.95 to 2.08)	Dark grey poorly sorted silt with gastropod shells at the upper (peat) contact, common shell debris in the upper 4 cm and occasional shell fragments throughout. The unit contains organic detritus, mainly plants. Very calcareous, with high clay and very high organic content. Gradational, planar basal contact.	Braided stream	
TG21 (1.83 to 1.95)	Dark greyish brown poorly sorted sandy silt with many small organic fragments throughout and a single shell fragment. There are two horizontal very thin beds with greater organic content, comprising horizontally oriented stems and detrital plant remains. Very calcareous, with high clay and very high organic content. Gradational, planar basal contact.	Braided stream	Landscape instability; shallow, fluctuating water table; waterlogging; fluctuating organic productivity; peaty pedogenic complex
TG20 (1.73 to 1.83)	Brown very poorly sorted gravelly silty sand containing plant debris, stems and fine rootlets. Calcareous, with moderate clay and organic content. Gradational, planar basal contact.	Braided stream	

Table 8.8 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core TG

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
TG19 (1.38 to 1.73)	Very dark greyish brown poorly sorted peaty silty sand with fine rootlets and organic detritus. Very calcareous, with moderate clay and low organic content. Gradational, planar basal contact.	Braided stream	Landscape instability; shallow, fluctuating water table; waterlogging; fluctuating organic productivity; peaty pedogenic complex
TG18 (1.07 to 1.38)	Thinly bedded dark brown to dark greyish brown organic-rich peaty clays interbedded with greyish brown poorly sorted sandy silt. Individual beds are horizontal with sharp basal contacts. There are very fine rootlets, leaf remains and organic detritus and occasional shells or shell fragments. Very calcareous, with very high clay and high organic content. Gradational, planar basal contact.	Braided stream	
TG17 (0.95 to 1.07)	Greenish grey poorly sorted silty sand containing vertically oriented fine roots and rootlets with leaf and stem detritus; organic content increases with depth. Calcareous, with moderate clay and organic content. Gradational, planar basal contact.	Braided stream	Landscape instability; shallow, fluctuating water table; waterlogging; organic productivity

Table 8.8 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core TG

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
TG16 (-0.33 to 0.95)	Greenish grey becoming bluish grey poorly sorted sandy silt. There are two 1-1.5 cm thick horizontal layers of light greenish grey silt and thin beds of fine sand with sharp upper and lower contacts with the silt. The sand beds extend both upwards and downwards irregularly for several centimetres. The unit contains carbonate concretions and organic material consisting mainly of vertically oriented stems and rootlets, with larger fragments of stems or leaves and one horizontally oriented piece of root or stem. There are occasional shells or shell fragments. Calcareous, with very high clay and high organic content. Basal contact is disturbed and unclear as it coincides with a thin bed of bluish grey fine sand.	Braided stream	Landscape instability; shallow, fluctuating water table; waterlogging; organic productivity
TG15 (-0.42 to -0.33)	Brown extremely poorly sorted gravelly silt containing very small shell fragments. The upper 2 cm are disturbed. There are fine (<1 mm thick) sub-horizontal fractures, not the full width of the core, throughout the unit. The gravel component comprises rounded small pebble-sized and sub-angular large pebble-sized clasts. Calcareous, with very high clay and high organic content. Sharp, irregular basal contact.	Muddy river	Landscape stability; waterlogging; organic productivity; weak pedogenesis

Table 8.8 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core TG

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
TG14 (-0.47 to -0.42)	Yellowish red very poorly sorted silty clast-supported gravel with dark red flecks up to 3 mm diameter. The gravel comprises slightly weathered, bladed, angular to sub-angular, large pebble to granule-size limestone clasts. Very calcareous, with low clay and organic content. Sharp, irregular basal contact.	Turbulent gravel-bedded river	Low water table; increasing aridity; reduced vegetation
TG13 (-0.64 to -0.47)	Reddish brown to strong brown extremely poorly sorted matrix-supported gravel comprising slightly weathered, compact-bladed, angular, large pebble to granule-size limestone clasts in a silt matrix. Shell fragments, including a broken gastropod shell, are found throughout the unit. Very calcareous, with moderate clay and organic content. Sharp, planar basal contact.	High-energy gravel-bedded river	Landscape stability; shallow water table; organic productivity; weak pedogenesis
TG12 (-0.67 to -0.64)	Strong brown very poorly sorted gravelly silty sand containing shell fragments. Calcareous, with low clay and organic content. Sharp, irregular basal contact.	Sand-bedded river channel	Shallow water table; increasing aridity; reduced vegetation
TG11 (-0.77 to -0.67)	Brown very poorly sorted slightly gravelly sandy silt. Very calcareous, with very high clay and high organic content. Gradational, slightly convex, basal contact grading into sand/silt laminations of underlying unit.	Muddy river	Wet, temperate climate; organic productivity
TG10 (-1.07 to -0.77)	Brownish yellow and light brown laminated/thin beds of very poorly sorted gravelly sandy silt. Laminations are slightly convex, occasionally rippled and upper contacts are occasionally iron-stained strong brown. Contains a fragment of calcified plant material. Very calcareous, with high clay and low organic content. Sharp, irregular, slightly convex basal contact.	Muddy river	

Table 8.8 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core TG

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
TG9 (-1.70 to -1.07)	Yellowish red becoming light reddish brown very poorly sorted clast-supported silty sandy gravel comprising moderately and slightly weathered, bladed, angular, very large pebble to granule-size limestone clasts. The clasts are imbricated at the upper contact and the largest pebbles are found towards the base of the unit. Rip-up clasts of highly weathered massive red clay with light greenish grey intraclasts are enclosed in reddish brown gritty silt and yellowish red coarse sand. The gravel contains a gastropod shell, shell fragments and some organic fragments. Very calcareous, with very low clay and low organic content. Sharp, planar basal contact.	High-energy gravel-bedded river	Shallow water table; increasing aridity; reduced vegetation
TG8 (-1.86 to -1.70)	Light brown becoming strong brown with iron staining very poorly sorted gravelly silty sand. There are manganese nodules and the unit is very shelly, with gastropod, bivalve and limpet shells and shell fragments, ostracods, foraminifera, chara oogonia, some of which are lightly cemented together. Very calcareous, with very low clay and organic content. Sharp, planar unconformable basal contact.	Sand-bedded river channel; interconnected streams and intertidal pools	Fluctuating water table; increasing aridity; reduced vegetation Freshwater gastropod shells AMS ^{14}C dated to 45460 ± 790 BP and AAR geochronology correlation of *Valvata piscinalis* gastropod shells of MIS 7/5e

Table 8.8 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core TG

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
TG7 (-1.93 to -1.86)	Yellowish brown becoming olive brown poorly sorted slightly gravelly sandy silt. The upper contact and first 1 cm below is iron stained and the change to olive brown colouring coincides with the presence of horizontally oriented organic fragments. Towards the base of the unit are irregular horizontal fractures <1 mm thick across the width of the core. Contains molluscs, ostracods, foraminifera, algae (*Chara*), coleoptera. Very calcareous, with very high clay and moderate organic content. Sharp, planar basal contact is marked by the presence of organic remains.	Braided stream; interconnected streams and intertidal pools	Landscape stability; fluctuating water table; organic productivity
TG6 (-1.97 to -1.93)	Grey poorly sorted sandy silt containing organic and shell fragments. Very calcareous, with very high clay and moderate organic content. Gradational, planar basal contact.	Braided stream	Wet, temperate climate; organic productivity; weak pedogenesis
TG5 (-2.38 to -1.97)	Yellowish brown poorly sorted sandy silt. Very calcareous, with very high clay and low organic content. Change in colour marks a sharp, irregular, flame-shaped basal contact.	Braided stream	Wet, temperate climate; organic productivity
TG4 (-2.46 to -2.38)	Pink poorly sorted sandy silt with black specks (<1 mm wide) running vertically through the unit. Very calcareous, with very high clay and low organic content. Sharp, irregular basal contact.	Braided stream	Landscape stability; organic productivity

Table 8.8 (continued): Summary of the stratigraphy, description, and inferred depositional and post-depositional environments of core TG

Unit (Altitude m OD)	Description	Depositional environment	Post-depositional environment
TG3 (-2.53 to -2.46)	Light reddish brown very poorly sorted clast-supported gravel comprising slightly weathered, compact-elongate, very angular and angular, large pebble to granule-size limestone clasts. Very calcareous, with very low clay content and low organic content. Gradational, irregular basal contact.	Turbulent gravel-bedded river channel	Shallow water table; increasing aridity; reduced vegetation
TG2 (-2.59 to -2.53)	Weak red extremely poorly sorted silty gravel comprising slightly weathered, platy and bladed, very angular to sub-angular large pebble to granule-size limestone and sandstone clasts and greenish grey rip-up clasts. Clasts are embedded in the weathered surface of TG1 and weathering increases downwards. Calcareous, with low clay and high organic content. Gradational, irregular basal contact.	Turbulent gravel-bedded river	Shallow water table; increasing aridity; reduced vegetation
TG1 (-2.67 to -2.59)	Reddish brown very poorly sorted slightly gravelly silt containing a single highly weathered large pebble-size clast. Very calcareous, with high clay and moderate organic content.	Muddy river	Wet, temperate climate; organic productivity

8.10 Summary of the depositional history of the minerogenic sediments

The stratigraphies record multiple depositional events interspersed with periods of erosion or non-deposition. The sedimentary characteristics of the cores indicate repeated episodes of fluvial activity, recording changes in fluvial style, stream competence, discharge regime, sediment:water ratios and material availability. Some cores demonstrate repeated fluvial inundation in a flashy regime, with channel inability to cope with rapid inundation. Episodes of intermittent stream activity, channel abandonment and reactivation, flooding, ephemeral stream flow associated with both single-thread and braided-stream planforms (Allen 1970, Reineck & Singh 1973), fluctuating groundwater levels and aeolian deposition are identified. There is evidence of reworking of pre-existing aeolian and glacial deposits, whilst lithological changes indicate possible changes in gravel provenance.

Climate varied throughout sediment deposition; periods of semi-aridity, climate amelioration, temperate and cool, wet climate are all recorded. There were periods of landscape stability during which pedogenesis took place, bioturbation of surfaces occurred and there was colonisation of exposed land surfaces by vegetation. However, repeated burial by subsequent deposits often prevented full soil development, resulting in repeated weak pedogenesis, whilst waterlogging resulted in hydromorphic soil formation. Intertidal deposits prior to *c*. 200 ka record sea levels slightly lower than at present.

Analyses indicate at least eight episodes of turbulent or high-energy gravel-bedded river aggradations (core NR) where the extremely to very poorly sorted, very angular and angular gravels suggest flows with sufficient energy to transport large clasts over a short time-span (Colombo 2005). At least six instances of braided stream flow are recorded (core PGA). Pleistocene braided stream deposition is usually recorded as gravel aggradations, attributed to cold stages (Gao *et al*. 2000, Vandenberghe 2001, Gibbard & Lewin 2002), although braiding may occur in rivers with fine-grained sediments (Reineck & Singh 1973). All recorded instances of braided stream deposition in the Gordano Valley involve silt and sand size material. This might reflect a reduction in stream competence at the valley fringes as a result of a change in bed gradient (Brewer & Lewin 1998), or highly seasonal stream flow, coupled with absence of vegetation, permafrost preventing infiltration and aeolian activity contributing an abundance of available sediment, resulting in the development of a sandy braided fluvial system (Mol 1997, van Huissteden & Kasse 2001, Vandenberghe 2001).

Silt/sand-bedded rivers are recorded on at least six occasions (core NR) reflecting deposition in a low energy river system (Mol 1997, Mol *et al*. 2000, Gibbard & Lewin 2002). There is also one occasion of deposition from turbulent flow in a sand-bedded river (core PG), probably reflecting a short-term increase in flow. Muddy river flow occurred on at least five occasions (core CGA), reflecting very low energy conditions with high suspended load (Vandenberghe 2001). There is one instance of mudflow (core PGA), representing low-speed viscous flow (Selby 1993). Finally, three episodes of aeolian deposition are recorded (core NR) which probably represent deposits deflated from exposed flood/braid plain sediment (Lowe & Walker 1997, Briant *et al*. 2004).

8.11 The post-depositional history of the minerogenic sediments

Relative changes in organic and carbonate content of the minerogenic sediments indicate periods of aridity, climatic amelioration and wet, temperate climates. Fluctuating water tables are inferred from the presence of manganese streaks, nodules and stained gravel clasts, iron mottling of sediment, Liesegang rings, carbonate nodules and carbonate deposits on clasts.

On the basis of sediment colour, organic, carbonate and clay content, pedogenesis is inferred on at least five occasions (cores CGB, CM and PGA); development of a pedocomplex is inferred for core TG. There are two clearly different periods of palaeosol formation on opposite sides of the valley, indicated by two different dates returned from radiocarbon dating of soil organic matter in CGA6 and NR15. If only one date had been obtained, it might have been assumed, despite their geographically wide spacing, that both palaeosols constituted part of the same event and they may then have been used for correlation between units of different cores.

Soil is often truncated by erosion prior to burial, and sharp upper boundaries for the majority of pedogenic units suggest erosion of one or more soil horizons (Catt 1990, Marriott & Wright 1993, Wright & Marriott 1996, Kraus 1999, Retallack 2001). This was followed by burial by fresh inputs of sediment and further soil development on the additional sediment. Stacked pedogenic units formed between episodes of deposition (for example, in cores CGB and PGA); these display similarities to those described at Kesselt, Belgium (Vandenberghe & Nutgeren 2001), although evidence for biological activity, which Vandenberghe & Nutgeren (2001) equated to a well-drained tundra soil, is lacking.

Vertically stacked palaeosols, truncated by subsequent erosional and depositional processes, (core CGB for example), often represent different periods of land surface stability formed in sedimentary systems undergoing net aggradation (Olsen 1998, Kraus 1999). In particular, sharp boundaries between consecutive pedogenic units (for example, between CGB10, CGB11 and CGB12) indicate a compound-truncated soil (Marriott & Wright 1993, Wright & Marriott 1996, Kraus 1999), and CGB11 represents an interval of increasingly rapid deposition, in which vegetation was initially able to grow, but was latterly overwhelmed by sedimentation. Given the steepness of the valley-side slope (dips of 40-60°), repeated downslope movement could account for vertically stacked pedogenic units. These are more likely to occur at the foot of a slope, where iron and manganese concretions are more common and mineral weathering weaker, because there is less leaching (Catt 1990). Repeated weak pedogenesis may therefore be the result of repeated colluvial burial, and although sedimentological analysis indicates deposition in a fluvial environment, this would not necessarily exclude deposition by debris flow.

Repeated stream flow and burial often prevented full soil development, resulting in a succession of minor palaeo-gleysols, (core CM for example). These were identified on the basis of elevated organic and clay content, and comprising grey horizons with iron mottles, although organic matter content of sediments does not necessarily reflect organic productivity since the amount of organic matter that accumulates also reflects processes of decomposition; very low organic content may reflect periods of high productivity during which there was also significant loss through decomposition (Mayle *et al.* 1999). This could account for why many of the pedogenic units of the Gordano Valley have low organic matter content. Conversely, high amounts of organic matter can be preserved at times of lower productivity when decomposition rates are significantly reduced (Mayle *et al.* 1999).

A number of geochemical changes, recorded as iron and manganese staining, Liesegang rings and manganese nodules in cores PG, PGA, CGA, CGB and NR on the valley margins indicate deposition under a relatively temperate climatic regime or post-depositional groundwater fluctuation (Retallack 2001). Carbonate nodules occurring as individual carbonate clasts irregularly distributed throughout the sediment in cores CGB and NR and carbonate deposits on gravel clasts are probably groundwater carbonate formations. These are characteristic of arid to semi-arid climates where amounts of precipitation are small or relatively high but intermittent and evaporation and evapotranspiration are high, leading to an annual soil moisture deficit (Jenkins 1985, Alonso-Zarza 2003). Candy (2009) reports groundwater carbonates from Pleistocene sites at West Stow and Clacton in eastern England which indicate arid or seasonally dry climates. However, although limestone within the catchment area would aid groundwater circulation, on reaching the valley floor groundwater movement would be impeded due to the relatively impermeable basement bedrock, forcing groundwater to move through the more permeable gravels (Stokes *et al.* 2007). This would mean both groundwater movement and water table were close to the surface, thus enhancing groundwater calcretisation (Alonso-Zarza 2003). Therefore, a near-surface, fluctuating water table is indicated for the formation of carbonate deposition on gravels of the Gordano valley.

8.12 The palaeontology of the minerogenic sediments

Palaeontological evidence indicates the presence of terrestrial, freshwater and intertidal palaeoenvironments within the Gordano Valley. Terrestrial environments are recorded close to the northern valley fringe. Fossil root traces in cores PGA and CGA indicate periods of vegetation growth and soil formation; the calcified burrow or root in PG1 is also consistent with pedogenic carbonate deposition (Alonso-Zarza 2003, Candy *et al*. 2006). Near-vertical bioturbation traces found in core CM could be root traces or, more likely, burrows; their shape suggests ichnofacies usually associated with littoral environments (Tucker 2003). The voids found in cores CGB and CM are also probably ichnofabric, possibly dwelling burrows, and indicate a water table below the base of these burrows at the time of their construction (Retallack 2001). Vertically orientated plant stems in CM5 and CM13 indicate *in situ* growth, pedogenesis and landscape stability (Tucker 2003), whilst *in situ* reed stems and organic material found in the upper units of core NR (NR16 and above) indicate vegetation growth prior to burial and suggest nearby shallow fresh or brackish water (McClintock & Fitter 1956). The green reed stem in NR25 suggests the presence of chlorophyll, photosynthesis and recent burial, although the depth of burial (2.54 m) would seem to preclude this possibility, suggesting possible disturbance of the two uppermost units of core NR. Freshwater environments are indicated by the commonly occurring plant and shell fragments, which were probably brought in by flood water, whilst pollen evidence indicates damp, disturbed ground, with fresh water nearby.

However, the most secure palaeontological evidence comes from two fossiliferous units in core TG which provide evidence of freshwater and intertidal environments. The brackish water assemblage of TG7 gives way (with a depositional hiatus) to the more freshwater assemblage of TG8. The mollusc assemblages of TG7 and TG8 are entirely freshwater species; there are no terrestrial or brackish water specimens. Absence of terrestrial species was used by Bates *et al*. (2002) to infer deposition in a large body of water rather than a small river channel at Allhallows, Kent. However, the domination of *Pisidium obtusale* of the mollusc assemblage of TG7 indicates accumulation in a small stagnant pool whilst *Ancylus fluviatilis* indicates the presence of a perennial small stream and *Radix balthica* (=*Lymnaea peregra*) and *Gyraulis laevis* inhabit slow moving, quiet water and pools in vegetation-rich environments. The molluscan evidence of TG8 also indicates accumulation in a fluvial environment; the dominance of *Valvata piscinalis* indicates flowing water, whilst *Ancylus fluviatilis*, *Pisidium subtruncatum* and *Sphaerium corneum* indicate a faster flowing thalweg. Conversely, *Radix balthica*, *Pisidium obtusale* and *Gyraulis laevis* inhabit slow moving slow moving streams and marginal standing water with rich vegetation. This suggests a river channel with faster flow and slow moving, almost stagnant water, in vegetation-rich shallow river margins and pools. It is possible the shells have been washed into TG7 from nearby, but the much larger numbers suggest that is not the case for TG8.

The mollusc assemblage is restricted in comparison to typical interglacial assemblages. There are only 8 species in TG8 and 7 species in TG7 whereas Preece (1999) records 37 species of freshwater molluscs from various Ipswichian (MIS 5e) Trafalgar Square sites and Coope *et al*. (1997) report 19 species of freshwater molluscs from Middle Devensian (MIS 3) deposits of the River Thames in South Kensington, London. This may be because their samples were obtained from a larger volume of material, or because the River Thames is considerably larger than any river that flowed through the Gordano Valley, or because these were entirely freshwater environments, whereas those of the Gordano Valley are estuary-marginal; Roe *et al.* (2009) record only 11 freshwater species from the MIS 9 and MIS 11 intertidal deposits at Cudmore Grove, Essex, where brackish water species were also recorded. Alternatively, increased inorganic deposition during progressively deteriorating late interglacial-earliest glacial (MIS 7a-6) climatic conditions, when deposits are poorly fossiliferous (Lewin & Gibbard 2010), may have resulted in a restricted mollusc assemblage.

There are two puzzles associated with the mollusc assemblages of TG: if TG8 is a fluvial environment and dry land is relatively close by, why are no terrestrial molluscs present? Secondly: if TG7 and TG8 are estuary-marginal environments, why are there no brackish water molluscs? A sample from Somersham, Cambridgeshire, with a sparse brackish fauna from an interglacial fauna typical of a stream near the limit of its tidal influence was considered anomalous by West *et al*. (1999). Similarly, these authors have suggested terrestrial mollusc assemblages are rarely encountered in cold stage deposits (West *et al*. 1999), which could explain the lack of terrestrial molluscs encountered in the Gordano Valley, although the presence of *Radix balthica*, *Pisidium obtusale* and *Gyraulis laevis* suggests these are temperate stage deposits. It is possible TG7 and TG8 may not be typical interglacial assemblages.

The ostracod evidence of TG7 and TG8 indicates the presence of coastal saline pools and estuary-marginal freshwater streams, with perennial flow, rich aquatic vegetation and algal-rich littoral intertidal marsh. The marine, estuarine and exotic species were probably transported in from the marine shelf on the tide, or storm surge such as that experienced in the Severn Estuary on 13 December 1981 (Proctor & Flather 1989), or alternatively have been reworked from an earlier deposit. This could be earlier in the same interglacial stage or from an earlier interglacial. TG7 is a predominantly freshwater assemblage whilst, in contrast to the mollusc faunas, that of TG8 is more compatible with mudflat to lower saltmarsh environments of a large estuary (Frenzel & Boomer 2005). Both ostracod assemblages are typically interglacial, demonstrating many similarities to the interglacial assemblage described at Somersham, Cambridgeshire, by West *et al*. (1999). The presence of *Finmarchinella angulata* and *Robertsonites tuberculatus* in both TG7 and TG8 may indicate slightly cooler conditions than those of the present day; Kidson *et al*. (1978) used their presence to infer cooler conditions for deposits in the Burtle Beds, Somerset.

The dominance of *Elphidium williamsoni*, *Haynesina germanica* and *Cibicides lobatulus* in the foraminiferal assemblages of TG7 and TG8 indicates intertidal low marsh, near a channel margin; marine, estuarine and exotic species were probably transported inland during occasional marine inundation and incorporated into the sediment (West *et al*. 1999, Horton & Murray 2007). Transport of intertidal species from the marine shelf onto intertidal marsh is known to occur in the Severn Estuary under present day conditions (Murray & Hawkins 1976). The foraminiferal assemblage described by Gilbertson & Hawkins (1974) at Holly Lane (sandy units 3 and 6) also indicated a near-marine environment and were attributed to local derivation from previous (undated) interglacial or glacial deposits. Alternatively, the estuarine, marine and exotic components have been reworked from an earlier interglacial deposit, although tests of various sizes are represented and specimens are well-preserved. If the assemblages have been reworked, they have most likely been transported only a short distance.

Similar low diversity ostracod and foraminiferal assemblages to those of TG8, and particularly of TG7 have been described for Boxgrove (Holmes *et al*. 2009), which suggests a similar environmental interpretation is applicable (Table 8.9). The Boxgrove ostracod assemblage was interpreted as having accumulated in small, shallow, permanent ponds, probably fed by springs or groundwater, and supporting rich aquatic vegetation.

Additionally, and similar to TG7, charophyte oogonia were abundant within the sediments, confirming the presence of aquatic vegetation (Holmes *et al*. 2009). All the Boxgrove ostracod taxa are essentially freshwater species, although many tolerate elevated salinity (Athersuch *et al*. 1989, Meisch 2000). The Boxgrove foraminiferal assemblage found within the pond facies is also highly euryhaline (Murray 1979), but may have been reworked from underlying regressive shallow-marine deposits from which ostracods are absent (Holmes *et al*. 2009).

Table 8.9: Comparison of Gordano Valley ostracod and foraminifera assemblage with that from Boxgrove (Holmes *et al*. 2009)

Species	Boxgrove	TG7 Gordano Valley	TG8 Gordano Valley
Potamocypris zschokkei	X	X	X
Ilyocypris bradyi	X	X	X
Prionocypris zenkeri	X	X	X
Candona neglecta	X	X	X
Herpetocypris reptans	X	X	
Elphidium williamsoni	X	X	X
Haynesina germanica	X	X	X
Ammonia falsobeccarii	X		
Cibicides lobatulus	X	X	X
Charophyte oogonia	X	X	X

Overall, the faunal evidence at Boxgrove does not suggest that salinity was markedly elevated (Holmes *et al*. 2009). In contrast, TG7 contains *Heterocypris salina*, an unequivocal ostracod indicator of elevated salinity (Meisch, 2000), although TG8 does not, whilst well-preserved foraminiferal tests of various sizes in TG7 and TG8 suggest that if these assemblages have been reworked, they have not been transported far.

Comparison with the Boxgrove assemblages suggests the presence of small, shallow, permanent, groundwater-fed ponds supporting a rich aquatic vegetation, in which salinity was slightly elevated from occasional marine inundation. This is supported for TG7 by molluscan and sedimentary evidence for a landscape of braided streams. However, evidence for TG8 suggests freshwater species accumulated in streamflow and marine and euryhaline taxa were carried in at high tide, a situation parallel to that described by West *et al*. (1999) at Somersham, Cambridgeshire.

8.13 The geochronology of the minerogenic sediments

The location of the dated minerogenic sediments, their ages, and their altitude are shown in Figure 8.1. It is possible to place a limited timescale on some events from the dates obtained, between which the chronology is floating. Three AMS radiocarbon dates have been obtained for the sediments, two from bulk sediment samples and one from mollusc shells. Although there can be problems with radiocarbon dates of bulk sediment samples, they are used here to provide an indication of the date of cessation of pedogenesis rather than an absolute date for sediment deposition. If these dates are accepted, then they provide a framework for deposition of the rest of the sediments.

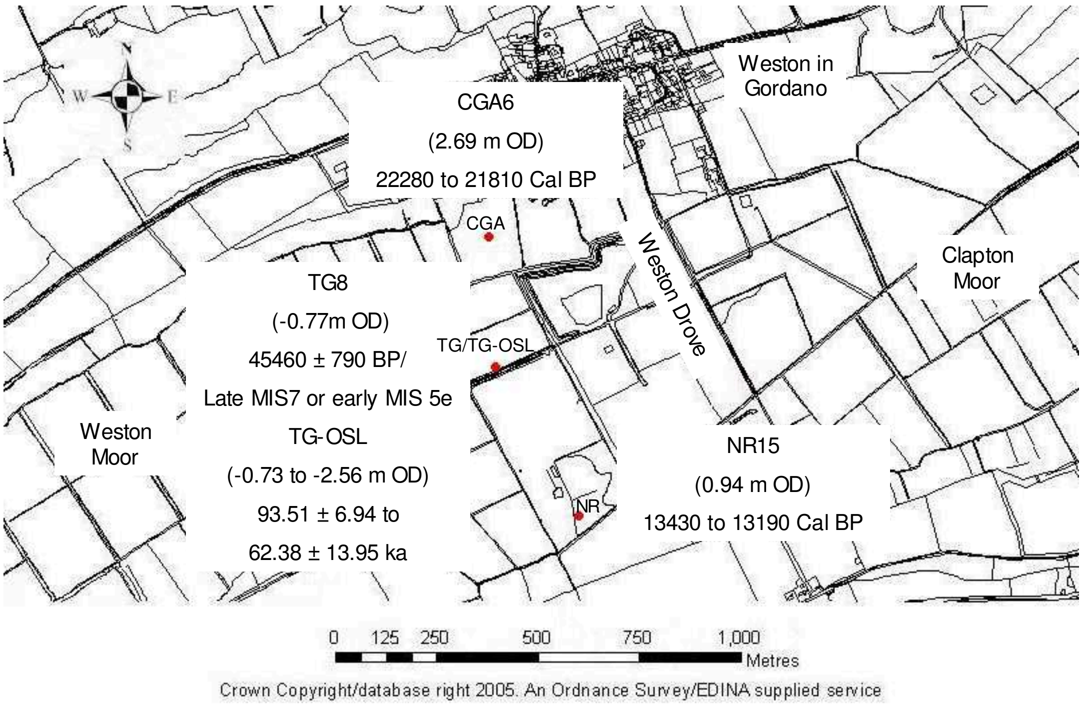


Figure 8.1: Locations of dated Pleistocene sediments, altitude and ages

The 13430 to 13190 Cal BP date for cessation of pedogenesis in NR15 approximates to the timing for the Younger Dryas (Loch Lomond) Stadial, indicating pedogenesis occurred during the Devensian Lateglacial Interstadial or earlier, and suggests that some of the overlying sediments may be Holocene (MIS 1). The 22280 to 21810 Cal BP date for cessation of pedogenesis in CGA6 approximates to the timing of the LGM extent of the BIIS, correlated with the Heinrich 2 event (Bowen *et al.* 2002, Guiter *et al.*

2003), and indicates pedogenesis occurring prior to MIS 2. This also suggests deposition of the overlying units probably took place after the LGM. The repeated episodes of weak pedogenesis displayed in these units suggest that they were deposited during a period of climatic fluctuation, such as is known to have occurred during the lateglacial period; for example, Walker *et al*. (2003) have shown at Llanilid, south Wales, that lateglacial climate underwent two episodes of marked climatic cooling interspersed with one of slight climate amelioration.

The age of mollusc shells in TG8 presents a problem. At the time the radiocarbon date was obtained it was assumed that the presence of freshwater molluscs indicated a wholly terrestrial environment, and a radiocarbon date of 45460 ± 790 BP, indicating a mid-Devensian (MIS 3) age for the mollusc shells, was consistent with this. However, AAR subsequently returned results indicating early MIS 5e (*c*. 130 ka) or late MIS 7 (*c*. 200 ka) for mollusc shells from TG8, whilst OSL dates (93.51 ± 6.94 to 62.38 ± 13.95 ka) of nearby core TG-OSL sediments indicate Early Devensian (MIS 5d–4) deposition. The mollusc shells were very numerous and in good condition, whilst ostracod shells from the same unit were in similar good condition, some even having left and right valves attached, indicating that they were *in situ*, so it is unlikely the shells were incorporated at a later date.

It is probable that the radiocarbon date is too young, being at the limit of the technology. If the radiocarbon date is correct then sea-levels in MIS 3 were much higher than has previously been thought (Lambeck *et al*. 2002a). Alternatively, if sea-level models for MIS 3 are correct, then the fossils represent an assemblage from an earlier interstadial or interglacial. Although AAR and OSL techniques do not have the same temporal limitation as radiocarbon dating, the OSL dates also appear to be too young; sea levels during interstadials MIS 5c and 5a were ~ 17 m lower than today (Cutler *et al.* 2003), much lower than that indicated by the faunal assemblages, so an Ipswichian (MIS 5e) age or earlier is more likely. This is supported by AAR geochronology correlation with early MIS 5e (*c*. 130 ka) or late MIS 7 (*c*. 200 ka) when sea levels were closer (~ -18 to -9 m relative to present sea-level, Bard *et al*. 2002) to that indicated for TG8. However, because of rapid lateral changes in sediments demonstrated in the Gordano Valley, the OSL dates are not necessarily incorrect. There is no evidence for fossiliferous deposits in core TG-OSL similar to those of core TG, so it is possible they refer to a different depositional episode. Acceptance of the AAR geochronology suggests deposition during MIS7a or early MIS 5e, both warm climatic intervals. Overall, it is likely that the AAR correlation is correct for

TG8 and that the OSL dates are correct for the adjacent sediments of core TG-OSL. Irrespective of the absolute chronology, the sedimentological and palaeoenvironmental interpretation remain valid.

8.14 Reconstruction of the Pleistocene palaeoenvironments of the Gordano Valley

The Gordano Valley Pleistocene palaeoenvironments have been reconstructed from the available sedimentary evidence. In making this reconstruction, it was necessary to find mechanisms which explain the aerial extent and surface morphology of the sediments whilst also accounting for the sedimentological variation that was identified during core analysis. Several environments have been identified which could account for the aerial extent, hummocky surface morphology and geometries of the minerogenic sediments found in the Gordano Valley, and these are considered first. A reconstruction of the Pleistocene palaeoenvironments is then provided.

8.14.1 Hummocky moraine

Hummocky moraine is deposited due to *in situ* glacial stagnation during deglaciation (Hambrey 1994, Bennett & Glasser 1996, Lowe & Walker 1997) or ice–marginal deposition (Evans 2003) whereby dead glacier ice is reduced to ice-cored moraine whose final decay leaves a series of hummocky moraines (Hambrey 1994). Hummocky moraine may form as a single area of hummocks and has a morphology of mounds, ridges and enclosed hollows with an irregular planform (Bennett & Glasser 1996). On Pedersenbreen, Svalbard, in the High Arctic, Bennett *et al*. (1996) found individual mounds to be of variable size and geometry, varying from 10–100 m in length and 2-3 m in width (Bennett *et al*. 1996). Figure 8.2 illustrates how this may have occurred in the Gordano Valley. This is consistent with the planform and surface morphology of the Gordano Valley sediments, albeit much altered by post-depositional erosion, and provides a theoretical model for their depositional environment.

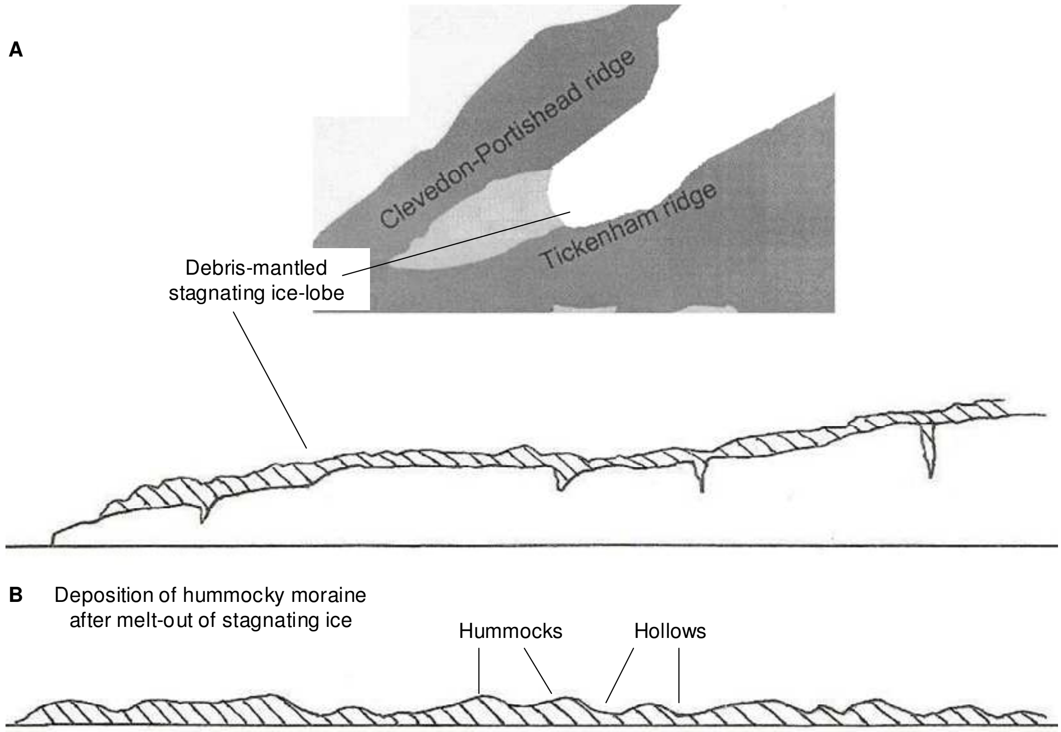


Figure 8.2: Theoretical model for deposition of hummocky moraine in the Gordano Valley. A. Lobe of debris-mantled stagnating ice in Gordano Valley. B. After melt-out of ice, debris is deposited on valley floor resulting in hummocky topography

Evidence for a glacial origin would take the form of poorly or non-sorted deposits with a wide range of clast sizes often with fragile clasts, polished or chattermarked clast surfaces, with crescentic gouges or striations, variable clast lithology including exotic clasts, angular to round clasts, or calcareous crusts on clasts (Hambrey 1994). However, although the Gordano Valley deposits meet some of these criteria (poor sorting, exotic clasts, crescentic gouges, chattermarks, calcareous crusts on clasts, clast roundness), a clear glacial signature is lacking for most of the Gordano Valley gravels. Furthermore, the presence of pedogenic units amongst the sediments suggests these are not glacial in origin whilst radiocarbon dates indicate that deposition of at least some of the sediments occurred after the LGM. It is unlikely therefore that the sediments represent primary glacial deposition.

8.14.2 Tidal channels

Hummock and hollow surface morphology may represent relict salt marsh topography which records the growth and decay of intertidal salt marsh creeks, such as Allen (2000b) documents in Holocene (MIS 1) coastal sediments in the Severn Estuary, Thames Estuary, Essex marshes, north Norfolk and Lincolnshire. These are essentially dendritic networks of meandering channels, salt pans and ponds and require sea level to be approximately the same as present day (Allen 2000b, Haslett 2000). Figure 8.3 illustrates a theoretical model of an intertidal salt marsh depositional environment resulting in the hummocky surface morphology of the Gordano Valley minerogenic sediments.

However, only two units in the Gordano Valley contain faunal evidence suggesting intertidal environments in what appears to be a particularly favourable location for their preservation and both units indicate fresh- as well as brackish water environments and sea level slightly lower than that pertaining today.

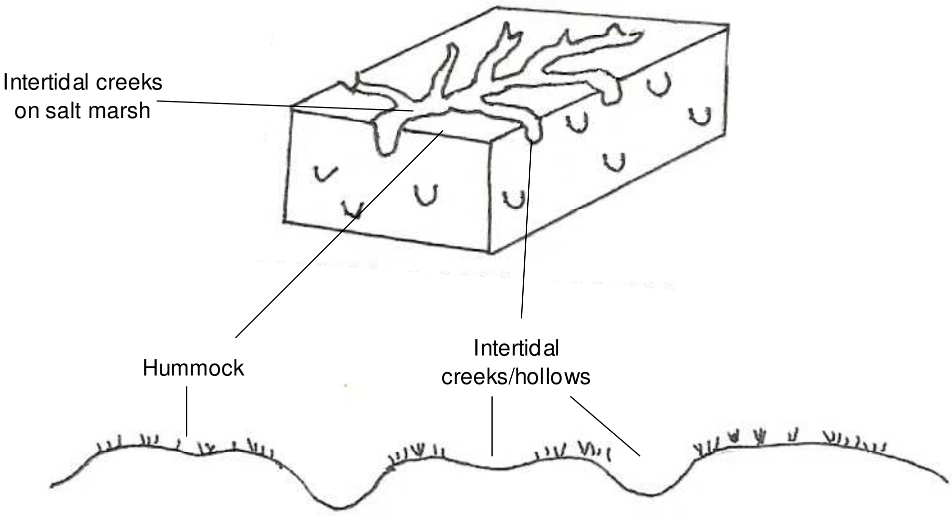


Figure 8.3: Theoretical model for intertidal salt marsh deposition of the Gordano Valley minerogenic sediments

8.14.3 Slope processes

Hummocky topography may result from cold-climate mass movement such as rockfall, debris slide, debris avalanche, debris flow (Selby 1993, French 2007) or periglacial solifluction, defined as slow mass wasting resulting from freeze-thaw action

(Ballantyne & Harris 1994, Matsuoka 2001). The most likely sediment source is from increased sediment production by periglacial processes during glacial stages and pre-existing poorly consolidated weathered deposits on the valley slopes and interfluves (Lecce 1990, Matsuoka 2001). These conditions would increase the potential for cold-climate mass sediment movement from the interfluves of the Clevedon-Portishead and Tickenham ridges; unvegetated, unconsolidated drift on slopes is vulnerable to debris flows, snow avalanches and slopewash (Ballantyne 2002, de Scally *et al*. 2010). However, there is little evidence in the Gordano Valley for the deposition of scree, except possibly in NR21. Therefore, deposition from rockfall, debris slide and debris avalanche is discounted, and this section will focus on the evidence for solifluction or debris flow.

The first slope process considered is solifluction. Solifluction deposits are synonymous with 'head' (French 2007) and tend to demonstrate lobate planform and hummocky surface morphologies (Matsuoka 2001). Head deposits vary considerably in their composition, but generally consist of unstratified or crudely bedded, coarse, unsorted or poorly sorted angular debris of local derivation, with usually a bimodal grain size distribution. Most are matrix-supported, with a frost susceptible silty or sandy matrix, and move downslope through periglacial mass movement processes (Harris 1987, Kellaway & Welch 1993, Lowe & Walker 1997, French 2007). These may represent slow and episodic or discrete events, commonly the result of major storms, and deposition may be separated by more stable conditions (Selby 1993).

Limestone soils, such as those of the Gordano Valley, favour fluid-like flows during high moisture periods when seasonal thawing of snowfields produces a prolonged low level supply of moisture. Low consistency limits and poor moisture retention produces supersaturated limestone soils and enhances the potential for shallow mudflows (Hutchinson 1991, Matsuoka 2010). As is evident in the Gordano Valley sediments, deposits may be centimetres to metres thick and often show one or more buried organic layers (Selby 1993, Hutchinson 1991, French 2007). Solifluction associated with seasonal thawing generally prevails on permafrost slopes (Ballantyne & Harris 1994). Average rates of surface movement are typically between 0.5 and 4 cm a^{-1} (Matsuoka 2001, French 2007) associated with thaw of surficial permafrost, sufficient for liquefaction of the upper ~ 60 cm to occur. Renssen & Vandenberghe (2003) have shown that the whole of southern England, including the Gordano Valley, was subjected to permafrost during the LGM, and discontinuous permafrost was present in the southern British Isles during the coldest part of the Loch Lomond (Younger Dryas) Stadial (Isarin 1997), potentially providing the necessary conditions for solifluction, although Murton & Belshaw (2011) consider cold and arid permafrost conditions would have suppressed the solifluction of coarse sediment. Post-depositional aridity has been inferred for a number of units of the Gordano Valley sediments.

However, there is no evidence from the Pleistocene morphology of the Gordano Valley for terrace or stepped slope development, commonly associated with solifluction deposits (French 2007). Furthermore, clasts in solifluction deposits are very angular to angular (Harris 1987); although clasts in a small number of units (TG3, NR2, NR6 and NR21) meet these roundness criteria for solifluction deposits, most of the Gordano gravels are predominantly angular/sub-angular, and are therefore probably not directly attributable to solifluction, although the generally greater degree of roundness could be due to periglacial remobilisation of pre-existing glacial deposits; where clasts are derived from till, they may show edge rounding due to glacial abrasion (Harris 1987). This is a possibility, given the presence amongst the Gordano gravels of exotic clasts which were probably reworked from pre-existing glacial deposits. However, no faunal remains which would support the inference of cold-climate depositional conditions were recovered from the Gordano Valley sediments, and many of the clasts demonstrate weathered surfaces indicating they were not prised from a rock outcrop by gelifraction processes, which suggests periglacial solifluction was not the depositional mechanism.

The second slope process considered here is debris flow; rapid mass movement of poorly sorted solid particles and water moving together as a single viscoplastic slurry (Costa 1988, Bertran *et al.* 1997). Debris flow is a complex process, with different styles depending on local geomorphology (Collcutt 1984). Flows can be either cohesive or non-cohesive depending on sediment concentration and the nature of fine material and the type of debris flow is limited by water to sediment ratios and sediment availability (Mather 1999). Debris flow sediments are typically unsorted, may possess inverse or normal grading, are matrix supported, lack internal structure (although this depends on water content and cohesivity of flow), and pebbles are often arranged without preferred orientation (Reineck & Singh 1973, Collcutt 1984, Mather 1999). Individual strata of debris flows can be as much as 3-4 m thick or as little as a few cm thick (Reineck & Singh 1973). Contacts between debris flows and underlying deposits are usually sharp and well-defined (Hooke 1967); many of the boundaries between Gordano Valley gravels and the underlying deposits are of this nature. Debris flow deposits are usually tabular, although this would be difficult to determine from cores, move at speeds of a few kilometres per hour, leaving low ridges of debris, or levees on either side of their track, and once stabilised will not remobilise without massive erosion (Collcutt 1984). Debris flows themselves are typically limited in erosive capability (Shakesby & Matthews 2002), as demonstrated by the series of debris flows in the Ebendon Valley, central Grampian Highlands, Scotland where Ballantyne & Whittington (1999) describe intercalations of peat between succeeding phases of debris flow accumulation.

Small drainage basins with steep slopes such as the Gordano Valley provide favourable conditions for flow initiation (Selby 1993, Brayshaw & Hassan 2009). Flows would be initiated from erosion, entrainment and transfer of accumulations of unconsolidated sediment from the interfluves to the valley floor as a result of liquefaction during rainstorms or a combination of snowmelt and intense rainfall (Beaty 1990, Selby 1993, Bertran *et al*. 1997, Blair 1999, Gabet & Mudd 2006, Sass & Krautblatter 2007, Sletten & Blikra 2007).

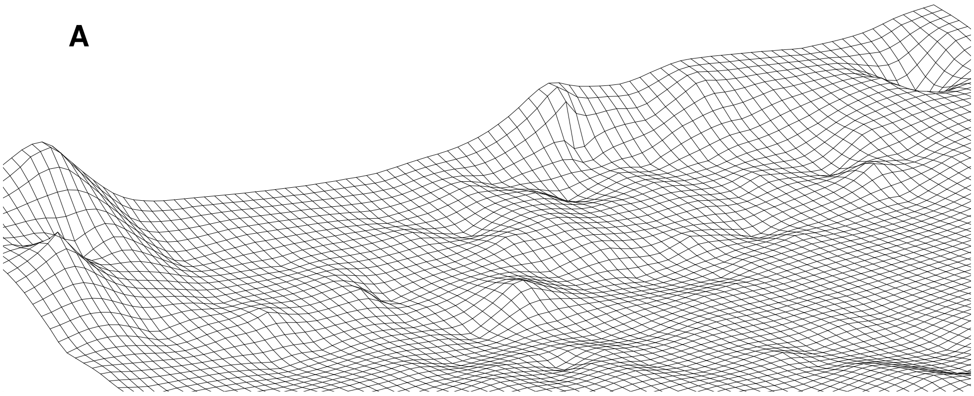
8.14.4 Fluvial processes

The principle sedimentological signal of the Gordano Valley is for fluvial deposition. All cores show evidence for repeated episodes of fluvial activity, which periodically had sufficiently high discharge to transport gravel-sized clasts. Coring was unable to resolve a flow direction, so it was not possible to determine if a palaeoriver originated within the valley or if the valley was merely a conduit for a river which originated elsewhere. The small catchment of the Gordano Valley is at odds with the size of the valley and the apparent volume of palaeodischarge; the morphology of the valley suggests the presence of a river which flowed counter to that of the present-day River Severn. However, according to Green (1992) the size of and shape of the valley is explained as the result of Palaeozoic post-depositional folding and faulting followed by extensive erosion of the exposed Devonian Old Red Sandstone and Carboniferous Limestone outcrops (Green 1992). Palaeodischarge is therefore explained in terms of changes in base level. This has been subject to change over time; general marine base level has undergone significant variation during the Pleistocene due to successive cold and warm stages (Colombo 2005) which have driven both eustatic sea level changes and fluvial activity (Harvey *et al*. 1999, Maddy *et al*. 2000, Stokes *et al*. 2007). In the Gordano Valley, intra-valley base level would be provided by the axial drainage which in turn would have a general base level provided by the mean sea-level surface in the Severn Estuary/Bristol Channel. A large fall in base level would thus have created an increase in total relief and accelerated rates of erosion, producing conditions conducive to the formation of gravel-bedded rivers along the valley axis. Conversely, a rise in base level would have reduced relief and increased valley floor aggradation.

These changes caused variations in critical stream power through changes in runoff and sediment supplied to the fluvial system (Harvey *et al*. 2003). The very poorly sorted angular and sub-angular gravels suggest flows with sufficient energy to transport large clasts over a short time-span, in turn implying hydraulic episodes produced by sporadic high-energy flows of the flash-flood type (Colombo 2005), possibly initiated from snowmelt under an Arctic nival discharge regime (Bryant 1983), unusually intense precipitation, or a combination of the two; Church (1988) found that rainfall on snow induced the most extreme floods in nival regions of Canada.

The main evidence for fluvial deposition comes from the presence of freshwater molluscs in GV3, GV5, TG7 and TG8, which indicate moderate stream flow; the main morphological evidence is the channel/basin from which TG was taken. Additionally, the presence of tufa clasts (cores PG, PGA and CM) may indicate deposition from an intermittently flowing stream which drained the valley interfluves. Hummocky surface morphology could be explained as scours consisting of small-scale asymmetrical troughs a few centimetres to metres wide (Reineck & Singh 1973, Jones *et al*. 1999) formed in unconsolidated sediment by flowing water. Such scours rapidly fill with sediment from suspension if the current velocity decreases suddenly and becomes relatively quiet. This type of deposition is common in river environments and the deposits of outwash plains and alluvial fans (Reineck & Singh 1973). Alternatively, since many of the deposits carry a braided stream sedimentological signal, surface morphology could be explained in terms of a braidplain. This would result in a shallow relief formed by abandoned channels and bars. Depressions would therefore occur where active channels were formerly present and hummocks would represent bars. This is illustrated in Figure 8.4.

A



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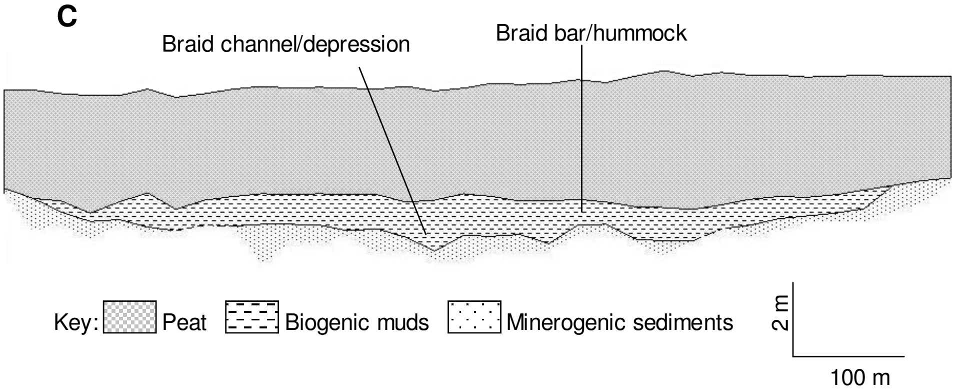

Figure 8.4: Theoretical model for braided stream deposition of hummocks on the valley floor. A. Detail of Gordano Valley minerogenic surface. B. Schematic drawing of formation of depression and hummock topography on a braid plain (redrawn from Allen 1970, Figure 4.7, p 141). C. Cross section (Section 1) showing depression and hummock topography

8.14.5 Alluvial fan processes

The main condition for alluvial fan formation is intermittent stream action, which may be the result of intense rainfall or snowmelt, and a sudden change of slope, leading to deposition (Reineck & Singh 1973). Alluvial fans occur in diverse settings from arid to humid climates and from tectonically active mountain fronts to tectonically stable footslopes (Wells & Harvey 1987). Fans are usually classified as 'fluvial dominated', 'debris flow dominated' depending on the dominant depositional process or 'mixed', when neither fluvial nor debris flow is dominant. There are changes of depositional type down-fan, from proximal debris flows confined within channels to distal unconfined sheet flows (Harvey 1990, Mather 1999), and with changes in fan geometry, whereby distributary channels transfer sheetflow sediments from central to lateral and proximal to distal parts of the fan (Mukerji 1990). During intermittent dry seasons, sub-aerial exposure of muddy surfaces can result in the development of mud cracks. Thin, horizontal lamination is also common in fine-grained muddy sediment and current ripples may be locally present in sandy layers. In zones where stream activity is common, pebble-size sediments are found as channel lag deposits. Pebbles usually show horizontal orientation and imbrication (Reineck & Singh 1973).

The main depositional processes involved are fluvial, hyperconcentrated flow and debris flow. These processes form a continuum which reflects sediment:water ratios. Hyperconcentrated flow is a depositional process transitional between fluvial and debris flow, which is 'hyperconcentrated' with sediment (40% to 70% by weight; Table 8.10; Costa 1988). It is synonymous with 'mudflow' (Bull 1962) and represents a fluid pulse of

Table 8.10: Classification of water and sediment flows (after: Costa 1988)

Flow	Sediment concentration	Flow type
Fluvial	1-40% by weight 0.4-20% by volume	Newtonian
Hyperconcentrated flow	40-71% by weight 20-47% by volume	non-Newtonian?
Debris flow	70-90% by weight 47-77% by volume	Viscoplastic

sediment moving down-fan which is more viscous than fluvial flow (Costa 1988, Reineck & Singh 1973, Selby 1993, Mather 1999). In hyperconcentrated flow, the solids and water are separate components of the flow and the sediment is kept in suspension by turbulence (Costa 1988, Hartley *et al*. 2005). It is commonly found on alluvial fans in semi-arid regions (Wells & Harvey 1987, Harvey *et al*. 1999, Mather 1999, Jones 2000).

Morphometric distinctions can be made between debris flow and fluvial dominated fans; debris flow dominated fans are of limited extent, whilst the spatial extent of fluvial deposits within a fan dispersal area is greater because the potential transportation distance for fluvial flows is greater, and the gradient needed to maintain flow is less, so fluvial flow transports sediment across the upper parts of a fan and deposits it at more distal points (Hooke 1967). Fluvial fans therefore tend to be larger, with a gentler gradient, than debris flows (Mather 1999). Sedimentary evidence diagnostic of alluvial fan debris flow has been described by de Scally *et al*. (2010) and includes weak stratification, lack of sorting and the presence of matrix-supported angular to sub-angular clasts. In addition, gravel beds which alternate with sandy, silty and muddy beds laid down more or less parallel to the surface are indicative of alluvial fan deposition (Reineck & Singh 1973). However, Sletten & Blikra (2007) report difficulties in distinguishing between fluvial, debris flow and hyperconcentrated flow deposits, particularly in cores where lateral relationships between individual sediment units could not be traced. Fluvial, hyperconcentrated flow and sheetflow have been found to occur as integral components of debris flow, frequently occurring lower on the alluvial fan (Sletten & Blikra 2007, de Scally *et al*. 2010).

The irregular surface of alluvial fans has been attributed to the presence of wide-spread abandoned channels as debris flows have diverted to other courses (Beaty 1990, Bennett & Glasser 1996, Benn & Evans 1998), reworking of debris flow surfaces by sheet flow to produce a braided stream appearance (Lecce 1990, Blair 1999, Hartley *et al*. 2005) and stacking of lobes and mounds and depressions produced by settling of clasts near the surface (Wells & Harvey 1987).

An alluvial fan model is one that appears to incorporate much of the aerial extent, surface morphology and sedimentology of the Gordano Valley minerogenic sediments, although if this interpretation is correct, only the more distal parts of fans, where deposition is dominated by flowing water rather than debris flow, have been investigated in this thesis. The various types of fluvial deposition identified in the Gordano Valley sediments are consistent with an alluvial fan setting. Alluvial fans typically demonstrate clearly defined single-thread channels, wide, poorly-defined braided channels, unconfined sheet flows or matrix-rich fluid flows depending on volume of water available for discharge (Bull 1962, Harvey *et al*. 1999, Mather 1999), and, as inferred for the Gordano Valley, may be perennial, intermittent or ephemeral. All cores demonstrate evidence of streamflow and most demonstrate deposition from braided streams and muddy rivers; evidence for changes in fluvial style over time is also known from the Sajó-Hernád alluvial fan in Hungary (Gábris & Nagy 2005).

Although the full aerial extent of the sediments studied in this thesis is unknown, post-depositional alteration of fans by locally operating geomorphic processes (Kochel 1990), such as the dissection and deformation following fan abandonment described by Mather (1999) in the Sorbas Basin, southeast Spain, may have removed relict features, making this difficult to determine. Steeper channels are inherently less stable than low-grade channels, so debris flow initiation is more likely in a steep channel (for example, Nightingale Valley or Tickenham Col) than a low-grade channel (Brayshaw & Hassan 2009). Deposition is usually focused at the foot of feeder channels, centred on the point of emergence onto the valley floor, although Jones (2000) found that in a glacial-marginal area of the central Pyrenees, Spain, debris flow-dominated fans coincided with gullies or scars, rather than tributary streams.

Figure 8.5 shows a number of possible feeder channels from the valley sides to lobate features which correspond to deposits mapped by the British Geological Survey as Triassic (Figure 3.1), although Cretaceous flint fragments found among the gravels in this study suggests these are Pleistocene rather than wholly Triassic deposits. Lobes have built up at the base of the Clevedon–Portishead ridge and Tickenham ridge where there is an abrupt change from a steep to a gentle slope. The lobes are aerially more extensive along the Clevedon-Portishead ridge than Tickenham ridge. The slopes of the Gordano Valley interfluves are ~ 69° (BGS 2004), whilst the valley floor is relatively flat, which would generate the topography necessary for alluvial fan development. Major climate change would have influenced the supply of water and sediment from source areas (Harvey *et al*. 1999, Hartley *et al*. 2005).

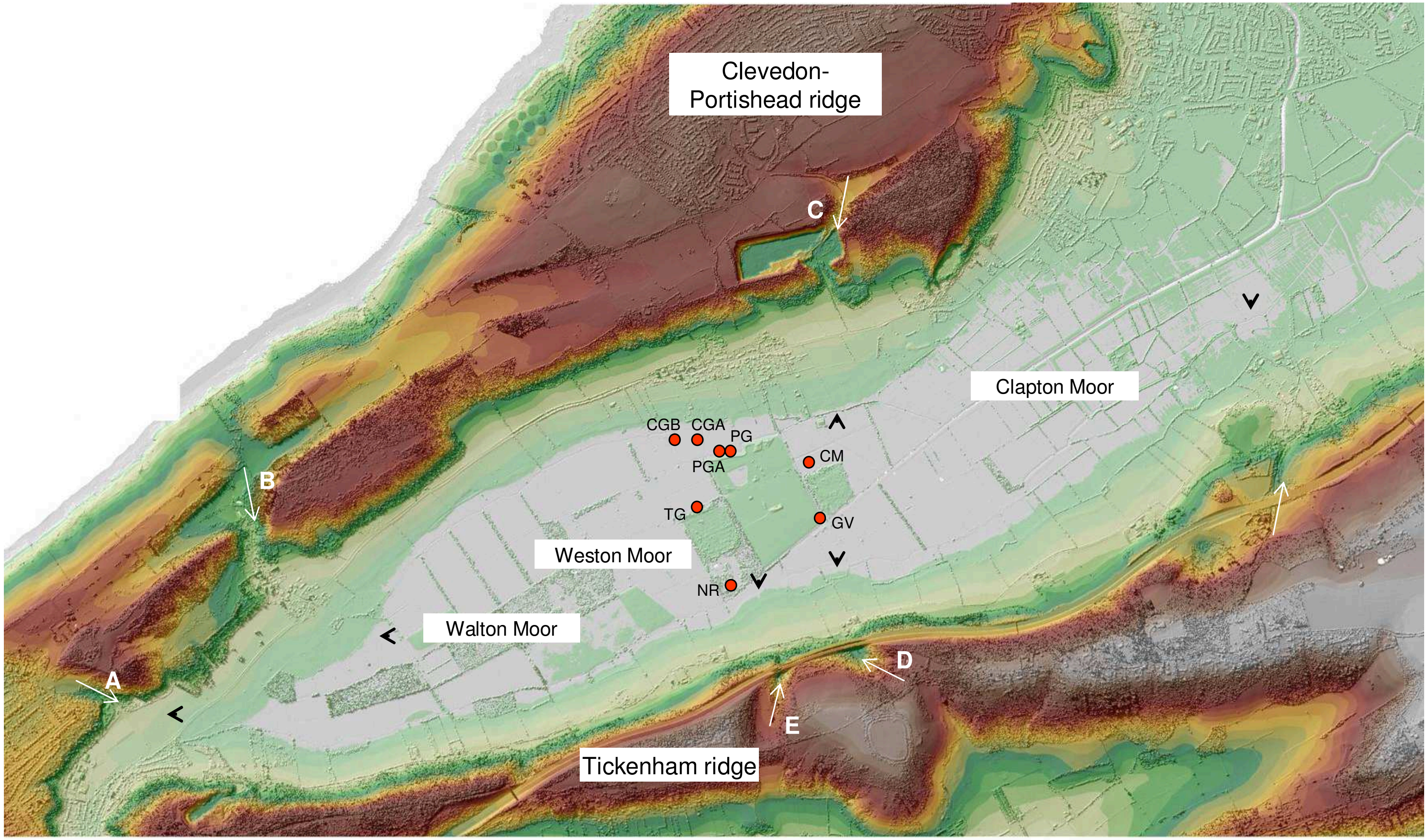

Figure 8.5: LiDAR image of the Gordano Valley topography (darker shading indicates higher altitude) compiled from data supplied by the Environment Agency. Relationship of lobate features (black arrows) at valley margin to feeder channels (white arrows) is shown. A: Holly Lane. B: Walton Valley. C: Nightingale Valley. D: Wynhol. E: Tickenham Col. Locations of percussion cores are indicated by red circles

A hummocky surface morphology has been shown to be consistent with alluvial fan deposition (Wells & Harvey 1987, Beaty 1990, Blair 1999, Hartley *et al*. 2005) and this is most evident on the northern side of the Gordano Valley where cores PG, PGA, CGA and CGB were extracted (designated the Weston in Gordano fan hereafter). The gravel patches on Clapton Moor are probably remnants of lobes emerging from channels, a phenomenon noted by Bull (1964) and Hooke (1967).

Because there is limited transport or sorting, alluvial fan sediment is typically of local provenance (Reineck & Singh 1973, Jones 2000). Sedimentological analysis of the Gordano gravels has indicated that the gravels are of mainly local provenance, with reworked pre-existing glacial material from the interfluves. The Gordano gravels are predominantly moderately weathered and angular/sub-angular, which suggests they were available for transport prior to the LGM. The gravels of cores PG, PGA and CGB all show an up-core change from a limestone dominated lithology to one dominated principally by brown sandstone. This suggests a change in provenance for the upper gravels of these cores; a possible source is Nightingale Valley, where Carboniferous limestone and Devonian Old Red Sandstone are overlain by glacial drift of mainly Carboniferous limestone, with some erratic rock types (Hunt 1998b, 2006e), and headward erosion into the glacial drift deposits is a likely scenario for the lithological change. Figure 8.6 illustrates the interfluve sediment source and flow from Nightingale Valley for the Weston in Gordano fan.

Debris flows would have been initiated from accumulations of soliflucted material in gullies followed by erosion, entrainment and transfer of sediment from the interfluves to the valley floor as a result of liquefaction during intense rainfall events such as that which resulted in floods in the Mendip Hills in July 1968, when underground drainage was overwhelmed resulting in flash flood-type overland flow (Hanwell & Newson 1970, cited in Farrant & Smart 1997, Simms 1997), or a combination of snowmelt and intense rainfall (Beaty 1990, Blair 1999, Gabet & Mudd 2006, Sass & Krautblatter 2007, Sletten & Blikra 2007). This would provide both sufficient discharge and gravels of local provenance for the formation of an alluvial fan on the valley floor. A modern analogue, in terms of rainfall intensity and mobilisation of unconsolidated glacial deposits, might be the events recorded by Wells & Harvey (1987) who describe a rainstorm in June 1982 on Howgill Fells, northwest England in which up to 80 mm of rain fell within 2.5 hours, over half of which is estimated to have fallen in 45 minutes. Overland flow, shallow landslides and gully reactivation delivered an influx of coarse sediment which often buried earlier fan deposits in up to 3 m of vertical sediment accumulation and generated 13 alluvial fans at the mouths of small tributary valleys. Although these are much thicker deposits in comparison to those of the Gordano Valley (generally decimetre thicknesses), the implication is that deposition of the Gordano Valley alluvial fans may represent only a few hours of deposition over the Devensian period.

Image withheld for copyright reasons

Figure 8.6: Theoretical model for source and flow of sediment for the Weston in Gordano fan. A. Flow from the high-level valley above Nightingale Valley (solid arrows) and flow across the fan (broken arrows). Contours are at 10 m intervals. B. Interfluve sediment supply for fan (redrawn from Lecce 1990, Figure 1.1, p 4)

Only four gravel units on the Weston in Gordano fan display the diagnostic characteristics of debris flow (de Scally *et al*. 2010), the remainder being fluvial, and this fan is accordingly classified as predominantly fluvial. In contrast, core NR (Clapton Wick fan hereafter) contains five debris flow-type gravels and is probably better classified as a mixed fan. This is supported by the smaller fan sizes along the north facing slope of the

Gordano Valley in comparison the south facing slope (Figure 8.5) and reflects different processes operating on north facing and south facing slopes.

As for most of the Gordano Valley deposits, organic matter and fossil remains are rarely found in alluvial fan sediments although plant remains may be locally present (Reineck & Singh 1973). Although the presence of shell fragments at the base of voids found in the sediments of cores CGB and CM led to an interpretation that these were burrows, voids are also a characteristic feature of alluvial fan deposits, where they may develop from entrapment of air or decay of entrapped vegetation (Reineck & Singh 1973, Collcutt 1984), which could provide an alternative explanation. Fine horizontal cracks found in sediments of cores PGA, CGA, CGB and CM have been attributed to difficulties in extracting the liners from the corer, but interlaminar openings in thinly laminated sediments are also characteristic of alluvial fan deposits (Reineck & Singh 1973), again providing an alternative explanation.

Weakly pedogenetic, vertically stacked units (cores PGA and CGB) indicate that there was little erosion and sedimentation was sometimes rapid but unsteady, resulting in the formation of compound palaeosols (Kraus 1999). Multiple discrete episodes of pedogenesis recorded in most cores suggest pulses of sedimentation interspersed with brief periods of landscape stability, which also fits an alluvial fan setting.

An alluvial fan setting would also explain the apparent discrepancy between OSL ages and AAR correlation for the sediments. The dynamics of alluvial fan sediment deposition, with periodic switching of the main channel from one part of the fan to another and the formation of distributary channels across the fan surface, may have resulted in incision and infilling of channels to approximately the same level in the same part of the fan, potentially bringing sediments of widely differing ages into close proximity. A similar scenario was envisaged for apparently aberrant sediment ages from an alluvial fan setting at Latton, Wiltshire, by Lewis *et al.* (2006).

8.15 Synthesis of Gordano Valley Pleistocene palaeoenvironments

It is clear from the previous sections that several environments have been present in the Gordano Valley during the Pleistocene and that no single environment is responsible for the whole depositional sequence; six palaeoenvironments are inferred: muddy, silt-sand bedded and gravel-bedded rivers, braided streams, intertidal interconnected freshwater pools and alluvial fans. These are illustrated by schematic diagrams showing cross-sections of the Gordano Valley looking westwards up-valley towards East Clevedon Gap (Figure 8.7).

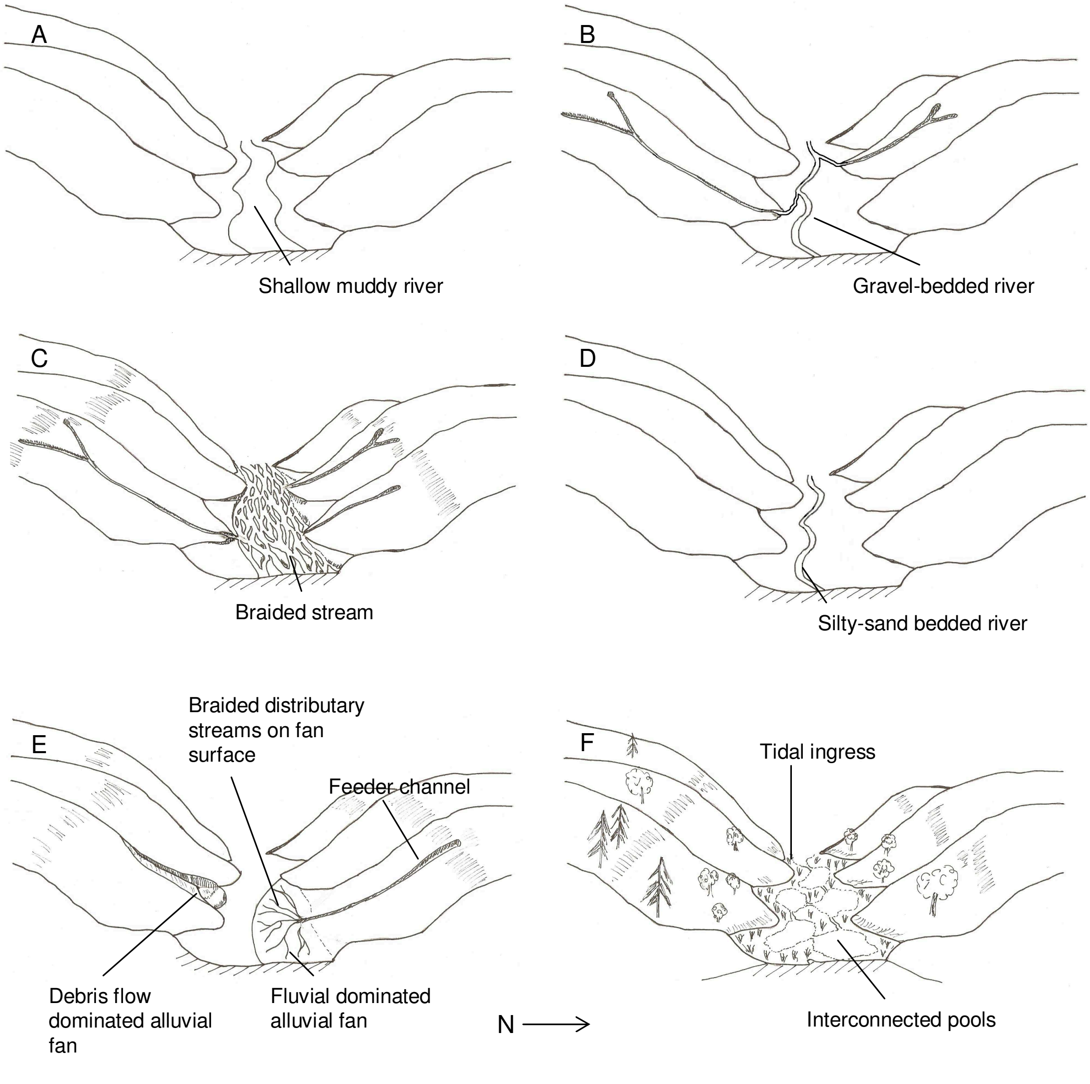

Figure 8.7: Palaeoenvironments of the Gordano Valley. A. Muddy river. B. Gravel-bedded river. C. Braided stream. D. Silty-sand bedded river. E. Debris flow and fluvially dominated alluvial fans. F. Interconnected intertidal freshwater pools

The dates obtained suggest that Pleistocene minerogenic sedimentation in the valley commenced before *c*. 200 ka and it is probable that deposits which have a glacial signature relate to glacial tills previously deposited on the valley interfluves. The majority of minerogenic sediments were probably deposited in three phases, the first during Early

Devensian (MIS 5d-4) time, the second following Devensian (MIS 2) glaciation, and the third during the Younger Dryas Stadial. Much of this deposition probably involved the reworking of earlier deposits, both from the interfluves and from the valley basin fill.

8.15.1 Pleistocene fluvial environments of the Gordano Valley

Four types of fluvial flow are inferred from the sediments of the cores located along the valley axis (cores GV, CM and TG, Tables 8.1, 8.7 and 8.8): muddy rivers flowed through the valley on at least three occasions, once prior to late MIS 7 or early MIS 5e, when climatic conditions were wet and temperate and sea level was slightly lower than present day, and twice after this. The rivers were probably fed by groundwater and would have had a lush aquatic vegetation. High energy gravel-bedded river aggradations are inferred on five occasions, probably fed by high discharge inputs from the valley sides; these were predominantly cold-climate events when there was little vegetation to maintain slope stability. Deposition from braided streams is inferred on four occasions when climatic conditions were either temperate and humid with a stable, organically productive landscape or cool and wet. Deposition in silt/sand-bedded streams is inferred prior to three separate intervals of climatic deterioration, increasing aridity and reduced vegetation cover.

8.15.2 Pleistocene intertidal environments of the Gordano Valley

On at least one occasion during a period of relatively high sea-level, either during late MIS 7 or early MIS 5e, the Gordano Valley was occupied by a large number of interconnected small pools at the limit of tidal influence (Table 8.8). The pools were probably fed by groundwater and open to tidal ingress, but were only reached during the highest spring tides. There was a rich aquatic vegetation and the pools and interconnecting streams were inhabited by a freshwater fauna that included molluscs and ostracods. Brackish water was periodically introduced into the valley during high tides, and marine shelf fauna were deposited.

Sedimentological evidence points to deposition in a braided stream (TG7) or under low energy conditions in a river channel (TG8). Faunal evidence indicates that these were fresh- and brackish water environments and that sea level that was approximately the same as that pertaining today.

8.15.3 Pleistocene alluvial fan deposits of the Gordano Valley

Alluvial fans were superimposed on the earlier fluvial environment, reorganizing the previous river morphology and sediments. An alluvial fan composed of reworked drift deposits from Portishead Down formed on the northern side of the valley at the end of the Nightingale Valley. Fan deposition probably started during MIS 5b, was focused at the foot of feeder channels and centred on the point of their emergence onto the valley floor. There were strong discharge variations, including turbulent flow and ephemeral stream discharge, with channel migration and periods of aridity between discharge events. Towards the fan toe, where the channel was unable to cope with flow, braided streams covered the surface, redistributing the sediment. Settling out of fine sediment in braid pools occurred during times of low flow. During brief periods of landscape stability there was pedogenesis on recently exposed surfaces. This was repeatedly halted by burial from a fresh input of material resulting in stacked pedogenetic units. Late in the fan's evolution there was a change in lithology, from predominantly limestone to predominantly brown sandstone, probably the result of headward erosion of the feeder channel cutting back through the limestone into the underlying sandstone. On the south side of the valley, smaller fans formed as repeated episodes of intense rainfall or rapid snow melt mobilised drift deposits on Tickenham ridge from where gravels were transported onto the valley floor via feeder channels at Tickenham Col, Wynhol and Court Hill Col. A second prograding fan may have formed in the Walton Moor region, possibly impounding water between the two fans, resulting in a shallow lake.

Overall, the Pleistocene of the Gordano Valley was probably an environment of alluvial fans, ephemeral braided streams and intermittent channel flow, interspersed with periods of stability during which soil formation commenced and warm intervals during which sea-level was relatively close to modern datums. In the next chapter, the reconstructed Pleistocene palaeoenvironments for the Gordano Valley are integrated with previous models for the Valley and the findings considered within a regional and wider context.