Palaeogene and Neogene deposits, Cainozoic of north-east Scotland

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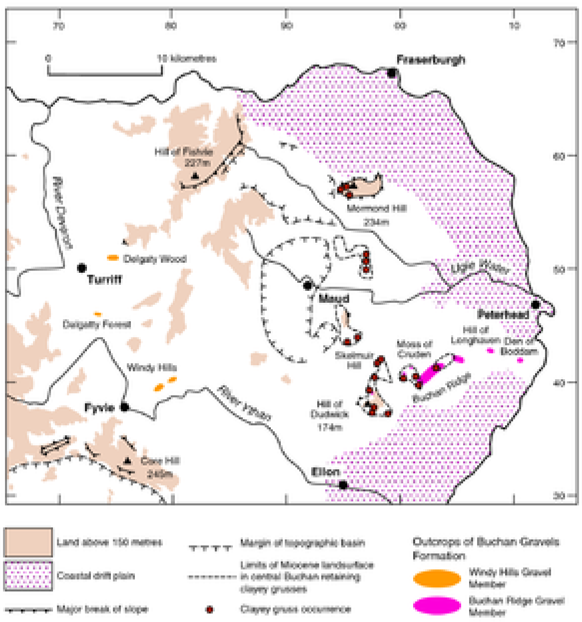
Introduction



Distribution of Miocene land surface and major topographical features. P915269.

During the Palaeogene and Neogene, the lowlands of north-east Scotland and adjacent areas along the edge of the Moray Firth and North Sea basins were areas of net erosion. Episodic uplift of the Inner Moray Firth Basin and adjacent land areas occurred at this time (Japsen, 1997) and consequently contemporaneous sediments offshore are largely confined to the region east of 1ºW (Andrews et al., 1990). No Palaeogene (Paleocene and Oligocene) sediments are known on land in northeast Scotland, but Neogene (Miocene and Pliocene) deposits do occur in the form of isolated bodies of gravel belonging to the Buchan Gravels Formation (P915269). Furthermore, a characteristic feature of the lowlands of north-east Scotland is the survival of deep weathering profiles (saprolites) that developed extensively during the late Cainozoic. Evidence of such chemical weathering is widely preserved in the current landscape and the saprolites preserved are potential resources of aggregate (Bulk mineral resources) and are factors influencing ground stability, local groundwater resources and land use.

The shoreline of north-east Scotland during the Neogene appears to have lain well to the east of the present coastline. Miocene littoral and sublittoral sands, containing glauconite, abundant shell debris and lignite, occur in the Moray Firth Basin in a north–south zone between 1° and 0°W (Andrews et al., 1990). Lower Pliocene and Miocene sediments are locally absent, implying mid-Pliocene uplift and erosion. Lignitic clays of possible Pliocene age occur in BGS Borehole 81/19, 150 km north-east of Fraserburgh. Pollen of hickory is abundant, implying warm, generally frost-free conditions at this time. The abundance of well-ordered kaolinite invites comparison with the kaolinitic Buchan Gravels (Andrews et al., 1990).

The former, and perhaps continued, existence of small bodies of Upper Cretaceous, Palaeogene and Neogene rocks in the inner Moray Firth is indicated by the occurrence of chalk clasts in tills in north-east Buchan and Caithness, glacial rafts of Miocene clay at Leavad in Caithness (Crampton and Carruthers, 1914), and of Tertiary palynomorphs within the matrix of tills in eastern Buchan.

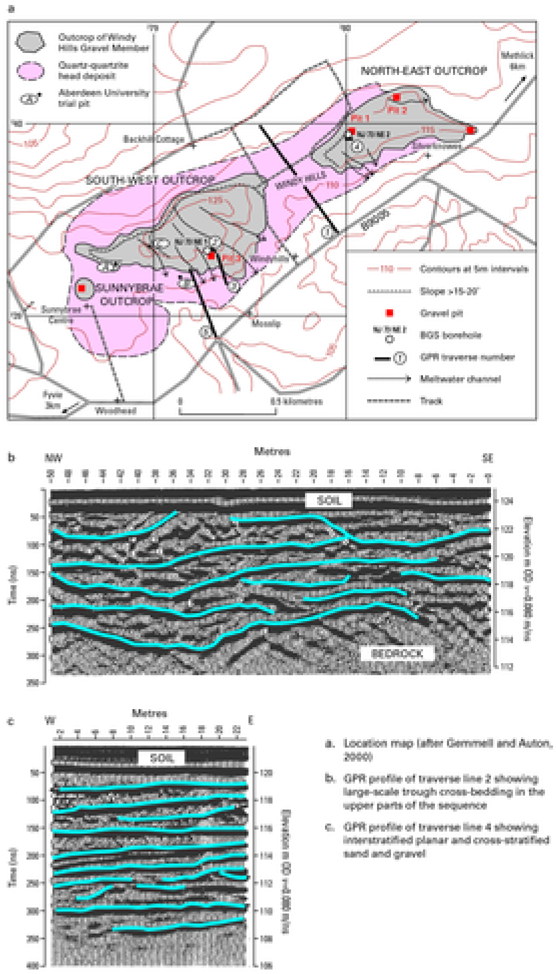
Studies of the clay mineralogy of sediments in the North Sea Basin show an increase during the late Miocene of illite, the appearance of chlorite and a corresponding reduction in kaolinite (Karllson et al., 1979; Berstad and Dypvik, 1982). These changes appear to correspond with transition to a cooler climate and a reduction in the intensity of chemical weathering. The ratios of clay minerals remain relatively stable through the Pliocene, despite fluctuations in climate. There are, however, some anomalous occurrences of kaolinite that may represent reworking of older material (Andrews et al., 1990). The overall change in clay mineralogy has been correlated with a switch towards the development of sandier, less mature weathering profiles under humid temperate climates on land in north-east Scotland (Hall, 1985).

Buchan Gravels Formation

Sediments assigned to the Buchan Gravels Formation occur in two distinct areas of Buchan as a discontinuous cover on ridges, hills and valley benches (P915269). The deposits crop out at elevations between 75 and 150 m above OD, between Den of Boddam (NK 115 416) and Delgaty (NJ 746 508). The gravels in each area are lithologically distinct. In the west, quartzite and quartz-dominated gravels occur between Windy Hills and Turriff on Sheet 86E Turriff. In the east, flint dominated units are found on summits of the broad ridge (‘Buchan Ridge’) that extends from Hill of Dudwick (NJ 979 378) to Stirling Hill (NK 125 413) on Sheet 87W Ellon and Sheet 87E Peterhead, respectively.

Despite having been geologically investigated for more than 150 years and the subject of much recent research (Gordon and Sutherland, 1993 provide citations of the earliest studies), the precise age and origin of the gravels remain controversial. They have been assigned a variety of formal and informal names: Buchan Ridge gravels (McMillan and Aitken, 1981), Cruden flint gravels and Windy Hills-Turriff quartzite gravels (Kesel and Gemmell, 1981), Buchan Ridge Gravels and Windyhills Gravels (McMillan and Merritt, 1980; Merritt, 1981), Buchan Gravels Group (Hall, 1984, 1985), Buchan Gravels Formation (Hall, 1986), Buchan Ridge Formation (Hall, 1987), Buchan Gravels (Hall, 1987, 1991) and Buchan Ridge Gravel (Bridgland et al., 1997). The quartz-quartzite gravels are formally assigned here to the Windy Hills Gravel Member and the flint gravels to the Buchan Ridge Gravel Member.

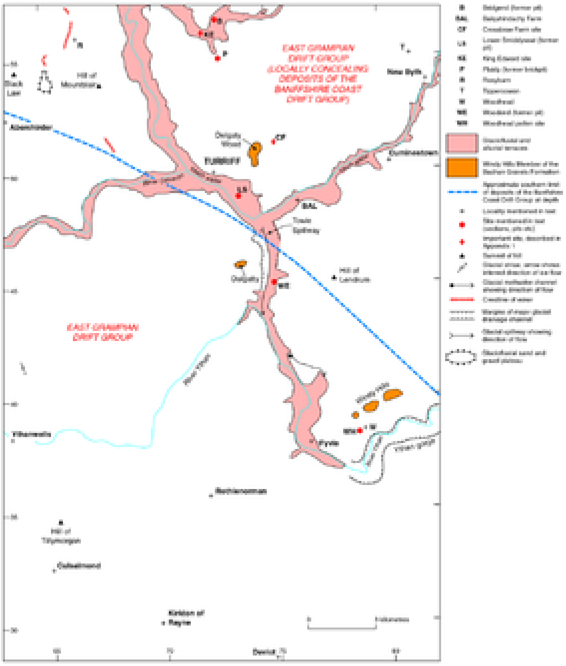
Windy Hills Gravel Member



The principle outcrops of the Windy Hills Gravel Member of the Buchan Gravels Formation near Fyvie. P915316.


Quartz-quartzite gravel of the Windy Hills Gravel Member at its type locality. P104101.

In the type area, around Windy Hills (NJ 800 398), 12 km south-east of Turriff (P915269; P915316), white, coarse quartz and quartzite gravel underlies two flat-topped ridges trending north-east at surface elevations of between 115 and 125 m OD (P104101). Over 14 m of gravel occurs locally, interbedded with quartz- and mica-rich sand and resting on deeply weathered bedrock (Merritt, 1981). In the type sections of the Windy Hills Gravel Member (NJ 800 400) and BGS Borehole NJ73NE2, 700 m north-north-east of Windyhills (NJ 797 393), up to 11.3 m of gravel, interbedded with pale yellow, clayey pebbly sand, overlies deeply weathered and kaolinised Dalradian schistose pelite. Pebbles and cobbles of quartzite and vein quartz in the gravel are comparatively fresh and some carry chatter or percussion marks. In contrast, most pebbles of granite and metasedimentary rock are decomposed to kaolinitic sand, although fresh angular metamorphic clasts have been recently recovered from beneath kaolinised gravel in a trial pit close to the southern margin of the south-western spread of the member (Gemmell and Stove, 1999). Sparse flint pebbles are also present within the whitened gravel, as are very rare clasts of chert reported by Flett and Read (1921). The latter possibly originated as fossiliferous chert nodules in Cretaceous Greensand (information from N Trewin, Aberdeen University, 1981). Further detailed locational and sedimentological data from the gravel at Windyhills is available.



Glacial and glaciofluvial features and the distribution of glacigenic deposits on Sheet 86E Turriff. P915375.

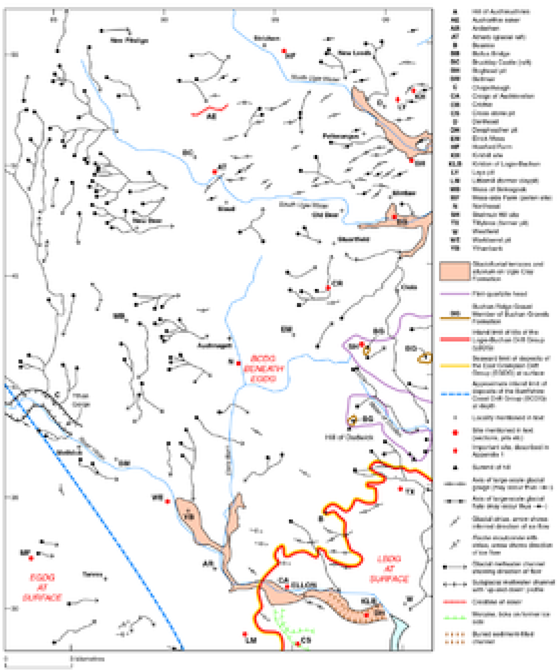
Quartz- and quartzite-rich gravels occur at two other localities near Turriff (P915375). Exposure at Dalgatty Forest (Hospital Wood) (NJ 735 460) is poor, but a former pit, at a surface elevation of around 115 m OD, showed 3 m of quartzose gravel and white sand (Peacock et al., 1977). Flett and Read (1921) observed quartz- and quartzite-rich gravel and sand at elevations of 107 to 122 m OD in a number of pits in the Wood of Delgaty (NJ 744 508). Characteristic features are an abundance of quartzite clasts, up to 30 cm in diameter, and flint representing up to 10 per cent of the coarse gravel clasts. Some flints contain fossils of Late Cretaceous age (Salter, 1857). Clasts of brown sandstone are also reported (Peacock et al., 1977).

Each of the deposits of the Windy Hills Gravel Member at the Windy Hills type site rests on a valleyside bench at an elevation of around 110 m OD. Transport from a westerly source is consistent with the distribution of the gravel bodies along a proto-Ythan–Deveron river system. A western provenance is also suggested by lithological similarities between the clasts and the Dalradian quartzites of Banffshire (Koppi, 1977; Kesel and Gemmell, 1981) and by the concentrations of ilmenorutile in the matrix, probably derived from the Younger Basic igneous masses (Hall, 1983). Recycling of clasts from Devonian conglomerates is likely, as the rounding of the pebbles and cobbles contrasts sharply with the rather angular nature of most of the quartz sand grains.

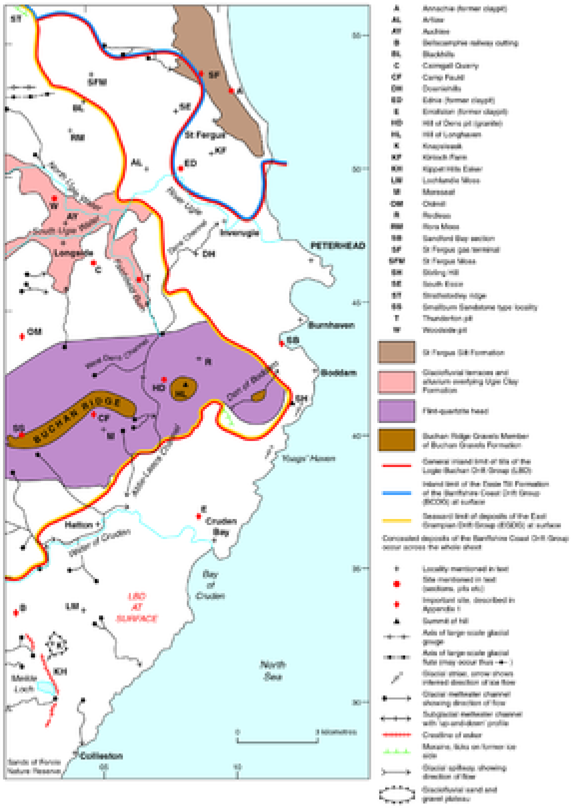
The member was derived from a terrain that had extensive development of kaolinitic saprolites, but also had significant areas of relatively fresh rock. Stripping of saprolites provided first-cycle quartz grains, mica sand and kaolinitic silt. Erosion of fresh outcrops yielded clasts of granite and schist at Windy Hills and possibly Devonian sandstone at Delgaty. Some well-rounded pebbles and sand grains might have been recycled from older Tertiary gravel deposits. Following their deposition, the Windy Hills deposits were weathered throughout, with kaolinisation of clasts other than quartzite and also of the subjacent bedrock (Koppi, 1977; Koppi and FitzPatrick, 1980).

Broken sand grains in the Windy Hills Gravel Member may be the product of high-energy fluvial transport in the Neogene, or Quaternary glacial and glaciofluvial transport (Hall, 1983; Kesel and Gemmell, 1981; Gemmell and Auton, 2000). However, some of the grains may have been derived from the in situ decomposition of quartzo-feldspathic clasts within the deposit and others could be derived from glacigenic units within the Dalradian MacDuff Slate Formation. However, the member is regarded by most as being Neogene in age on account of its distinctive lithology and the extent of postdepositional chemical weathering (Windy Hills). It is locally overlain by till (Flett and Read, 1921) and must predate the cutting of the Ythan gorge, the floor of which is at least 75 m below the base of the unit at Windy Hills. The position of the Windy Hills Gravel Member in a former course of a protoYthan–Deveron river system, contrasts with the ridge-top location of the Buchan Ridge Gravel Member and suggests that the Windy Hills Gravel Member is the younger of the two members of the Buchan Gravels Formation.

Buchan Ridge Gravel Member

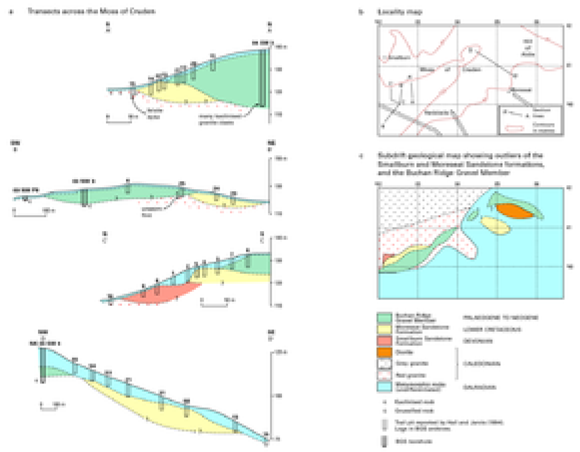


Glacial and glaciofluvial features and the distribution of glacigenic deposits on Sheet 87W Ellon. P915376.



Glacial and glaciofluvial features and the distribution of glacigenic deposits on Sheet 87E Peterhead. P915377.

The flint-dominated deposits of the Buchan Gravel Formation occur as isolated high-level masses in eastern Buchan (P915269; P915376 and P915377). Exposure is generally poor and localised surface concentrations of flint suggest that other small gravel deposits may be concealed beneath Quaternary sediments.



Investigations on the Buchan Ridge (after Hall and Jarvis, 1994). P915317.

Moss of Cruden The largest mass of the Buchan Ridge Gravel Member underlies the ridge of the Moss of Cruden, extending from Moss of Auquharney (NK 018 399) to Hill of Aldie (NK 059 414) and includes small outliers on the flanks of Smallburn Hill (NK 016 405) (P915317). The size of the in situ gravel body has probably been over-estimated in the past, owing largely to the widespread development of younger flint-rich diamictons beyond the gravel outcrop. The diamictons have been recorded in an extensive network of trial pits, which have also shown that localised glacitectonic disturbance of Quaternary diamictons and gravels is widespread around Moreseat. Similar disturbance may also have affected parts of the gravel body in the Moss of Cruden type area.

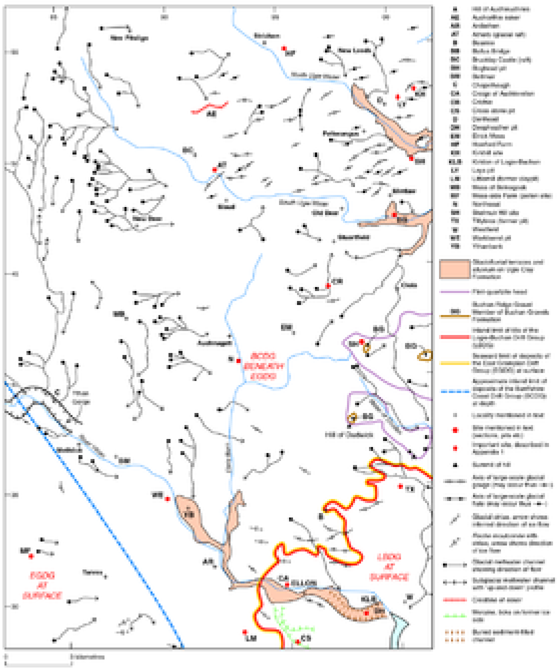
Records from a BGS borehole (NK04SW3) suggest the gravel exceeds 25 m in thickness beneath the highest point of the Moss of Cruden (McMillan and Aitken, 1981) and subsurface data indicates that similar material infills at least two west-southwest-trending channels, one running along the Moss of Cruden ridge and the other transverse to the Hill of Aldie. Temporary excavations and boreholes on the Moss of Cruden show white, clay-bound coarse gravels with minor sand and silt units (Merritt, 1981). Gravel clasts are dominantly flint with quartzite and vein quartz; they are generally well-rounded pebbles and cobbles, many bearing numerous chatter marks. Some flints contain fossils of Cretaceous age (Jamieson et al., 1897) and a 75 ×30 cm block of Greensand was recovered from the gravel at Hill of Aldie (NK 062 410) by Kesel and Gemmell (1981).

The deposits originally contained less resistant clasts, probably mainly of granite, and these have decomposed to ‘ghosts’ of white sandy clayey silt. This decomposition extends throughout the known thickness of the deposit and into the underlying bedrock. Both sand and gravel units are bound, and in places, supported by white, kaolinitic sandy clayey silt. Flett and Read (1921) record clay pits on the Hill of Aldie, but it is unclear if these pits worked beds within the gravel or kaolinised bedrock.

Surface textures of sand grains from the Buchan Ridge Gravel Member at Moss of Cruden are similar to those from the Windy Hills Gravel Member, but grain breakage is more widespread (Hall, 1983). Rounded grains show thick precipitation surfaces, with silica coatings and fine euhedral overgrowths. Crescentic chocks are well developed indicating high-energy aqueous transport. Originally rounded grains are normally fragmented. However, interpretation of this latter feature is difficult, as the only samples from deep within the gravel body come from boreholes and breakage may be a drilling artifact.

As at Skelmuir Hill (see below), the base of the Buchan Ridge Gravel Member, in places, contains large nodules of flint and boulders of quartzite. The unworn flints resemble those in remanié deposits derived directly from solution of the chalk, such as the Eocene Tower Wood Gravels of south-west England (Hamblin, 1973). The gravel member rests on kaolinised granite and metasedimentary rock (McMillan and Aitken, 1981; Hall et al., 1989) and on highly weathered Lower Cretaceous Moreseat Sandstone (Hall and Jarvis, 1994). A kaolinitic silt, exceeding 6.5 m in thickness, occurs in a temporary pit (NK03NWP1) at East Backhill (NK 0089 3978) (Merritt, 1981). It was formerly recorded as either a unit within the member or deeply weathered granitic bedrock, but recent investigation has shown it to be a decomposed felsite dyke.

A ground probing radar (GPR) survey and resistivity soundings on the northern slope of the Moss of Cruden have confirmed that the feather edge of the Buchan Ridge Gravel Member rests on weathered Lower Cretaceous sandstone (Results of shallow geophysical surveys). Low-angle cross-stratification within the member dips towards the axis of the ridge. The resistivity and GPR data indicate that around 15 m of gravel lies beneath the crest of the ridge resting on granite weathered to clay. The gravels here fill a channel running parallel to the line of the ridge. Pitting and borehole data indicates that the gravel at Hill of Aldie fills another channel (McMillan and Aitken, 1981; P915317).



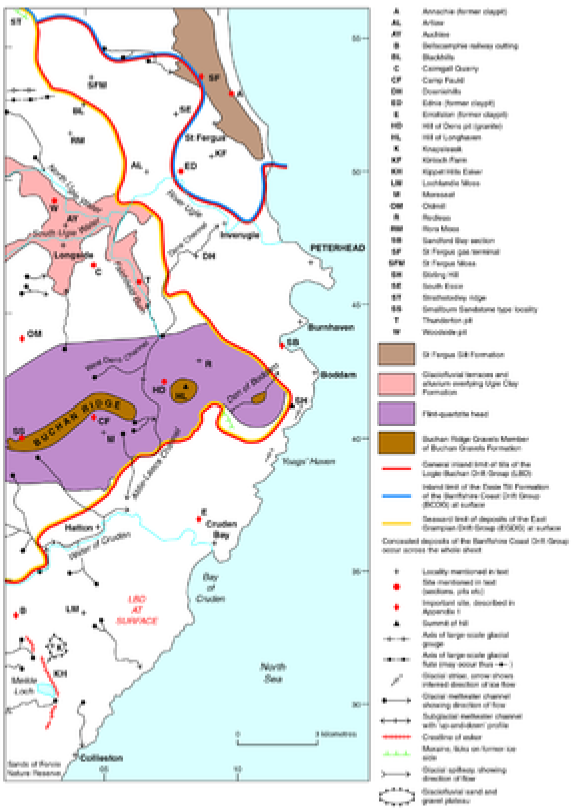
Glacial and glaciofluvial features and the distribution of glacigenic deposits on Sheet 87W Ellon. P915376.

Skelmuir Hill A small deposit of yellowish brown, flint-bearing gravel was discovered at this locality (NJ 986 415) (P915269; P915376) by Bridgland et al. (1997). The limits of the deposit are uncertain, but the total area of outcrop is unlikely to exceed 0.04 km^2. The gravel reaches a maximum altitude of 148 m OD and attains a thickness of at least 8 m, apparently resting against a relatively steep rock margin. The deposit has a number of distinctive features. It contains large numbers of boulders up to 0.8 m across. These include relatively angular clasts derived from the local psammites and quartzites, but also rounded boulders with percussion scars (P104121, P104122). The clasts include a greater proportion of less durable rock types than has been recognised at other sites. These 'ghost' clasts originally formed part of a clast-supported gravel containing pebbles and cobbles of brown flint. A basal boulder layer includes distinctive large, angular flint clasts, up to 0.25 m across, with flaked surfaces resulting from impact. The Skelmuir deposit appears to represent a basal facies of the Buchan Ridge Gravel Member resting within a steep-sided channel or against a cliff (Bridgland et al., 2000).

Flint clasts recovered from the base of the Buchan Ridge Gravel Member in a trial pit on the Moss of Cruden. P104121.

Flint clasts recovered from the base of the Buchan Ridge Gravel Member in a trial pit on the Moss of Cruden. P104122.

Hill of Dudwick A small body of flint gravel rests within a depression at an elevation of about 170 m OD to the north of the summit of the Hill of Dudwick (NJ 979 378) (Kesel and Gemmell, 1981; P915269; P915376). Up to 5 m of structureless clay-bound gravel is reported, and it is clear that at least the upper part of the deposit has been disturbed by glacial action. Surface concentrations of flint and quartzite suggest that another small gravel mass may be concealed in the ground to the south of Whitestones Hill (NJ 978 391).



Glacial and glaciofluvial features and the distribution of glacigenic deposits on Sheet 87E Peterhead. P915377.

Hill of Longhaven Flett and Read (1921) reported flint gravels above the 300 foot (90 m) contour in the vicinity of Newton and Mount Pleasant, presumably beneath the summit of the Hill of Longhaven (NK 085 420) (P915269; P915377).

Den of Boddam The flint gravels in the vicinity of the Den of Boddam (NK 114 414) partly fill a deep channel cut into the Peterhead Granite (P915269; P915377). The deposit has a base at around 70 m OD, considerably below other occurrences, and it has been suggested that the gravel has been periglacially or glacially reworked (Hall, 1993a). However, recent pitting at Den of Boddam has shown that only the upper part of the gravel body has been thus disturbed, whereas the presence of intact weathered clasts and traces of bedding suggest that the rest of the deposit is in situ. The gravel consists of rounded cobbles and pebbles of flint and quartzite, up to 25 cm across, in a kaolinitic matrix. Kaolinised clasts of granite, probably Peterhead Granite, are common. The deposit has been considerably disturbed by the activities of late Neolithic flint miners (Bridgland et al., 1997; Bridgland and Saville, 2000).

Origin of the Buchan Ridge Gravel Member

The origins of this member remain controversial in terms of the provenance of the gravel constituents, depositional environment and age.

The main constituents of the gravel are flint, quartzite, vein-quartz and kaolinitic silt and sand. It has long been held that the flints are derived from a former Chalk cover (Wilson, 1886). The discovery of little-worn flints at the base of the gravels at Skelmuir Hill (Bridgland et al., 1997, 2000) and Moss of Cruden (Hall, 1993a) confirms that Chalk once covered this area. Furthermore, the recent discovery of Lower Cretaceous strata preserved beneath the gravels at Moss of Cruden suggests that a succession of Cretaceous sedimentary rocks formerly existed in this area. The quartzite clasts bear mineralogical similarities to metaquartzitic rocks in north-east Scotland (Kesel and Gemmell, 1981), but may have been recycled from ORS conglomerates (Hall, 1993a). Careful observations of 'ghost' clast structures at Skelmuir Hill (Bridgland et al., 1997, 2000) suggest that the amount of original less-durable material in the gravels may have been significantly under-estimated by other workers, including Hall (1982). This indicates erosion of the local granite and metamorphic bedrock and incorporation into the basal facies of the gravels.

The kaolinitic matrix of the Buchan Ridge Gravel was partially derived from highly weathered saprolites, because discrete beds of kaolinitic silt occur within the gravels and the clay mineralogy shows little variation with depth in the gravels (Hall, 1982). However, the gravels were deeply weathered after deposition, and kaolinisation of nonquartzitic clasts has occurred throughout the deposit at Moss of Cruden and into the underlying bedrock. Secondary alteration is less thorough at Skelmuir Hill, but the former weathering profile may have been considerably truncated there. The clay-bound nature of the beds of gravel is largely a result of secondary infill of voids by clays derived from the weathering of feldspathic clasts and sand, followed by collapse and deformation (McMillan and Merritt, 1980; Merritt and McMillan, 1982; Bridgland et al., 1997). The member is apparently undisturbed at depth, but the individual bodies have been affected to different degrees by glacial disturbance, deformation and thrusting during the Pleistocene.

Marine, fluvial and glacial origins have been suggested for the Buchan Ridge Gravel Member. Evidence adduced for deposition as beach gravel includes:

abundance of well-rounded and chatter-marked flint clasts (Flett and Read, 1921; Koppi and FitzPatrick, 1980; Bridgland et al., 1997)

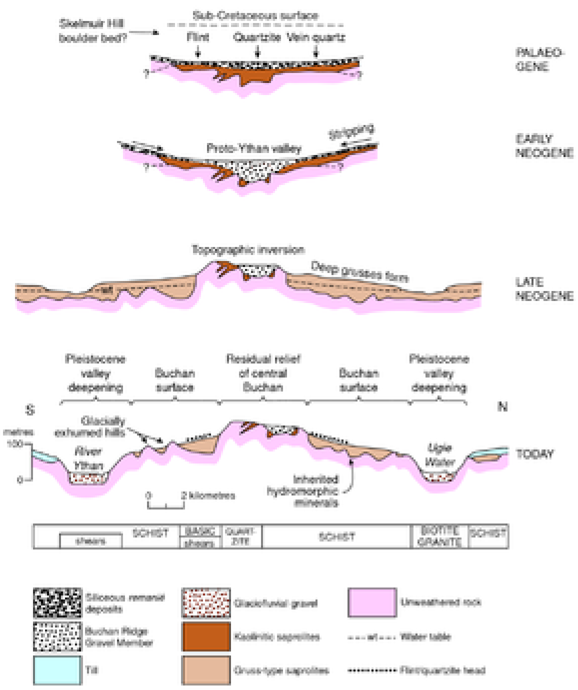
- the apparent original open-work character of parts of the deposit (McMillan and Merritt, 1980; Merritt and McMillan, 1982)
- the presence of large, flaked flint blocks at the base of the Skelmuir deposit (Bridgland et al., 1997, 2000)
- the coarse calibre of parts of the gravel body suggesting that it formed in a high-energy beach

environment, rather than a river environment, because the surrounding land surface was probably of low relief

Difficulties for the last interpretation include the presence of well-rounded and chatter-marked clasts. These are similar to those occurring within the Windy Hills Gravel, which most agree is of fluviatile origin. The beds of kaolinitic silt and clay are more difficult to account for within beach gravel than a fluvial sequence. Evidence in favour of fluviatile deposition includes:

- the occurrence of each of the gravel bodies within channels cut in bedrock
- the association of kaolinitic gravels with a deeply weathered land surface is characteristic of other Palaeogene, Neogene and early Pleistocene river gravels in north-west Europe, including south-west England (Hamblin, 1973) and the Low Countries (van den Broek and van der Waals, 1967; Friis, 1976)

Deposition in a glacial or glaciofluvial environment is supported by the presence of beds of matrix-supported gravel and of broken, previously rounded quartz grains. However, trial pits have shown that the gravels contain a range of relatively undisturbed sedimentary structures and glacial disturbance is likely to have been restricted in its effects. Transport by meltwater is more difficult to refute if the widespread breakage of quartz grains at depth within the Buchan Ridge Gravel Member is not a result of the drilling process.



Summary of Cainozoic relief development in central Buchan. P915267.

Despite much investigation, the age of the member remains uncertain. The gravels are clearly post-Cretaceous in age, as they contain flint, and they predate the Late Pleistocene, as they are overlain by till (Whittington et al., 1998). The degree of postdepositional alteration is striking and certainly far exceeds that shown by the felsite-rich Leys Gravel of Middle Pleistocene age found at Kirkhill (Hall and Jarvis, 1993a). The constituents of the Buchan Ridge Gravel Member were derived in part from a highly weathered land surface and the kaolinitic style of weathering has been related to warm climates that prevailed before the Pliocene (Hall, 1985). However, absolute dating of the weathering of bedrock and of the gravels is lacking and kaolinitic fluvial deposits are known from Europe to span the whole of the Palaeogene, Neogene and the earliest Pleistocene. Significant landscape modification has occurred since deposition, with probable uplift and topographic inversion (P915267), but the timing of these events is unknown.

If the Buchan Ridge Gravel Member is fluvial, rather than glaciofluvial in origin, then the upper parts of the former river catchment have been destroyed by erosion. Furthermore, the energy required for boulder transport is likely to have come from steep river gradients resulting from regional tectonic uplift and tilting towards the North Sea. Uplift such as this brought about deposition of kaolinitic sands in the inner Moray Firth both in the Eocene and Pliocene (Andrews et al., 1990). If the gravels are marine in origin then deposition occurred during a period when sea level fluctuated over 75 m and all contemporaneous fine-grained sediments have been destroyed by erosion, which is perhaps unreasonable. Most would agree that the wide elevation range and localised distribution of deposits of the Buchan Ridge Gravel Member suggest that the individual bodies were deposited over a considerable time period. There is a distinct possibility that beach deposits formed during the post-Cretaceous marine regression were later fluvially reworked.

Channel-fill deposits at the mouth of the River Spey

A borehole survey of sand and gravel resources around Garmouth, at the mouth of the Spey (Aitken et al., 1979) revealed the existence of a deep rock-cut channel extending below present sea level. The channel is filled with medium- and fine-grained greenish grey quartzose sands. Thin seams of pale greenish grey, sandy silty clay are also present, containing illite with kaolinite; 20 m or more of glaciofluvial gravel cover the deposits. The channel is interpreted as a possible preglacial channel of the River Spey. An enigmatic kaolinitic 'channel-fill' deposit was also found at depth in a borehole sited on the 'Mosstodloch' glaciofluvial terrace on the Muir of Stynie (NJ 3284 6152) (Aitken et al., 1979).

References

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