Identification of Springston Formation Gravel lobes in the Christchurch Formation

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EXECUTIVE SUMMARY

Springston Formation deposition within the Christchurch City area in the last 10,000 years is assessed in this joint project of Environment Canterbury (ECan) and GNS Science. Pre-historic Springston Formation deposition, particularly gravel deposition associated with gravel deposition from the Waimakariri River, is assessed with maps of surface features, geological logs and radiocarbon dates of recent sediments.

Springston Formation depositional lobes, proposed from an interpretation of surface features and geological logs, in Christchurch City area, include, by surface catchment:

- Halswell River catchment
  - Halswell.
- Heathcote River catchment
  - Heathcote River A (located around Wigram Airfield);
  - Heathcote River B (located around Curlett's Drain catchment);
  - Heathcote River C (located in the historic Wilson's Creek catchment).
- Avon River catchment
  - Fendalton (between the airport and the City Centre, approximately).
- Styx River catchment
  - Belfast.

Surface features that are used in this interpretation include maps of a survey of Christchurch in 1856 before urbanization, soils, geomorphic features associated with recent Waimakariri River deposition, location of springs and ground elevation.

Springston Formation gravel sediments, identified from geological cross-sections, are:

- vertically connected to Riccarton Gravel mainly in the west of Christchurch City;
- unconnected to Riccarton Gravel in central–east of Christchurch City.

Springston Formation gravel sedimentation is interpreted as a series of lobate features including:

- 'connected' gravel lobes in Halswell, Woolston, Sydenham, Fendalton, Belfast and Old South Branch areas;
- 'unconnected' gravel lobes in Halswell, Sydenham, Fendalton and Belfast areas.

Connected gravels link to unconnected gravel lobes, with the exception of the Woolston connected gravel lobe. The Woolston connected gravel lobe is isolated from other connected gravels and from unconnected gravel lobes. However geological data in the area of the Woolston connected gravel lobe is relatively sparse and future drilling may identify links between this gravel lobe and other Springston Formation gravels.

Radiocarbon dates of sediments in the Christchurch City area are used to identify a chronology of Springston Formation gravel sedimentation. The chronology of sedimentation is summarised as, from older to younger, with ages rounded:

- Woolston connected gravel up to about 7800 years ago;

- Halswell connected gravel about 8800 years ago to about 5000 years ago;
- Sydenham connected gravel about 6300 years ago to about 2800 years ago;
- Sydenham unconnected gravel in two depositional phases:
  - phase 1 sedimentation started 4100 years ago, however the end of sedimentation is undated;
  - phase 2 sedimentation started 3000 years ago, however the end of sedimentation is undated;
- Fendalton connected gravel began at an unknown time and ceased about 4400 years ago;
- Fendalton unconnected gravel in two depositional phases:
  - phase 1 4200 years ago to 3000 years ago;
  - phase 2 2000 years ago to 1600 years ago;
- Belfast unconnected gravel, depositional ages unknown;
- Old South Branch connected gravel 4000 years ago to 80 years ago.

The locations of gravel deposition changed significantly in the period 4400 to 4000 years ago in the Sydenham, Fendalton, and Old South Branch gravel lobes. These gravel lobes deposited sediments into the pre-historic Christchurch estuary.

Recommendations coming from this work include:

- improvements to current radiocarbon data held by Environment Canterbury including cross-referencing to sample analysis and adding available records of samples not collected from wells;
- a forward programme of radiocarbon data collection with priorities in the Sydenham area;
- complete digitizing of Wilson (1989) elevation map for Christchurch City;
- a forward programme of shallow drilling to improve our knowledge of links between Springston Formation unconnected gravel lobes;
- development of 3D datasets defining the Springston gravel lobes;
- development of a 3D model of the geological evolution of Christchurch over the last 10000 years.

1.0 INTRODUCTION

Groundwater is the sole source of drinking water for the approximately 350,000 Christchurch City citizens. An understanding of the geology of near-surface sediments under Christchurch City is fundamental to an understanding of the groundwater resource and to the protection of the quantity and quality of this resource.

Environment Canterbury commissioned GNS Science to identify Springston Formation gravel lobes in the Christchurch Formation as part of a re-assessment of the geology of Christchurch. These lobes are near the ground surface and probably play an important role in groundwater flow between the Christchurch City groundwater recharge zone and the springs that support flow in Christchurch City rivers. They probably represent pre-historic floodways of the Waimakariri River.

Springston Formation gravel lobes in Christchurch City are identified with an assessment of surface features of Christchurch City and an analysis of sub-surface occurrence of gravel sediments under the City.

Surface features of Christchurch City used to assess gravel lobe location include maps of:

- waterways, swamps and vegetation of Christchurch in 1856 (White et al. 2007);
- soils;
- geomorphic features associated with recent Waimakariri River deposition;
- location of springs;
- estimated groundwater discharge from sediments to stream beds; and
- ground elevation.

The geographical distribution of Springston Formation gravel lobes, and links to Springston Formation gravels in the Christchurch City groundwater recharge zone, are identified with:

- a three dimensional geological model (White, 2007);
- a map of surficial fine sediment thickness; and
- interpretation of geological sections derived from lithological logs.

Geological sections are interpreted as a three-dimensional distribution of Springston Formation gravels within the Christchurch Formation.

A chronology of Springston Formation gravel deposition is proposed using:

- radiocarbon ages of samples from shallow sediments; and
- radiocarbon ages of samples from wells.

This chronology includes Springston Formation deposition within the last 10,000 years in the Christchurch City groundwater recharge zone and in the gravel lobes under Christchurch City.

2.0 SURFACE FEATURES

Soils, geomorphology, spring location, stream baseflow and ground elevations in the Christchurch City area give evidence of sub-surface geology. Therefore relevant surface features are collated as GIS datasets for the purposes of assessing the surface expressions of subsurface gravel lobes.

2.1 Historic Christchurch water features and vegetation

Christchurch City water features and vegetation, mapped in 1856 (Scott 1963), are summarised by White et al. (2007). Water features (Figure 1) include: rivers, creeks, springs, swamps and ponds. Vegetation (Figure 1) includes: bush, flax, grass, fern and rushes.

Lobate features representing relatively dry ground are clearly identified in the 1856 map of Christchurch City (Figure 2) in the headwaters of the Halswell, Heathcote, Styx and Avon rivers as follows:

- Halswell River catchment
  - a lobate feature in the headwaters of the Halswell River where Nottingham Creek rises.
- Heathcote River
  - A, lobate feature in the headwaters of the Heathcote River, approximately surrounding Wigram Airfield, where the Heathcote River rises;
  - B, lobate feature in the headwaters of the Heathcote River, approximately from Sockburn to Spreydon, coincident with Curlett's Drain;
  - C, lobate feature in the headwaters of the Heathcote River, approximately from Sockburn to Addington, where old Wilson's Creek (White et al. 2007) rises.
- Avon River
  - lobate feature labelled "Fendalton" where the major streams of the Avon River rise in the headwaters of the Avon River.
- Styx River (Purarekanui Creek on Figure 1)
  - lobate feature where the headwaters of the Styx River rise.

2.2 Soils in Christchurch

Soil texture and profile available water are described by Landcare Research (Trevor Webb, pers. comm.) in a compilation of Christchurch City soil maps. A GIS version of these maps was supplied by Environment Canterbury (Ellery, pers. comm.). The variation of soil texture can be explained by geological, hydrogeological and hydrological phenomenon that occurred in the past.

Profile available water (PAW) represents the water available for pasture growth to a depth of 1 m. PAW depends on the capacity and the texture of the soil. The unit used is the millimetre. The range of PAW is from about 15 mm to 300 mm in the Christchurch City area.

The soil texture is represented in Figures 3 and 4 and profile available water is represented in Figure 5 and Figure 6. Soil texture generally corresponds to soil PAW.

The soil texture that has the maximum available water is silt loam and fine sandy loam with a maximum PAW in the range 200-300 mm.

Channels of Christchurch rivers are possibly identified by the soil map. In particular a sandy loam soil texture is associated with current channels of the Styx, Avon, Heathcote and Halswell rivers (Figure 7). Other, pre-historic channels of these rivers are possibly identified in association with the sandy loam soil texture.

2.3 Geomorphic features associated with recent Waimakariri River deposition

McPherson Associates (2004) map of the recent Waimakariri River flood plain (Figure 8) includes eight geomorphic features (Table 1). The area coloured green on Figure 8 was not mapped.

Table 1. Geomorphic features identified by McPherson Associates (2004).

Geomorphic feature	Notes
Waimakariri River bed	Active and inactive river bed between stop banks.
Old South Branch	Channel of Waimakariri River to 1932.
Harewood Floodway	Pre-historic channel of the Waimakariri River.
Airport Floodway	Pre-historic channel of the Waimakariri River.
Halswell Floodway	Pre-historic channel of the Waimakariri River.
Springston Formation 3	Gravel fan surface leading to urban areas bearing present river course and majority of pre-historic floodways.
Springston Formation 2	Older gravel than Springston Formation 3 characterised by dunes and thin loess.
Springston Formation 1	Oldest Springston Gravel surface characterised by dunes and loess deposits.

The area has a very large range of geomorphic settings and the map of M^{c}Pherson Associates (2004) is simplified to six geomorphic units in Figure 9. The main features that characterise the Christchurch area include:

- a dark tone mainly representing coastal deposits. The coastal deposits are composed of sand dunes and tidal deposits present in the lagoons and swamps;
- the light and mid-grey tones represent the floodplain and the extents of pre-historic floodways;
- the vertical stripes show the location of the pits and excavations below the natural floodplain surface;
- horizontal stripes represent the Waimakariri River and streams with a border of willows, pine plantations and minor scrub;
- the crosswise stripes characterise the dry courses of the old river bed.

The geomorphic map (Figure 10) identifies (presumed) pre-historic channels of the Waimakariri River including:

- Old South Branch;
- Harewood Floodway;
- Styx;
- Airport Floodway;
- Halswell Floodway.

Note that the geomorphic map is not complete so boundaries on the edges of the mapped areas (e.g. between the Airport floodway and Halswell floodway) may not represent geomorphic features.

2.4 Location of springs

Locations of springs from three sources (Environment Canterbury, Christchurch City Council and the 1856 map) are plotted in Figure 11.

2.5 Estimated groundwater discharge to surface water

Discharge of groundwater to surface water is estimated by White et al. (2007) using observations of surface flows held by Environment Canterbury and Christchurch City Council.

Figure 12 represents estimated discharge of groundwater to surface water (i.e. baseflow) for catchments in Christchurch City. The thickness of the red line is proportional to the baseflow of the streams. This representation of baseflow shows flow in the main stream and shows the localities of flow gains in stream headwaters.

2.6 Sediments in stream beds

Christchurch City Council (Van Nieuwpoort pers. comm.) is currently surveying features of Christchurch City streams including sediment type in streams and rivers (Figure 13).

Gravel, as a proportion of stream bed sediment type (Figure 14) indicates significant occurrence of gravely river beds in the following areas: Old South Branch, Upper Styx River Papanui – Richmond, Upper Avon and Upper Heathcote (Hoon Hay). This figure plots gravel as a percentage of bed sediment type from the Christchurch City Council 'vwInorganicsubstrate' data set.

2.7 Ground elevation

Topographic elevation contours in the Christchurch area are approximately 40 meters in the west and approximately 5 meters in east Christchurch (Figure 15). The contours are digitised from a map in Wilson (1989) registered on stream and estuary positions plotted in Wilson (1989).

Curvature of elevation contours appears to identify features that may relate to gravel lobes (Figure 16) including:

- Styx – relatively elevated ground level north of Belfast;
- Fendalton – relatively elevated ground between Christchurch International Airport and St Albans, and possibly Richmond;
- Yaldhurst – Sydenham – elevated ground level between north-west Christchurch, approximately from Yaldhurst Road, to the Heathcote River;
- Hoon Hay – relatively elevated ground east of Hoon Hay;
- Wigram – relatively elevated ground between Islington and Wigram airfield.

2.8 Evidence of pre-historic floodways from surface features

Evidence of pre-historic floodways from surface features is assessed in this section by over plotting maps developed in Section 2.1 to Section 2.7.

Figure 17 combines:

- proposed lobes from the 1856 map (Figure 2);
- streams mapped in 1856 (Figure 1);
- soil texture (Figure 4).

Figure 17 indicates that sandy loam soil textures are associated with proposed lobes and 1856 streams as follows:

- Halswell lobe and Halswell River;
- Heathcote lobe A and B with the Heathcote River (main stream);
- Heathcote lobe C with Wilsons Creeks/Heathcote River;
- Fendalton lobe with Avon River (main stem);
- Fendalton lobe with Avon River (Dudley Creek);
- Styx lobe with Styx River.

Figure 18 combines:

- proposed lobes from the 1856 map (Figure 2);
- streams mapped in 1856 (Figure 1);
- the geomorphic map (Figure 9).

Figure 18 indicates a correspondence between proposed lobe location, 1856 streams and geomorphic features, for example:

- the “Halswell Floodway” of McPherson Associates (2004) links to the Halswell lobe, Heathcote lobe A and Heathcote lobe B;
- the “Airport Floodway” of McPherson Associates (2004) links to the Fendalton lobe;
- the Styx lobe is associated with the Styx River but McPherson Associates (2004) do not map wide floodways within the area of the Styx lobe.

Figure 19 combines:

- proposed lobes from the 1856 map (Figure 2);
- springs mapped by ECan, Christchurch City Council and in the 1856 map (Figure 11);
- baseflow of rivers in Christchurch (Figure 12).

Figure 19 indicates:

- most springs in the Halswell and Heathcote catchments are south, or east, of the boundary of proposed lobes from the 1856 map;
- most springs in the Avon River catchment are westward of the proposed lobe boundaries from the 1856 map;
- springs in Papanui are north of the proposed lobe boundary from the 1856 map;

- springs in the Styx catchment are generally close to, or westward of, the proposed lobe boundary from the 1856 map.

Figure 20 combines:

- proposed lobes from the 1856 map (Figure 2);
- proposed lobes from the elevation map (Figure 16).

Figure 20 indicates:

- the “Wigram” lobe identified in the elevation map is associated with the Halswell lobe and Heathcote lobe A;
- the “Yaldhurst” lobe identified in the elevation map is associated with Heathcote lobe C and possibly associated with Heathcote lobe B;
- the “Fendalton” lobe identified in the elevation map is associated with the Fendalton lobe of the 1856 map;
- the “Styx” lobe identified in the elevation map is associated with the Styx lobe of the 1856 map.

Figure 21 combines:

- floodways from the geomorphic map (Figure 10);
- soil texture (Figure 4).

Figure 21 indicates that floodways proposed by McPherson Associates (2004) are associated with sandy loam soils. It appears that sandy loam soils are associated with river channels discharging from the areas mapped by McPherson Associates (2004) as floodways.

Figure 22 combines interpretations of three maps with full coverage of the Christchurch City area to represent pre-historic channels of the Waimakariri River:

- proposed lobes in the 1856 map (Figure 2);
- lobes proposed from the elevation map (Figure 16);
- soils indicating pre-historic channels (Figure 7).

These three maps are used to summarise surface information that indicates pre-historic channels as these maps have near-full coverage of the Christchurch City area. The McPherson Associates (2004) is not used here as the map covers only a small portion of the Christchurch City area. This representation of pre-historic channels is developed to compare with sub-surface gravel lobes in Section 4.

3.0 SUBSURFACE FEATURES

3.1 Geological logs

3.1.1 General geological logs

Eight geological cross-sections (Figure 23) are generated from the Environment Canterbury geology data base. In each plot, geological logs are collated from a zone within 500m of the section line. The legend for each cross-section is plotted in Figure 24.

The upper 10 – 25m of cross-sections one (Figure 25), two (Figure 26), three (Figure 27) and four (Figure 28) show shallow Springston Formation gravel lobes (coloured blue). They are covered with clay and sand. Cross-section five (Figure 29) shows a large volume of gravel from +10m of elevation to more than -40m below sea level (Riccarton Gravel). Cross-sections six (Figure 30) and seven (Figure 31) show few gravel layers close to the ground surface but a large gravel lobe from -10m to -40m of elevation (Riccarton Gravel). Gravels are the most common sediments in cross-section eight (Figure 32).

3.1.2 Geological cross-sections and data processing

Geological cross sections are generated in the Christchurch City area for:

- South Christchurch City (Figure 33 and Appendix 1);
- Central-West Christchurch City (Figure 34 and Appendix 2); and
- South-West Christchurch City (Figure 35 and Appendix 3);
- North Christchurch (Figure 36 and Appendix 4).

These sections (Appendices 1, 2, 3 and 4) plot geological logs within 500 m of the section, i.e. a 1 km ‘strip’ of geological logs.

Springston Gravel is identified from the cross-sections as:

- gravel lobes connected vertically to Riccarton Gravel (e.g. Figure 37 and Figure 38);
- gravel lobes unconnected to the Riccarton Gravel (e.g. Figure 39 and Figure 40).

Ground surface on each section and the top of the Riccarton Gravel are also identified in the cross-sections.

These observations are converted into a three-dimensional data set using the following process in ArcGIS and Earth Vision software:

- register the sections;
- assign codes to the digitised points as follows
  10 = ground surface
  20 = gravel connected to Riccarton Gravel
  30 = gravel unconnected to Riccarton Gravel
  40 = top of Riccarton Gravel
  50 = lobes of fine sediment within gravel.

These interpreted outlines are digitised from the cross sections with the codes for each line as a projection on the y-coordinate (x is seen as constant, i.e. digitising in a y-z coordinate-system) and exported as a 2D-lineshapefile (ESRI-format)

Two datasets are produced:

- a polyline-dataset for the interpolation of the surface of the Riccarton Gravel and preliminary topography, and
- a dense point raster for the interpolation of gravel and non-gravel deposits in 3D-space.

Within the ArcGIS-environment and extension ET-GeoWizard-Tool (free download) the following steps are performed:

- densification of vertices on lines to 1 vertex every 10m;
- conversion of lines to points with profile-coordinates (y-z);
- calculation of x coordinates as a linear function of y according to
  dim xs,ys,xe,ye as long
  xs = 2474000
  ys = 5743500
  xe = 2477700
  ye = 5748800
  shape = xs+((xe-xs)/(ye-ys))* ([X]-ys)
- merge of all files into a single one (one per unit);
- export points as a text-file (tab-separated) and import with predefined free header to Earthvision as a .dat file.

Within ArcGIS-environment and extension ET-GeoWizard-Tool (free download) the following steps are performed:

- multiplication of the digitized polylines' z-value for the purpose of better editing within the shapefiles by the raster calculator on the attribute-table's field [shape] according to Ianko Tchoukanski's collection of VB-scripts for ArcGIS in GeoCalculate5.0 (free download):

```
Dim pPoint As IPoint
Dim pPolyline As IPolyline
Dim pPointColl As IPointCollection
Dim pNewPointColl As IPointCollection
Dim pZA As IZAware
Dim dY As Double
Dim i As Long
'=========================
'adjust the parameters below
dY = 20
'if Z value from a field is to be used unremark the following line
'remove the quotation marks and adjust the field name
'dY = "[Z_FIELD]"
'=========================
If (Not IsNull([Shape])) Then
  Set pPolyline = [Shape]
```

```
    If (Not pPolyline.IsEmpty) Then
      Set pPointColl = pPolyline
      Set pNewPointColl = New Polyline
      For i = 0 To pPointColl.PointCount - 1
        Set pPoint = pPointColl.Point(i)
        pPoint.Y = pPoint.Y*dY
        pNewPointColl.AddPoint pPoint
      Next i
      Set pPolyline = pNewPointColl
      Set pZA = pPolyline
'     pZA.ZAware = True
      End If
    End If

    Shape = pPolyline
```

- closure of all polylines and creation of a polygon at the base for the Riccarton Gravel;
- creation of polygons from polylines within ArcToolbox;
- attribution of all polygons with given codes for units;
- creation of a raster with 20m spacing from polygons with ArcToolbox;
- creation of a pointshapefile from that raster;
- adding X and Y coordinates to the attribute table;
- multiplication of Y by 1/20 to re-establish correct coordinates (method mentioned above);
- calculation of real Y from X (method mentioned above);
- merge of all files to a single one with standard names of columns;
- export as a text-file (tab-separated) and import with predefined free header to Earthvision as a .pdat file.

Three-dimensional analysis is used to:

- assess connections between gravel lobes by tracing structures of Springston Gravel lobes (connected and unconnected to the basal Riccarton Gravel) back towards their origin; and
- identify features in the sections that identify depositional features. Analysis of the interpreted cross-sections is done within ArcGIS and Earthvision.

Therefore, as a first step, the maximum outline of unconnected gravel lobes is digitised in 3D-space and correlated with the known occurrence of Sydenham, Fendalton and Belfast gravel lobes of Springston Gravel. A lobe may be attributed as connected, though it is merely connected to a narrow extent, in the area of transition from a connected to an unconnected lobe. Therefore the analysis considered the strength of evidence for connection shown by the well logs.

Features in the sections are correlated by connecting the tops of potentially correlated lobes with 3D lines and marking the trend of deposition. Where possible, these lines are traced towards the west using the shape and occurrence of connected and unconnected gravels. Additionally, any structures indicating possibly contemporaneous deposition are marked on the cross-sections by 3D lines. Well data used in the 3D geological model (Section 3.2) are also considered in the 3-D analysis.

A system of text-codes for the unconnected gravel-lobes is introduced with the first letter S, F or B regarding the correlation to the Sydenham, Fendalton or Belfast gravel lobes, respectively. The following letters refer to the hierarchical order of splitting into sub-lobes by naming lobes of the same sub-hierarchy A, B, C, etc, from the south to the north. For example the Fendalton gravel lobe F can be subdivided into the lobes FA, FB, FC, FD and each of these can also be subdivided into sub-lobes naming them FAA, FAB, FBA, FBB and so on.

3.1.3 Interpretation

The "unconnected" gravel lobes (Figure 41) are classified as either Belfast, Fendalton, Sydenham or Halswell. These lobes cover most of western, central and southern Christchurch City.

Unconnected gravel lobe location is compared with the occurrence of unconnected gravel in the cross sections (Figure 42).

Connected Springston Gravel lobes (Figure 43) sit directly on Riccarton Gravel. Lobes are identified in Belfast, Fendalton, Sydenham, Woolston and Halswell. Geological cross sections that identify connected gravels are shown in Figure 44. The connected lobes in Belfast and Woolston may link to unconnected gravel above. The nature of possible links in these areas has not been explored in detail in this report.

Unconnected gravels generally occur further east than connected gravels (Figure 45). This indicates that early Springston Gravel deposition (i.e. the connected gravel) was followed by later Springston Gravel deposition within Christchurch Formation sediment as Springston Gravels were deposited in the palaeo-estuary from Waimakariri River channels.

3.2 Geological model

A geological model of the Springston Gravel and Christchurch Formation (White, 2007) includes lithological descriptions from 4596 wells in the Christchurch area (Figure 46). Lithological logs (Figure 47) show a layering interpreted as a glacial/interglacial sequence of sedimentary deposition in the Christchurch area.

The geological model identifies gravel lobes within the Christchurch Formation sediments, i.e.:

- Belfast area (Figure 48);
- Fendalton area (Figure 48), related to the Avon River (White, 2005);
- Sydenham area (Figure 49).

3.3 Surficial fine sediments

All bore log lithological descriptions from drillers are assigned lithological codes when they are entered into ECan's Wells Database. These codes are used to generate graphic representations of the bore log, either as individual bore logs or many bore logs, on cross-sections for hydrogeological interpretation. The computer is used to search the lithological codes for the depth at which first gravel was encountered in the bore logs. A map is generated in GIS showing the locations of wells and thickness of fine sediments. Fine

sediments comprise marine/estuarine sand /silt and alluvial silt and sand with peat. Fine sediments are annotated and colour coded according to a specified depth range. The following depth ranges are adopted: 0 - 0.9m, 1 - 2.9m, 3 - 4.9m, 5 - 9.9m, 10 - 14.9m, 15 - 19.9m, 20 - 24.9m, 25 - 29.9m, 30 - 34.9m, 35 - 39.9m, and 40 - 44.9m. Isopach contours are manually drawn in GIS for the following fine sediments thicknesses: 1, 3, 5, 10, 15, 20, 25, 30, 35 and 40m (Figure 50).

The isopach contours are drawn manually for two main reasons:

- the process allows geological interpretation of the data to be consistent with the known floodplain surface features, which is not possible, if contouring software (e.g. “Surfer”) is used. Former Waimakariri River channels entering Christchurch have been mapped (Brown & Weeber 1992, McPherson 2004) and some shallow and apparently isolated gravels are linked as channel features;
- it is easier to find and allow editing of anomalous data, e.g. gravel fill brought into various sites to form a firm building foundation base on softer sediments.

The isopach contours do not necessarily represent the total thickness of Springston Formation sediments overlying Riccarton Gravel because Springston Formation sediments represent former Waimakariri River channels that interfinger as lobes within the fine sediments.

Three broad zones are recognised:

- eastern (coastal) north and south of Banks Peninsula zone with no interbedded gravels above Riccarton Gravel, dominated by marine fine sediments, some alluvial silts at surface;
- central complex zone with interbedded/interfingering Springston Formation channels within marine and alluvial fine sediments. In some places Springston Formation sediments are in direct contact with Riccarton Gravel, especially towards the western side of Christchurch;
- western zone where soils are generally thin i.e. gravel is at, or near, the ground surface. There is no obvious marker bed separating Springston Formation gravels from Riccarton Gravel and therefore these gravels are difficult to distinguish in bore log descriptions.

The map of fine sediment thickness broadly corresponds with the extents of unconnected gravel lobes (Figure 51).

3.4 Radiocarbon dates

Radiocarbon dates measured by the GNS Science Rafter Radiocarbon Laboratory are identified from:

- records summarised by Grant-Taylor and Rafter (1971);
- Rafter Radiocarbon laboratory paper records (Chambers, pers. comm.);
- a search of the GNS Science PETLAB database for all radiocarbon samples held as of 13 August 2007 for metric map sheets M35 and M36;
- Environment Canterbury records of radiocarbon dates of samples from wells.

Samples are grouped into two sets:

- radiocarbon dates from shallow sediments. These include radiocarbon ages estimated in soils, peat, gravel, excavations and wells compiled from original radiocarbon records (Section 3.4.1), Figure 52 and Figure 53;
- radiocarbon dates from samples recorded by Environment Canterbury in their well database (Section 3.4.2), Figure 54 and Figure 55.

Radiocarbon ages were recalculated in May 2007 to the revised international half life (Chambers, pers. comm.).

Two radiocarbon dates are recorded by the Rafter Radiocarbon Laboratory: original analyses and recalculated dates in May 2007. Radiocarbon dates used in this report are those of the original analysis because:

- Environment Canterbury records original radiocarbon analysis in its database and the interpretation of the chronology of gravel lobe deposition includes shallow samples and ECan's samples from wells (Section 3.4.2);
- not all samples have recalculated (i.e. May 2007) dates;
- some recalculated radiocarbon dates are inconsistent with the original data. It appears that some recalculated ages require detailed checking which is beyond the scope of this report;
- recalculated radiocarbon dates are mostly within the standard error of the original data (Appendix 5, Table A5.1)

Estimates of age are used to assemble a chronology of gravel lobe, and gravel layer, deposition.

3.4.1 Radiocarbon dates from shallow sediments

Radiocarbon dates of shallow sediments in the greater Christchurch City area are listed in Appendix 5 (Table A5.1). Radiocarbon dates of shallow sediments in the Christchurch area are listed in Table A5.2.

The provenance of radiocarbon samples (Appendix 5, Table A5.3) is assessed from the records obtained during sample collection. Records obtained during sample collection are summarised by Grant-Taylor and Rafter (1971) and useful additional information is held in GNS Science, Rafter Radiocarbon Laboratory field sheets (e.g. notes, geological sections and geological logs).

Radiocarbon samples of shallow sediments that are used to assess the chronology of gravel deposition in Christchurch (Table A5.4) includes samples that have both:

- radiocarbon analysis (i.e. Table A5.2);
- geological information in the sample collection record (i.e. Table A5.3).

3.4.2 Radiocarbon dates from wells recorded by Environment Canterbury

The location, and well number, of wells with radiocarbon analyses recorded by Environment

Canterbury in the Christchurch area (Appendix 6) are shown in Figure 54 and Figure 55. The lithology of each radiocarbon analysis is determined (Figure 56) from the lithological descriptions held by Environment Canterbury (Appendix 6).

Radiocarbon analysis recorded by Environment Canterbury (Appendix 6) are a subset of all radiocarbon analyses (Appendix 5). Analyses held by Environment Canterbury are classified by formation and are used to identify ages of sedimentation in the Christchurch Formation and Springston Formation.

On Figure 56 lithologies are classified for each radiocarbon sample within the Christchurch Formation as:

- NBS – New Brighton Sands;
- CFF – Christchurch Formation fine sediments;
- CF undif – either fine sediments or New Brighton Sands – the geological log is not clear;
- CFF? SFF? – either Christchurch Formation or Springston Formation – the geological log is not clear.

The NBS and CFF classifications are preliminary to separating the Christchurch Formation into two members on the basis of depositional environment and permeability properties; these members will be defined in a paper that will follow this report.

Other lithologies are classified for radiocarbon samples taken from formations other than Christchurch Formation or Springston Formation as:

- Bromley – Bromley Formation;
- Linwood – Linwood Formation;
- Heathcote – Heathcote Formation;
- Riccarton – Riccarton Formation.

3.5 Chronology of Springston Formation deposition from radiocarbon dates

Radiocarbon dates are used to propose a chronology of Springston Formation deposition in the last 10 000 years in Christchurch.

Firstly, radiocarbon samples in the Christchurch Formation are assessed to determine minimum and maximum deposition ages of gravel lobes. Then radiocarbon ages are used to identify the commencement of gravel lobe deposition. Lastly, radiocarbon are used to identify a chronology for phases of gravel deposition within gravel lobes.

3.5.1 Range of deposition using Christchurch Formation radiocarbon dates

3.5.1.1 New Brighton Sands

New Brighton Sands samples with radiocarbon dates (Figure 57) are located in the south-east of Christchurch City close to, or overlapping with, Springston Gravel lobes from Figure 41. One radiocarbon date gives an indication of the maximum age of Springston Gravel deposition:

- well M36/1187 has a radiocarbon age from a sample below Springston Gravel lobe SBCAA (Figure 57 and Appendix 7). Therefore deposition of gravel lobe SBCAA began less than 7820 years ago.

3.5.1.2 Christchurch Formation fine sediments

Christchurch Formation sediments with radiocarbon ages, within the geographic boundaries of proposed gravel lobes from Figure 41, are identified for New Brighton Sands (Figure 57) and Christchurch Formation fine sediments (Figure 58) as located:

- below the proposed gravel lobes; or
- within the proposed gravel lobes.

Samples below the proposed gravel lobes indicate a maximum age of Springston Gravel deposition (Table 2).

Table 2. Maximum age of gravel lobe as indicated by Christchurch Formation radiocarbon ages below the gravel lobe.

Springston Gravel lobe code	Christchurch Formation Well	Maximum age of Springston Gravel lobe
BBA	M35/1175	8030
FB	M35/2243	5450
FB	M35/1974	8000
FA	M35/2208	7120
FA	M35/1987	6200
SBCAA	M36/1187	7820

3.5.2 Springston Formation

3.5.2.1 Commencement of Springston Formation gravel lobe deposition

Radiocarbon samples in Springston Formation sediments (Figure 59) are categorised as from connected or unconnected gravels (Figure 60) based on the map of gravel lobes in Figure 42. Radiocarbon ages in connected gravels are typically greater than radiocarbon ages in unconnected gravels (Figure 61). Radiocarbon ages in the west are typically older than radiocarbon ages in the east (Figure 61).

Radiocarbon ages in Springston Formation sediments are typically greater in deeper samples (Figure 62). Radiocarbon ages in Springston Formation sediments are typically oldest in the Halswell area (Figure 63).

Radiocarbon samples (shallow sediment samples and samples from wells) close to the base of Springston Formation gravels (Figure 64) are identified (Table 3) to estimate the age of commencement of gravel deposition.

Table 3. Radiocarbon samples identifying the base of Springston Formation gravel deposition.

Sample well number	Depth (m)	Age of commencement of Springston Gravel deposition (years)	Easting (m)	Northing (m)	Elevation (m)	Stratigraphy	Lobe name	Lobe code	Sample position	Connection*
R 392/2 NZ 306	10	3750	2480294	5742031	-4	SFF	Fendalton	FB		u
R 1559/1 NZ 712	14	6450	2473684	5738346	6	SFF	Halswell	HA		c
M35/1364	10	4020	2476380	5749140	19	SFF	Belfast	BB		c
M35/2149	7	2040	2480950	5742510	5	SFF	Fendalton	FB		u
M35/2149	10	4240	2480950	5742510	5	SFF	Fendalton	FB		u
M35/2208	6	1585	2480700	5741700	6	SFF	Fendalton	FA		u
M35/5572	8	6330	2474200	5740300	20	SFF	Sydenham	S		u
M35/6102	14	6660	2473490	5740300	22	SFF?	Sydenham	S		c
M36/0981	11	2990	2477100	5739200	14	SFF	Sydenham	SBC		u
M36/1060	10	4060	2478000	5739800	12	SFF	Sydenham	SCB		u
M36/4017	13	8820	2473480	5737610	20	SFF	Halswell	HA		c

* u unconnected gravel
c connected gravel

The age of commencement of Springston Formation gravel deposition (Figure 64) and ages within gravel lobes (Figure 63) appears to follow a chronology (from oldest to youngest and ages rounded):

- Halswell area approximately 8800 years ago to 6500 years ago;
- Sydenham area approximately 6600 years ago to 3000 years ago;
- Fendalton area approximately 5500 years ago to 1500 years ago;
- Old South Branch approximately 4000 years ago.

Therefore:

- older gravel sediments are deposited in west and south Christchurch;
- deposition has generally moved towards the north in more recent times, and
- deposition of gravels in Sydenham, Fendalton and Old South Branch overlap in time so depositional centres probably don't move consistently northwards in a step-wise fashion.

The age of commencement of gravel deposition for the following gravel lobes may be identified by radiocarbon dates:

- Fendalton lobe FA1585 years ago;
- Fendalton lobe FB 2040 – 5450 years ago;
- Sydenham lobe SBC 2990 years ago;
- Sydenham lobe SCB 4060 years ago.

3.5.2.2 Deposition of Springston Formation gravel layers within gravel lobes

Springston Formation gravel layers occur within gravel lobes (e.g. identified in Figure 45). These layers represent episodes of gravel deposition that are identified in geological information relevant to shallow samples (Appendix 5) and well logs (Appendix 6).

The start and end of gravel layer deposition is assessed using radiocarbon dates from samples located at the bottom and the top of gravel layers.

Some gravel layers have radiocarbon analyses from near the bottom, or top, of the gravel unit. The radiocarbon age is assigned to the bottom, or top, of the gravel layer if the radiocarbon sample is taken from within one metre of the gravel layer boundary.

Radiocarbon samples located at the bottom, or top, of gravel sediments (Table 4) are identified by "P codes" as outlined in Table 4 and Appendix 5:

- iax immediately above the shallowest gravel layer;
- ibx immediately below the shallowest gravel layer;
- iay immediately above the 2nd shallowest gravel layer;
- iby immediately below the 2nd shallowest gravel layer.

Phases of gravel deposition identified by radiocarbon dates are summarised in Figure 65 and Table 5. Radiocarbon ages are used to identify the start and end of gravel deposition, estimated from shallow sample provenance (Table 4) and well logs (Table 3).

Radiocarbon ages, shallow sample provenance and well logs appear to identify two phases of unconnected gravel deposition in each of the Sydenham and Fendalton gravel lobes:

- Sydenham SCB located in the Addington area and possibly associated with the proposed Yaldhurst lobe (Figure 16) and the Heathcote “C” lobe (Figure 19);
- Sydenham SBC located in the Spreydon area and possibly associated with the proposed Yaldhurst lobe, or the proposed Wigram lobe, (Figure 16) and the proposed Heathcote “A” and “B” lobes (Figure 19);
- Fendalton F1 observed in the Fendalton gravel lobes F, FA and FB (Table 4). F1 is a chronostratigraphic unit and is used here in preference to geographic-based lobe codes;
- Fendalton F2 observed in the Fendalton gravel lobes FA and FB (Table 4). F2 is a chronostratigraphic unit and is used here in preference to geographic-based lobe codes.

Two phases of Springston Formation gravel deposition in the Fendalton gravel lobe are identified in the central city by:

- provenance information from radiocarbon samples R2359/3 and R2359/4 (Figure 52);
- provenance information from radiocarbon sample R1393/2 (Figure 52).

Provenance information for radiocarbon sample R1393/2 indicates a gravel lobe younger than “F2”. However Table 5 and Figure 65 do not include a gravel lobe younger than F2 as no radiocarbon dates are observed in gravels younger than F2.

Table 4. Radiocarbon analyses that identify the start and end of Springston Formation gravel deposition.

R_number	F_number	NZ_number	Locality	Grid reference (NZMS260 easting)	Grid reference (NZMS260 northing)	Depth to RC sample (m)	C14 age - original analysis (years before present) without error	P_code	Lobe_code
1391	S83/f502	NZ 576	Prebbleton	2471200	5729066	0.6	5650	iax	Outside
5069	S83/f516	NZ 3946	Templeton	2465423	5740118	0.56	5020	iax	Outside
2359/1	S84/f566	NZ 1096	University of Canterbury Ilam	2476347	5742875	3.3	3750	iax	F (F1)
2359/2	S84/f567	NZ 1097	University of Canterbury Ilam	2476347	5742875	1.3	3300	iax	F (F1)
2359/7	S84/f573	NZ 1102	Christ's College Christchurch	2479839	5741932	4.5	3030	iax	FA (F1)
9553/2	M35/f16	NZ 5587	Law Courts	2480400	5742200	5.5	1900	iax	FB (F2)
1393/2	S84/f551	NZ 551	BNZ Site Cathedral Square	2480575	5741671	5.7	1585	iay	FA (F2)
1000/8	S83/f510	NZ 433	Williamson's Farm Lincoln	2471022	5728788	0.6	2440	ibx	Outside
1556/1	S76/f511	NZ 709	Belfast Christchurch	2476325	5749184	9.2 - 10.7	4020	ibx	B
1559/2	S84/f558	NZ 713	Sockburn Christchurch	2474108	5740274	7.5	6330	ibx	S
2359/3	S84/f568	NZ 1098	Cnr Manchester & Salisbury ChCh	2480926	5742500	6.8 - 8.0	2040	ibx	FB (F2)
2359/8	S84/f574	NZ 1103	Christ's College Christchurch	2479839	5741932	9.6	4200	ibx	FA (F1)
693/2	S83/f508	NZ 383	Waimakariri Rd Templeton	2468172	5739802	0.4 - 0.6	3500	ibx	Outside
693/3	S83/f509	NZ 384	Boyes Farm Broadfields	2465856	5736377	0.6 - 0.8	6495	ibx	Outside
9767/3	m35/f9581	NZ 6515	Central Police Station	2480300	5741600	13.1 to 14.0	4204	ibx	FA (F1)
2359/4	S84/f569	NZ 1099	Cnr Manchester & Salisbury ChCh	2480926	5742500	9 - 9.9	4240	iby	FB (F1)
1724/1	S84/f563	NZ691	Heathcote	2484101	5738808	16.8 - 17.7	7821	iby	W

The lobe code “Outside” indicates the sample is outside the Christchurch City area.

Table 5. Proposed chronology of Springston gravel deposition.

Gravel lobes	Code	Approximate start of gravel deposition (years B.P.)*	Approximate end of gravel deposition (years B.P.)[1]	Notes
Old South Branch	OSB	4000	80[2]	River shifted from this area by engineering works.
Fendalton	F2	2000	1600	The start of gravel deposition is indicated by provenance information from radiocarbon sample R2359/3 (Table 4). The end of gravel deposition is indicated by provenance information from radiocarbon sample R1393/2 (Table 4).
	F1	4200	3000	The start of gravel deposition is indicated by provenance information from radiocarbon sample R2359/8 (Table 4). The end of gravel deposition is indicated by provenance information from radiocarbon sample R2359/7 (Table 4).
	F	?	4400	End of connected gravel deposition estimated from wells M35/2465, M35/1366 and M35/1495. The start of gravel deposition is unknown.
	SBC	3000	?	The start of gravel deposition is indicated by well M36/0981. The end of gravel deposition is unknown.
	SCB	4100	?	The start of gravel deposition is indicated by well M36/1060. The end of gravel deposition is unknown.
	S	6300	2800	The start of gravel deposition is indicated by well M35/5572. The end of gravel deposition is indicated by sample R1000/1.
Halswell	H	8800	5000	The start of gravel deposition is indicated by well M36/4017. The end of deposition is indicated by sample R5069.
Woolston	W	?	7800	End of gravel deposition indicated by the deep radiocarbon date from well M36/1187.

[1] years before present rounded to the nearest 100 years.
[2] gravel deposition ceased in 1932 when the residual South Branch flow stopped (McPherson Associates 2004).

The Woolston connected gravel lobe may be older than 7800 years because:

- well M36/1187 records “shingle brown sand and salt” from a depth of 17.9 m to a depth of 24.6 m;
- well M36/1187 has a radiocarbon sample at 16.8 m to 17.7 m immediately above the shingle layer;
- therefore the shingle layer is older than 7800 years ago;
- the well is close to cross section S840;
- the cross sections (e.g. sections S810, S830 and S840) classify gravels in the depth intervals 17.9 m to 24.6 m as connected Springston Formation gravels.

However the geological classification of the gravel in Well M36/1187 at 17.9m to 24.6 m does not clearly identify connected gravel because:

- the well log classifies the gravel as Riccarton Gravel.

Inferences about Springston Formation gravel deposition from Figure 64 and Figure 65 include:

- the Woolston connected gravel may join to the Halswell connected gravel because the age of Woolston connected lobe (older than 7800 years ago) is consistent with ages in the Halswell connected lobe. However sections S790 and S780 (Appendix 1) don’t identify connected gravels that could link Woolston lobe with the Halswell lobe. Note that geological logs are scarce on these sections and future drilling may identify links.
- gravel deposition in the south of Christchurch City is older than gravel deposition in the north;
- gravel deposition in the various gravel lobes (Halswell, Sydenham, Fendalton and Old South Branch) overlap in time;
- about 4400 years ago connected gravel lobe deposition in the Fendalton area ceased;
- about 4000 – 4200 years ago unconnected gravel deposition in Fendalton and Sydenham began;
- deposition of the SCB gravel lobe, which began approximately 4100 years ago, occurs at a similar time to the Fendalton F1 gravel lobe – maybe these two gravel lobes are related through contemporaneous deposition;
- deposition in the OSB lobe began about 4000 years ago and maybe this is related to the onset of unconnected gravel lobe deposition;
- deposition of the SBC gravel lobe began approximately 3000 years with gravel originating from the Yaldhurst area or the Wigram area;
- the Fendalton gravel lobe F2 overlies F1 in the central-to-north-east central area (radiocarbon analyses R2359/3 and R2359/4). The earlier F1 deposition phase is observed at the University of Canterbury, Christ’s College, the Central Police Station and corner of Manchester and Salisbury Streets. Therefore maybe deposition of gravel lobe F2 occurred on the northern side of the gravel lobe F1.

4.0 SYNTHESIS OF SURFACE AND SUBSURFACE FEATURES

The locations of unconnected gravel lobes, and connected gravel lobes, (Figure 66) indicate potential pathways for groundwater to recharge springs. For example (from south to north):

- the occurrence of springs in the Halswell area, immediately to the east and north-east of Halswell township, appears related to the Halswell gravel lobe. Water from these springs discharges to the Halswell River and to the Heathcote River (Figure 67). Therefore groundwater flow in the Wigram gravel lobes discharges to the Halswell River and the Heathcote River;
- few springs are mapped in the Wigram-Sydenham area (Figure 66);
- most of the baseflow increase in the Heathcote River occurs near Cashmere. Groundwater for this may originate from unconnected Sydenham gravel lobes or from the connected Halswell gravel lobe (Figure 67);
- springs in the Fendalton area supply approximately 40% (approximately 840 L/s) of the Avon River baseflow (Figure 67). The location of these springs is very close to the eastern boundary of connected Fendalton gravel (Figure 66). This observation indicates that:
  - the horizontal boundary between the high-permeability connected Fendalton gravel and low-permeability Christchurch Formation sediments probably plays a key role in forcing groundwater flow to the surface,
  - a potential pathway between Riccarton Gravel and the springs is identified via Fendalton connected, and unconnected, gravel, and
  - locations of stream beds in the headwaters of the Avon River appear to mirror somewhat the location of Fendalton connected gravel;
- the location of springs in Papanui appears related to the location of the Papanui gravel lobe (Figure 66). Baseflow in the stream discharging from the area of these springs is estimated as 232 L/s (Figure 67) in Dudley Creek. The location of Dudley Creek (Figure 67) is similar to the southern boundary of the Papanui gravel lobe;
- springs are associated with the Belfast gravel lobes (Figure 66) and most flow from these spring discharges to the Styx River catchment. Approximately 100 L/s of estimated baseflow presumably from the southern-most Belfast gravel lobe discharges to the Avon River catchment.

The locations of unconnected gravel lobes are similar to the locations of surface features that identify possible pre-historic channels (Figure 68). For example:

- the Halswell lobe identified by the 1856 map (Figure 19) by soil type and by elevation appears to link to the Halswell unconnected gravel lobe (Figure 68) and the Halswell connected gravel lobe (Figure 66). The surface expression of this lobe has also been termed the “Islington Channel” by other workers;
- Heathcote lobe A (Figure 19) identified by the 1856 map, by soil type and by elevation appears to link to the Sydenham unconnected gravel lobe;
- Heathcote lobe B (Figure 19) identified by the 1856 map and by soil type appears to link to the Sydenham gravel unconnected gravel lobe;
- Heathcote lobe C (Figure 19) identified by the 1856 map, by soil type and by elevation (i.e. the Yaldhurst lobe of Figure 16) appears to link to the Sydenham gravel unconnected gravel lobe;

- the Fendalton lobe (Figure 19) appears to link to the Fendalton unconnected gravel lobe except in the Papanui area (see below);
- the Belfast lobe (Figure 19) in the west and south has a location that is similar to the Belfast unconnected gravel lobe.

A few areas of difference between the surface features and the gravel lobes are observed:

- unconnected gravel lobes do not show continuity (Figure 68) across the Yaldhurst lobe (Figure 16). This is because continuity of gravel deposition between gravel lobes SCB and SBCB (Figure 41) is not shown in well logs. More drilling is recommended in the Spreydon-Addington area to assess continuity of these gravel lobes and investigate the Yaldhurst lobe as a depositional feature. Radiocarbon dates indicate that deposition of the unconnected gravel lobe SCB began at about the same time (4200 years) as deposition of the unconnected Fendalton F1 lobe (Figure 65). Therefore deposition of the Yaldhurst lobe and the Fendalton 4200 year unconnected gravel lobe may have originated from a similar source area;
- the Papanui lobe (lobe FD, Figure 41) is not represented by: the 1856 map, by surface elevation and by soil type.

5.0 SUMMARY

Pre-historic Springston Formation deposition, particularly gravel deposition associated with gravel deposition from the Waimakariri River, is assessed with maps of surface features, geological logs and radiocarbon dates of recent sediments.

Springston Formation depositional lobes, proposed from an interpretation of surface features and geological logs, in Christchurch City area, include, by surface catchment:

- Halswell River catchment
  - Halswell.
- Heathcote River catchment
  - Heathcote River A (located around Wigram Airfield);
  - Heathcote River B (located around Curlett's Drain catchment);
  - Heathcote River C (located in the historic Wilson's Creek catchment).
- Avon River catchment
  - Fendalton (between the airport and the City Centre, approximately).
- Styx River catchment
  - Belfast.

Surface features that are used in this interpretation include maps of a survey of Christchurch in 1856 before urbanization, soils, geomorphic features associated with recent Waimakariri River deposition, river bed sediment type, location of springs and ground elevation.

Springston Formation gravel sediments, identified from geological cross sections, are:

- vertically connected to Riccarton Gravel mainly in the west of Christchurch City;
- unconnected to Riccarton Gravel in central–east of Christchurch City.

Springston Formation gravel sedimentation is interpreted as a series of lobate features including:

- ‘connected’ gravel lobes in Halswell, Woolston, Sydenham, Fendalton, Belfast and Old South Branch areas;
- ‘unconnected’ gravel lobes in Halswell, Sydenham, Fendalton and Belfast areas.

Connected gravels link to unconnected gravel lobes, with the exception of the Woolston connected gravel lobe. The Woolston connected gravel lobe is isolated from other connected gravels and from unconnected gravel lobes. However geological data in the area of the Woolston connected gravel lobe is relatively sparse and future drilling may identify links between this gravel lobe and other Springston Formation gravels.

The distribution of unconnected gravel lobes generally reflects the distribution of surface features that potentially indicate the location of gravel lobes including: the 1856 map, soils, geomorphic features associated with recent Waimakariri River deposition, river bed sediment type and ground elevation.

Groups of springs are commonly associated with gravel lobes, for example:

- springs east of Halswell are associated with the Halswell connected gravel;
- springs in the Avon River headwaters are associated with the Fendalton connected gravel;
- springs in the Dudley Creek catchment (Avon River) are associated with a gravel lobe in the Papanui area that is linked to the Fendalton gravel lobe.

Therefore the gravel lobes are probably the geological units that allow groundwater flow from unconfined aquifers west of Christchurch to springs in Christchurch City.

Radiocarbon dates of sediments in the Christchurch City area are used to identify a chronology of Springston Formation gravel sedimentation. The chronology of sedimentary deposition is summarised as, from older to younger, with ages rounded:

- Woolston connected gravel up to 7800 years ago;
- Halswell connected gravel about 8800 years ago to about 5000 years ago;
- Sydenham connected gravel about 6300 years ago to about 2800 years ago;
- Sydenham unconnected gravel in two depositional phases:
  - phase 1 sedimentation started about 4100 years ago, however the end of sedimentation is undated. Sediments in this phase may have originated from the Fendalton gravel lobe (deposition phase 1) with deposition in the Yaldhurst lobe;
  - phase 2 sedimentation started about 3000 years ago, however the end of sedimentation is undated;
- Fendalton connected gravel began at an unknown time and ceased about 4400 years ago;
- Fendalton unconnected gravel in two depositional phases:
  - phase 1 about 4200 years ago to about 3000 years ago;
  - phase 2 about 2000 years ago to about 1600 years ago;
- Belfast unconnected gravel, depositional ages unknown;
- Old South Branch connected gravel about 4000 years ago to 80 years ago.

The locations of gravel deposition changed significantly in the period 4400 to 4000 years ago in the Sydenham, Fendalton, and Old South Branch gravel lobes. These gravel lobes deposited sediments into the pre-historic Christchurch estuary. Sea level between in the period 4400 to 4000 years ago was about the same level as the current day (White 2001) and this period possibly represents the maximum westward marine incursion of the estuary. It appears that Springston Formation gravel deposition in the pre-historic estuary followed soon after the maximum westward marine incursion.

Generally the age of commencement of Springston Formation sediments youngs to the north, i.e. the Waimakariri has generally moved north in the last 8000 years.

6.0 RECOMMENDATIONS

6.1 Radiocarbon data

6.1.1 Environment Canterbury radiocarbon records

Environment Canterbury holds radiocarbon dates by well number and Rafter Radiocarbon Laboratory "F" ("Fossil Record" number) number (Appendix 6). The "F" numbers are attached to report number and cannot be searched.

It is recommended that "R" (Rafter Radiocarbon lab number) numbers replace "F" number references ("R" numbers and "F" numbers are described in Appendix 5) in the Environment Canterbury dataset because:

- Rafter Radiocarbon Laboratory data searches are more convenient with "R" numbers;
- "R" numbers include reference to "F" numbers and "NZ" numbers in the Rafter Radiocarbon Laboratory records.

6.1.2 Smith (1992) assigns a radiocarbon analysis to two wells

A date of 8820 $\pm$ 70 years is assigned to well M36/4017 and M36/4120 (footnote to Table A6.1, Appendix 6). The well number for this well should be clarified by Environment Canterbury.

6.1.3 Update Environment Canterbury radiocarbon records with non-well samples

Radiocarbon analyses from soils, pits and excavations provide very useful information on the history of sedimentation. Therefore these samples should be recorded in an Environment Canterbury database. The following steps are recommended for radiocarbon samples in the Christchurch area (i.e. those within the boundaries of map sheets M35 and M36):

- enter a "source" field for data in Table A5.1, Appendix 5), e.g. GNS Science, Rafter Radiocarbon Laboratory", "other";
- enter sample information for Smith (1992) radiocarbon samples measured by Waikato University (Appendix 6, Table A6.1);
- cross-check all Rafter Radiocarbon Laboratory samples (Table A5.1, Appendix 5) with

the well database of radiocarbon age (Environment Canterbury and Brown and Weeber, 1992, Appendix 1) and enter a well number field to Table A5.1 for samples from wells;
- for samples that are not from wells in the Environment Canterbury database, attach provenance information for sample collection records (Table A5.3, Appendix 5).

6.1.4 A forward programme of radiocarbon data collection is recommended

Radiocarbon analyses are very useful to establishing a chronology of Springston Formation sedimentation in Christchurch City. However many gaps occur in the data. For example dates on the onset of Springston Formation gravel deposition are not available for:

- connected gravel lobes e.g. Fendalton, Belfast and Woolston;
- unconnected gravel lobes in Sydenham, Papanui and Belfast.

Data on the end of gravel deposition are not available for many gravel lobes.

The forward programme could prioritise field data collection; most of these gravel lobes are quite shallow so sampling costs should not be great.

6.1.5 Priority issues for further investigation in order of priority

Further assessment of the chronology of Springston Formation gravel deposition in the Sydenham area is recommended to address the following questions:

- is the Woolston connected gravel lobe linked to the Halswell gravel lobe or the Sydenham gravel lobe?
- how many phases of gravel deposition occurred through the Sydenham area?
- what are the links between unconnected gravel lobes?
- are gravels in the Sydenham area linked to deposition of Fendalton gravels?
- what is the age range of deposition of the “Yaldhurst” gravel lobe?

This area is a priority as:

- groundwater chemistry measurements (Hanson pers. comm.) in South Christchurch show impacts of the use of land to the west of Christchurch;
- the connected gravel lobes (Halswell, Sydenham and Woolston) provide potential pathways for pollutants, from land use, to enter the Riccarton Gravel and impact on the groundwater system used by Christchurch City for drinking water;
- multiple gravel deposition phases means the area has a complex depositional history; and
- a relatively low density of well logs means that geological correlation is more speculative than in other areas of Christchurch.

Other priorities include:

- Springston Formation gravels in the Fendalton area to address the following questions:
  - what is the age of the “Papanui” (lobe FD, Figure 41) gravel lobe?
  - the geographic extent of the “F1” and “F2” (Figure 65) gravel deposition phases;
  - links to Sydenham gravels;

- Springston Formation gravels in the Belfast area to address the following questions:
  - age range of gravel sedimentation;
  - geological links to the Old South Branch gravels;
  - geological links to the Fendalton gravels;
- Springston Formation gravels west and north-west of Christchurch, between the city and the Waimakariri River. This area has fed gravel to Christchurch City. Very few radiocarbon samples have been collected in the area. Existing radiocarbon samples possibly identify flood events and these flood events may have been crucial in the switching of gravel deposition location (e.g. approximately 4000 years ago, Figure 65).

6.2 Publication of revised geological nomenclature

This report develops nomenclature for geological units that extends the existing published nomenclature (e.g. Brown and Wilson, 1988) with sub-formation names for the Christchurch Formation and Springston Formation. It is recommended that the new detail on Christchurch Formation and Springston Formation sediments identified in this report, and by White (2007), is published.

6.3 Ground elevation

Ground elevation data in Wilson 1989 represents a terrain map that is well suited to an analysis of pre-historic sedimentary deposition in Christchurch City. Only some of the ground contours in Wilson (1989) are digitised in this report (Figure 15). It is recommended that all ground contours in Wilson (1989) are digitised. A digital terrain model reconstructed from this data will have considerable advantages over LIDAR data as the Wilson (1989) data should be, unlike LIDAR data, not influenced by human infrastructure.

6.4 Improvements to geological characterisation of gravel lobes.

The extents of Springston Formation gravel lobes are assessed from geological cross sections in this report. However, geological cross sections can give equivocal interpretations of gravel lobe geometry where the density of wells logs is low. Gravel lobe geometry is a little unclear in the south-west of Christchurch City. Reassessment of the geological cross sections (southern sections: S1 – E1, S2 – E3, S3 – E3 and S4 – E4 Figure 23; south-west sections S1 – E1, S2 – E2 and S3 – E3, Figure 35) is recommended.

The definition of gravel lobes may be improved as more wells are drilled and a targeted drilling programme of shallow holes is recommended.

Priorities for further geological investigation of Springston Formation gravel lobes are, in order of priority from highest to lowest:

- the south Christchurch area in the vicinity of Addington to assess the distribution of relatively recent (i.e. the SBC lobe, Table 5) and relatively old (i.e. the SCB lobe, Table 5) gravel lobes;
- the south Christchurch area in the vicinity of Woolston to assess the distribution of the Woolston connected gravel lobe and links to other connected gravel lobes;

- the central Christchurch- Papanui area to assess the distribution of the most recent (i.e. F2, Table 5) gravel deposition in the Fendalton gravel lobe;
- the Belfast area to assess links between the Belfast lobe and the Old South Branch gravels;
- the Belfast area to assess possible phases of gravel links deposition in the Belfast gravel lobe;
- the area between the Belfast gravel lobe and the Fendalton gravel lobe to assess possible gravel connections between these two lobes that may have existed in the pre-historic Christchurch estuary.

6.5 3D datasets of Springston Formation gravel lobes

3D datasets defining the tops, bottoms and lateral extents of Springston Formation gravel lobes could be completed following geological assessment of cross sections in south-west Christchurch City (Section 6.4) and south Christchurch areas.

These datasets could be combined with Christchurch Formation palaeogeographic datasets (White 2007) and Christchurch geography pre-urbanisation (White et al. 2007) to produce a 3D model of the geological evolution of Christchurch in the last 10000 years.

7.0 ACKNOWLEDGEMENTS

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FIGURES

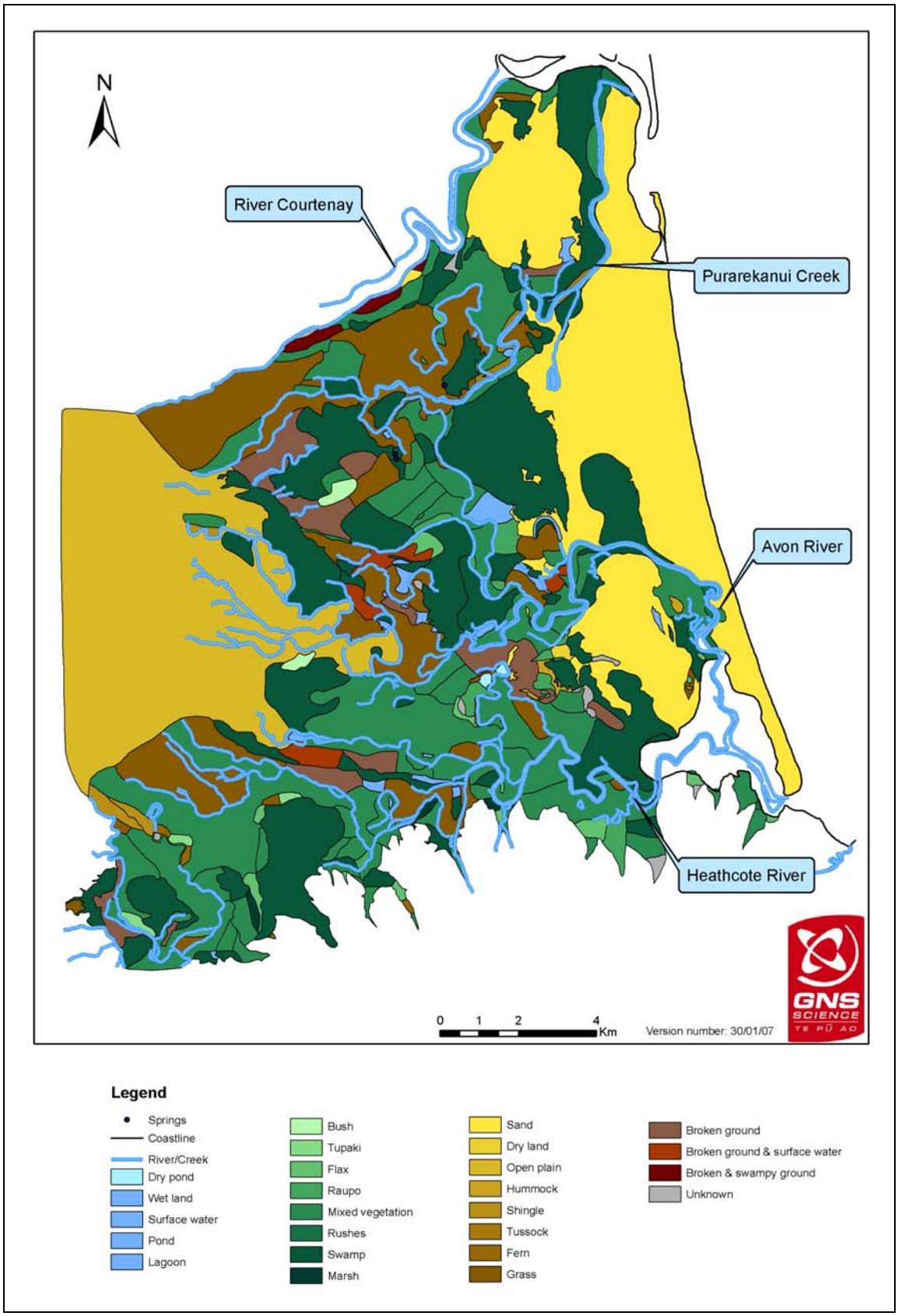


Figure 1. Water, vegetation and geographical features of the Christchurch area in 1856 (White et al. 2007).

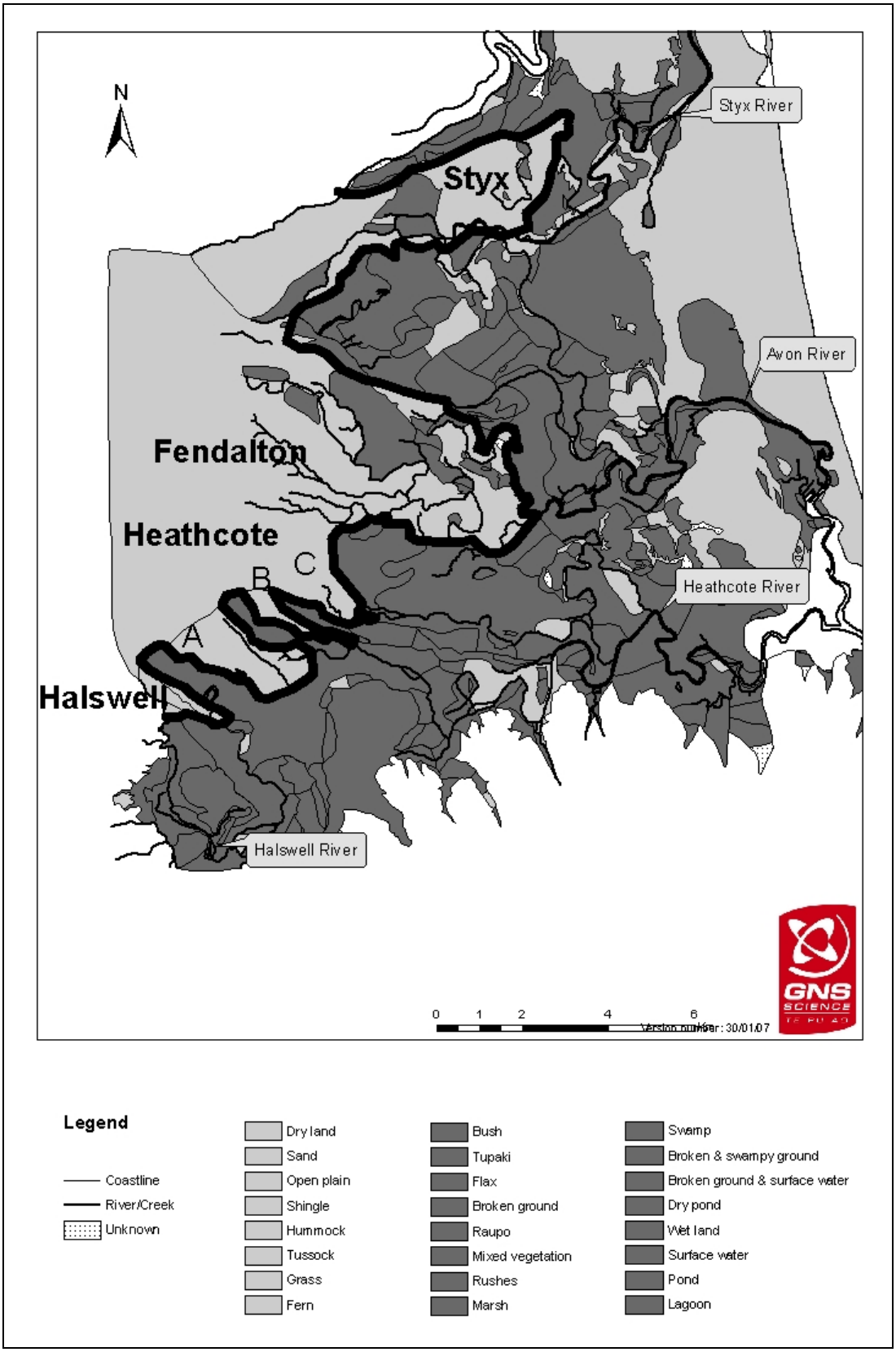


Figure 2. 1856 map of Christchurch City showing relatively dry and relatively wet features and lobes associated with stream headwaters.

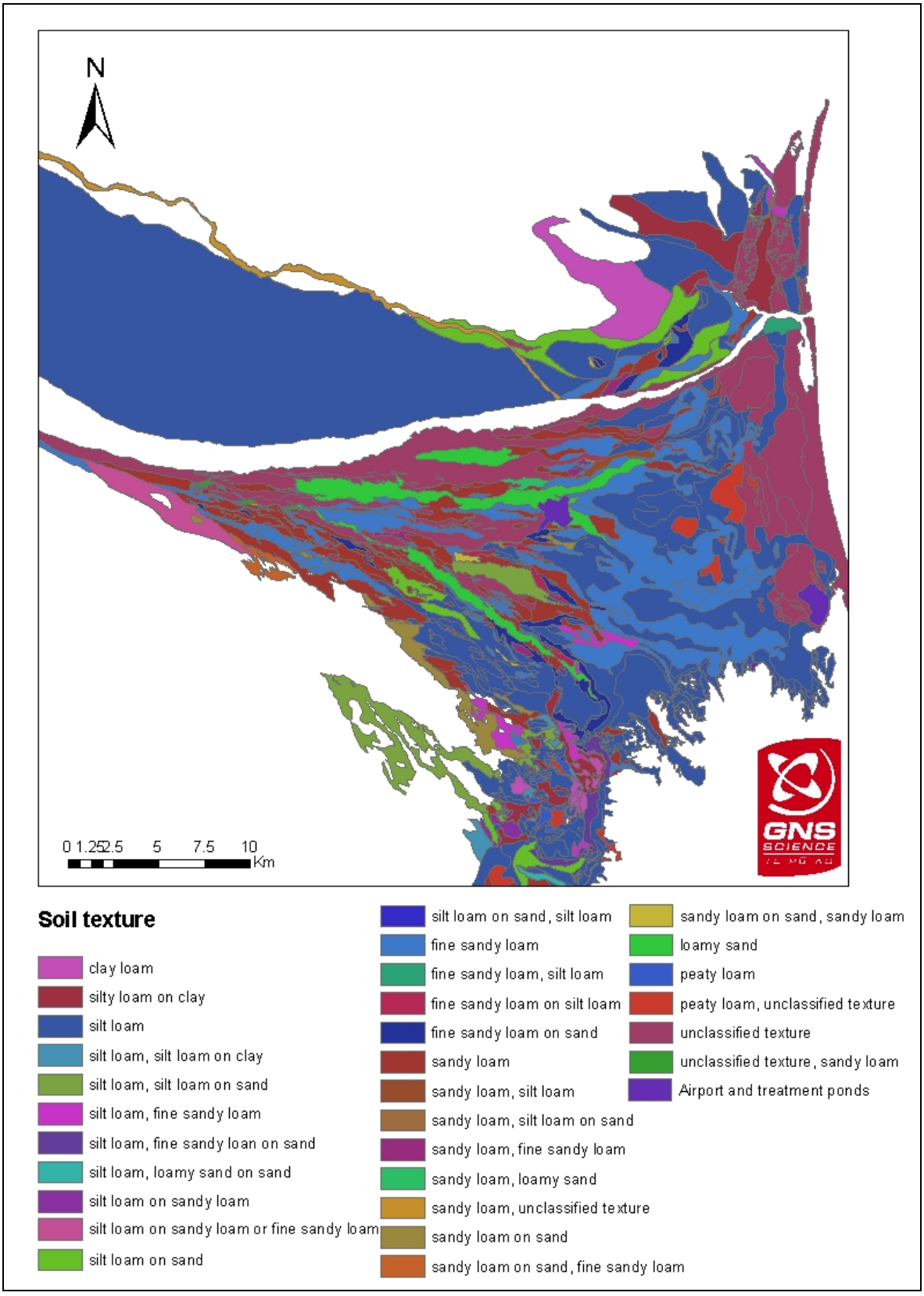


Figure 3. Soil texture in the Christchurch City area mapped by Landcare Research (Environment Canterbury pers. comm.)

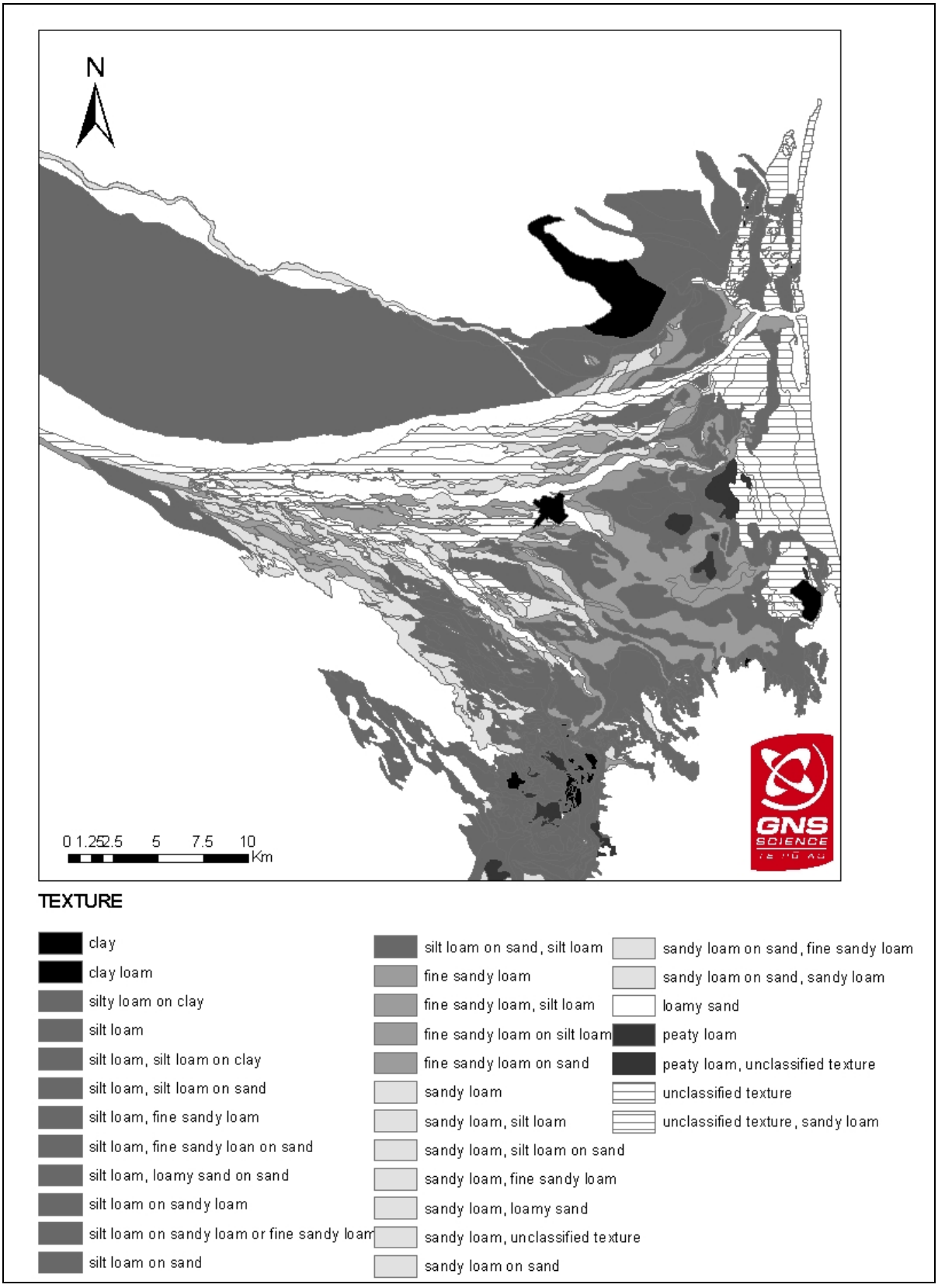


Figure 4. Soil texture in Christchurch City area mapped by Landcare Research (Environment Canterbury pers. comm.) in black and white.

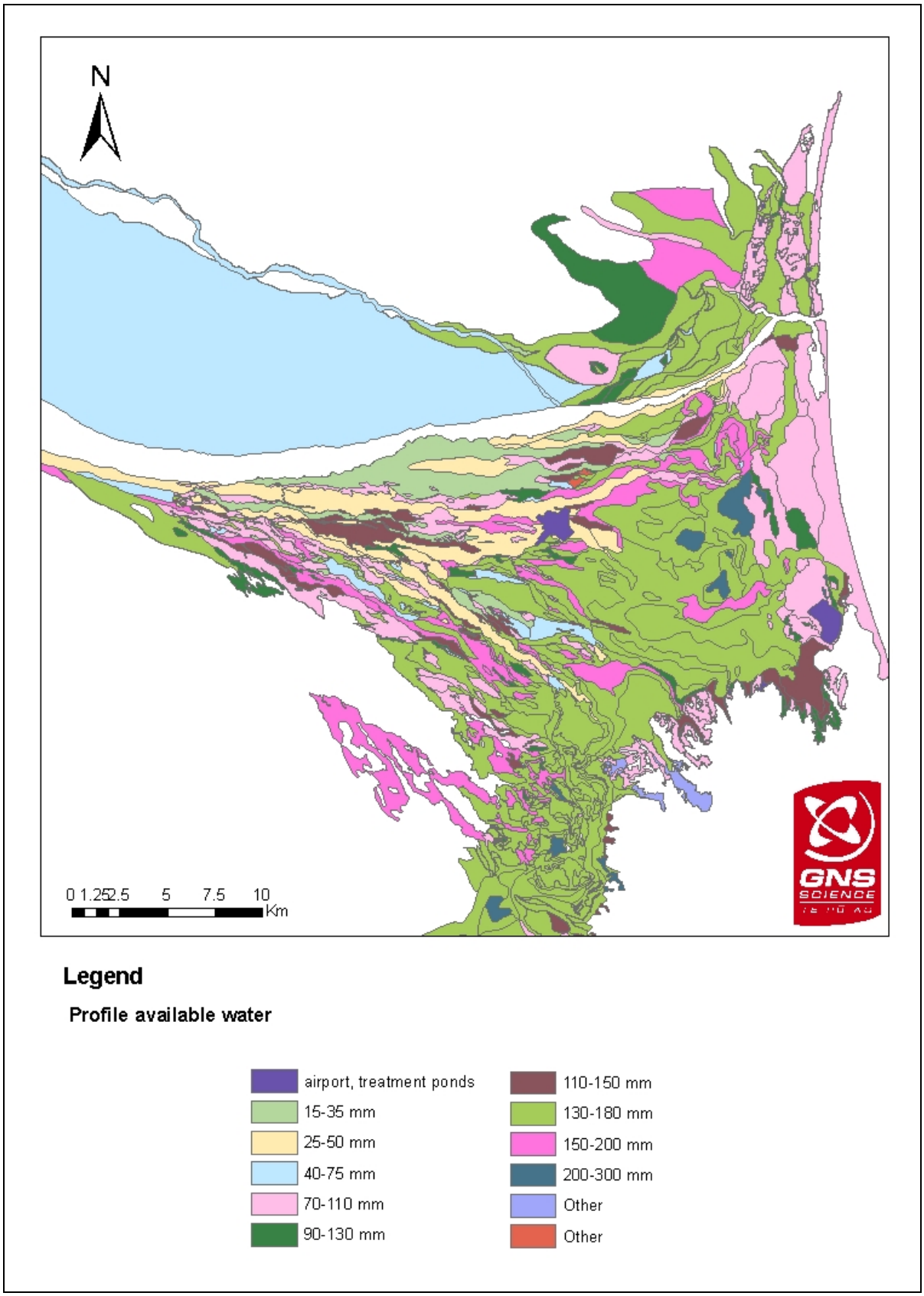


Figure 5. Profile available water of soils in the Christchurch City area.

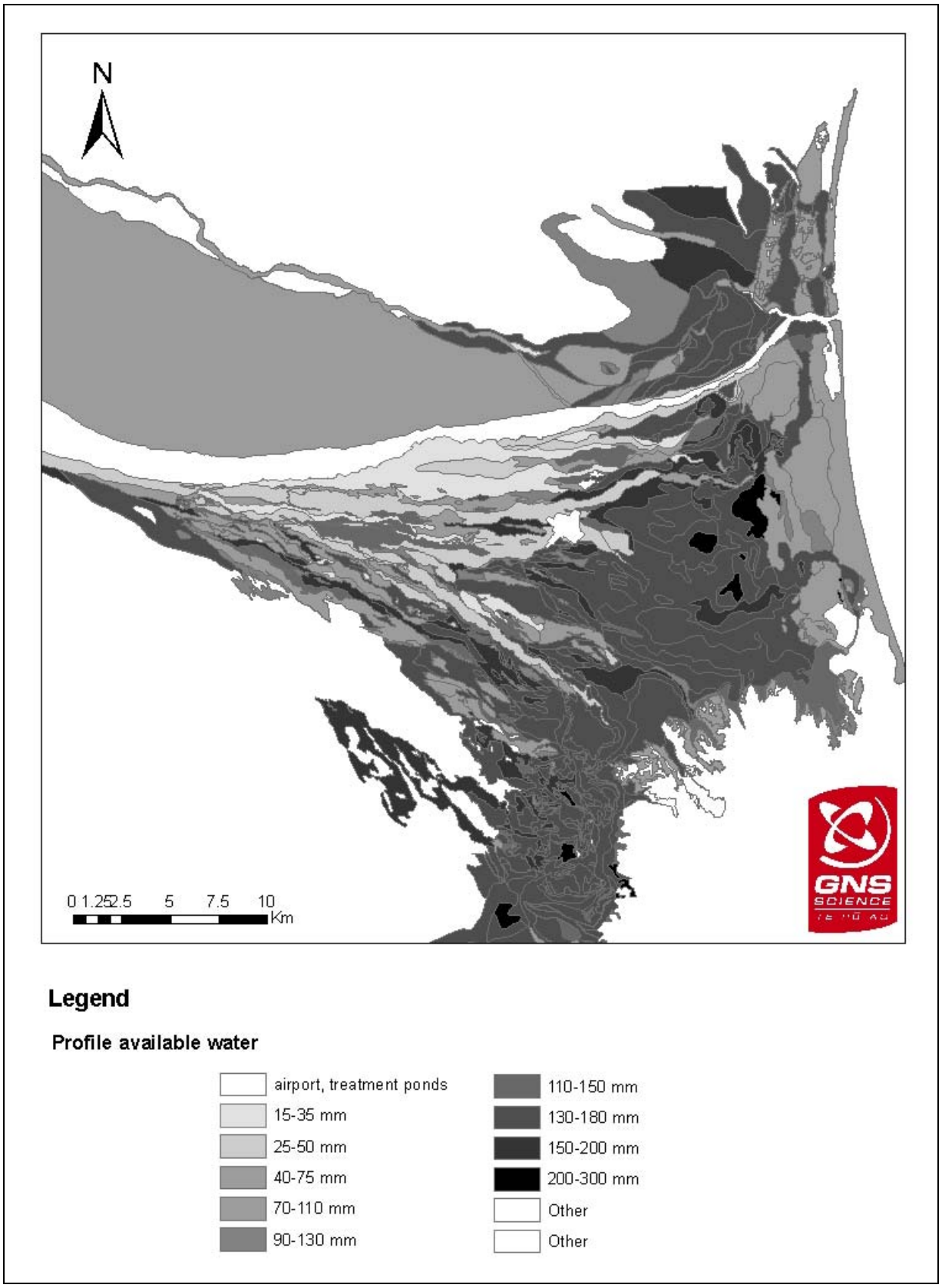


Figure 6. Profile available water of soils in the Christchurch City area, black and white version.

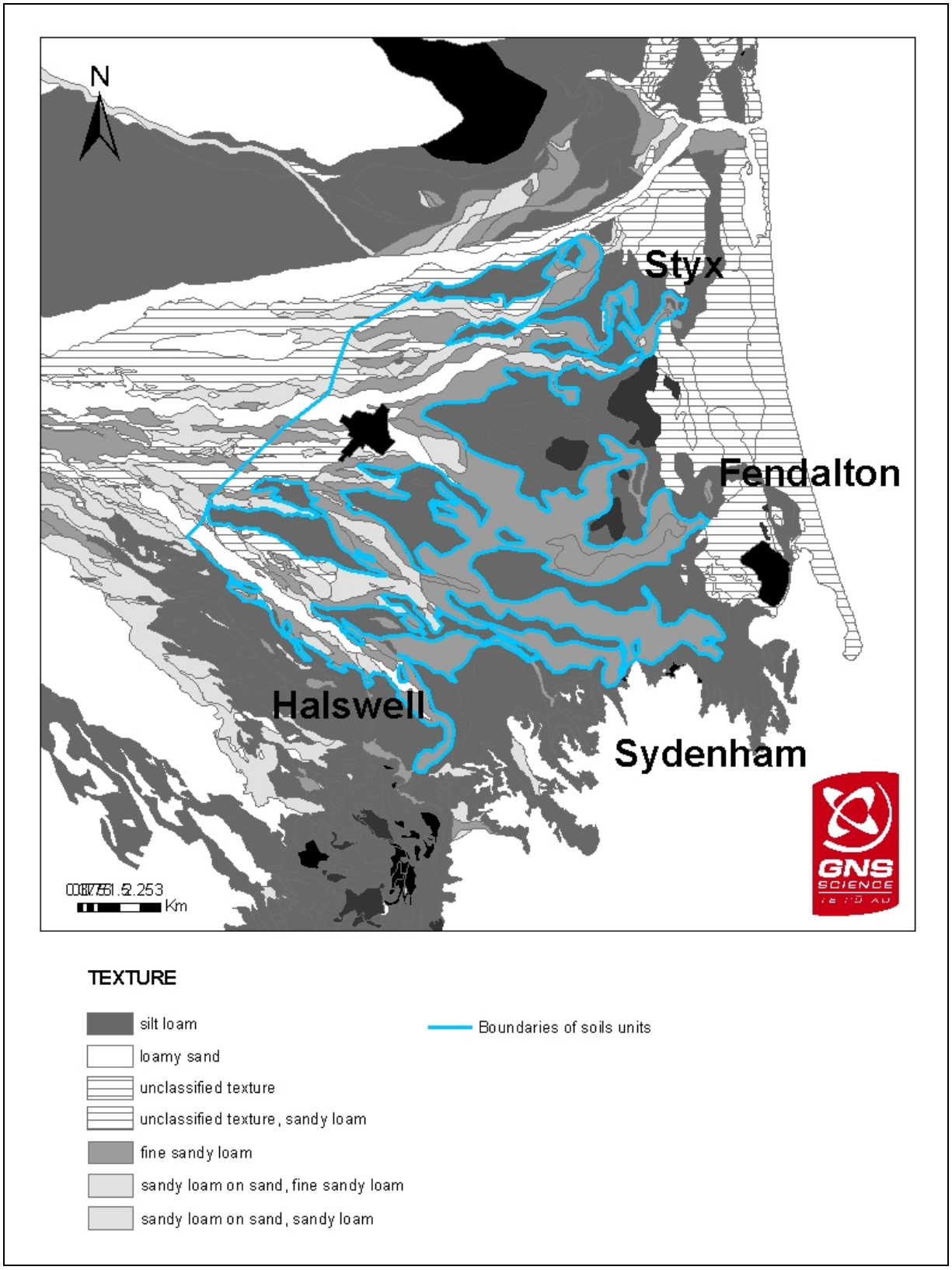


Figure 7. Sandy loam soil textures and possible associated pre-historic channels of Christchurch City rivers.

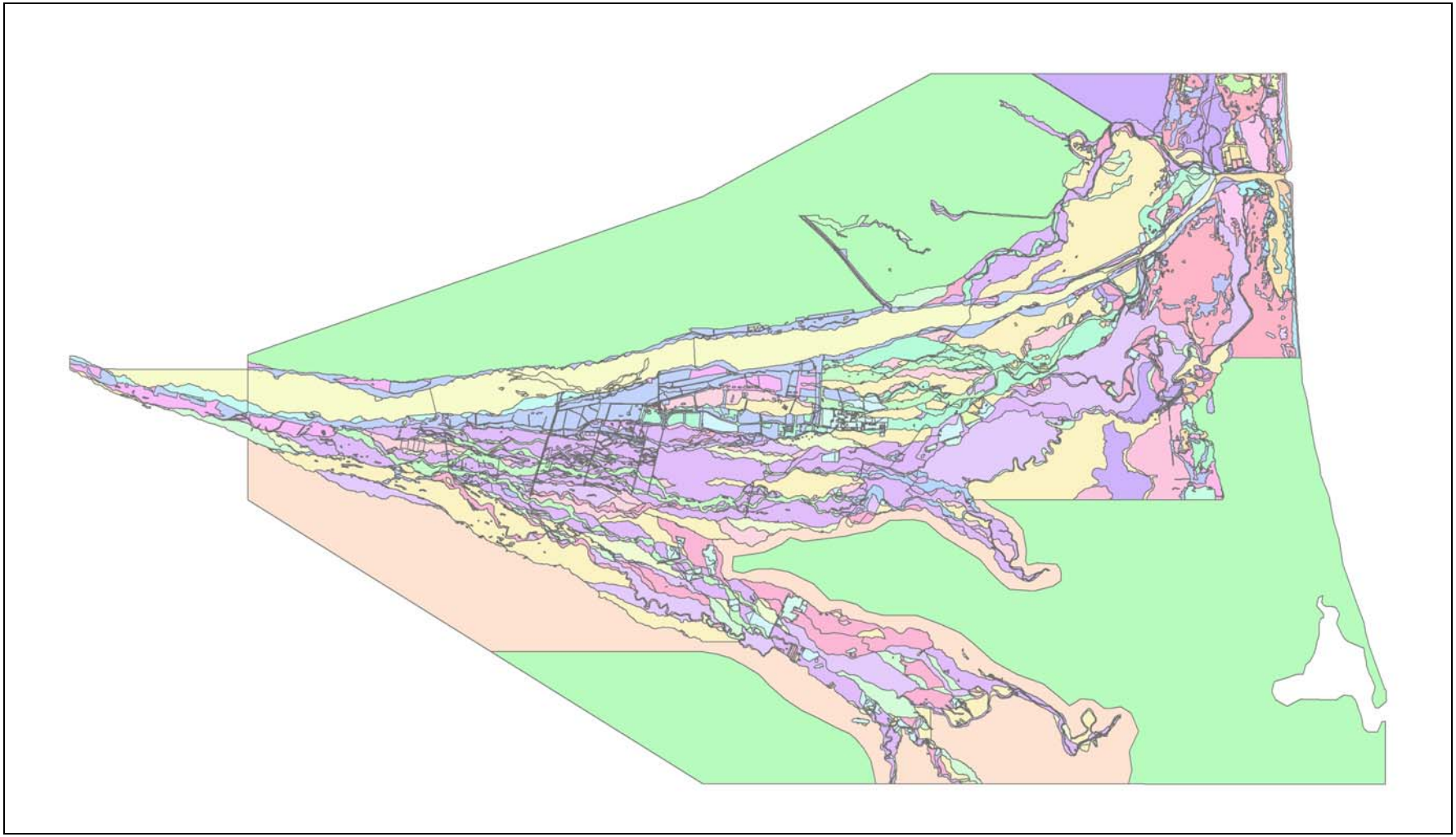


Figure 8. Geomorphic features of the Waimakariri River flood plain mapped by McPherson Associates (2004).

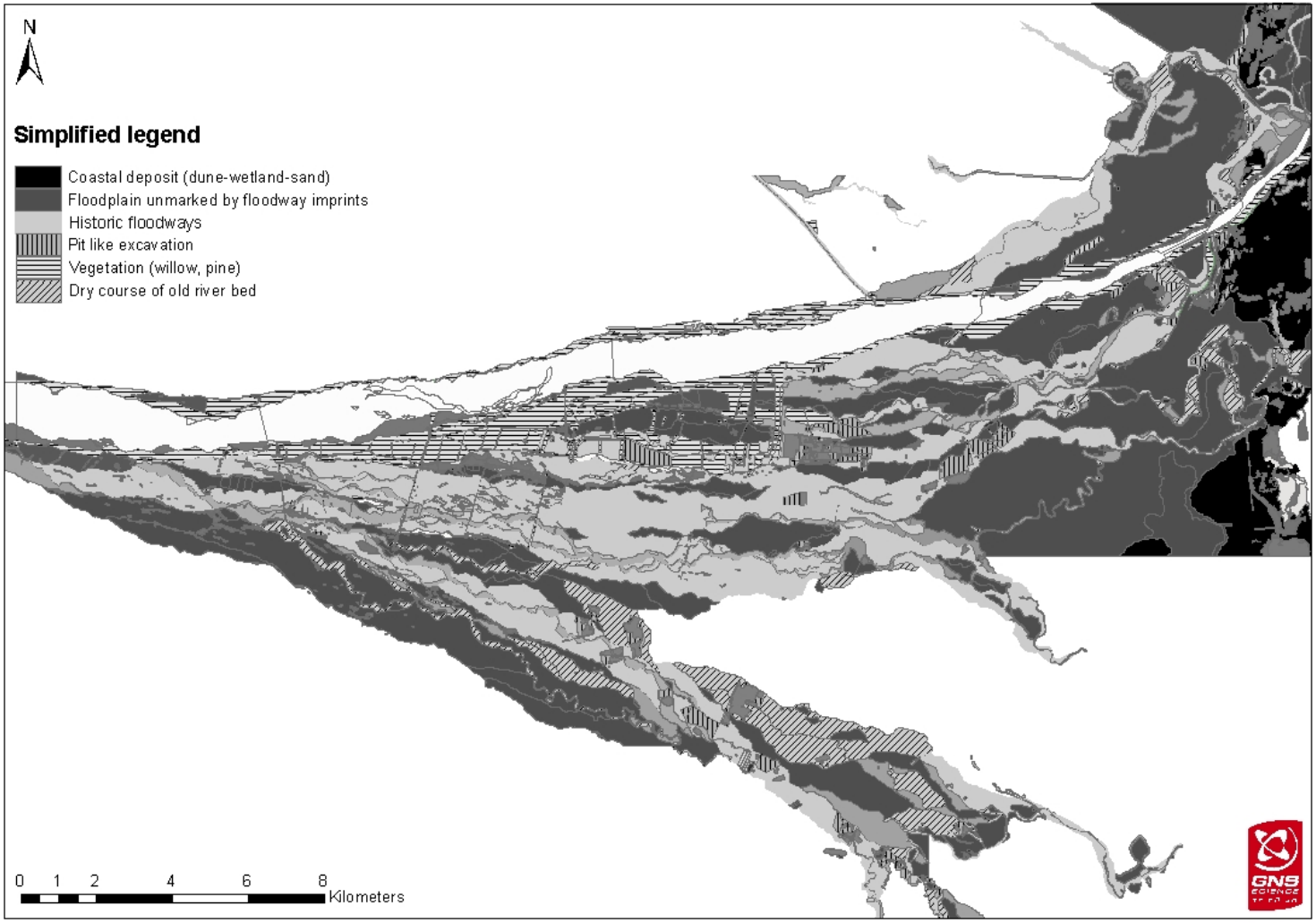


Figure 9. Geomorphic features of the Waimakariri River flood plain mapped by McPherson Associates (2004), black and white version.

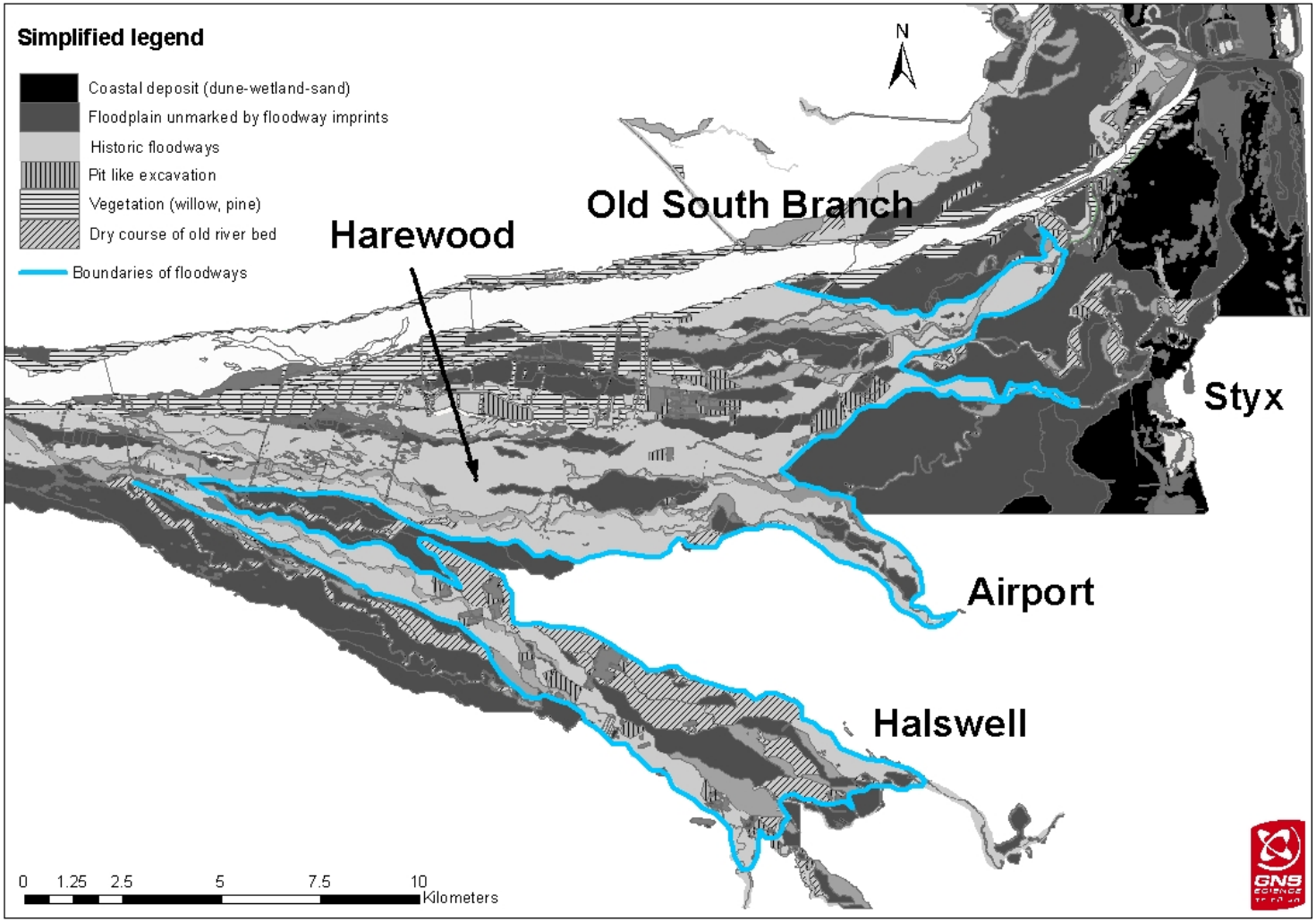


Figure 10. Geomorphic features of the Waimakariri River flood plain mapped by McPherson Associates (2004) with locations of floodways.

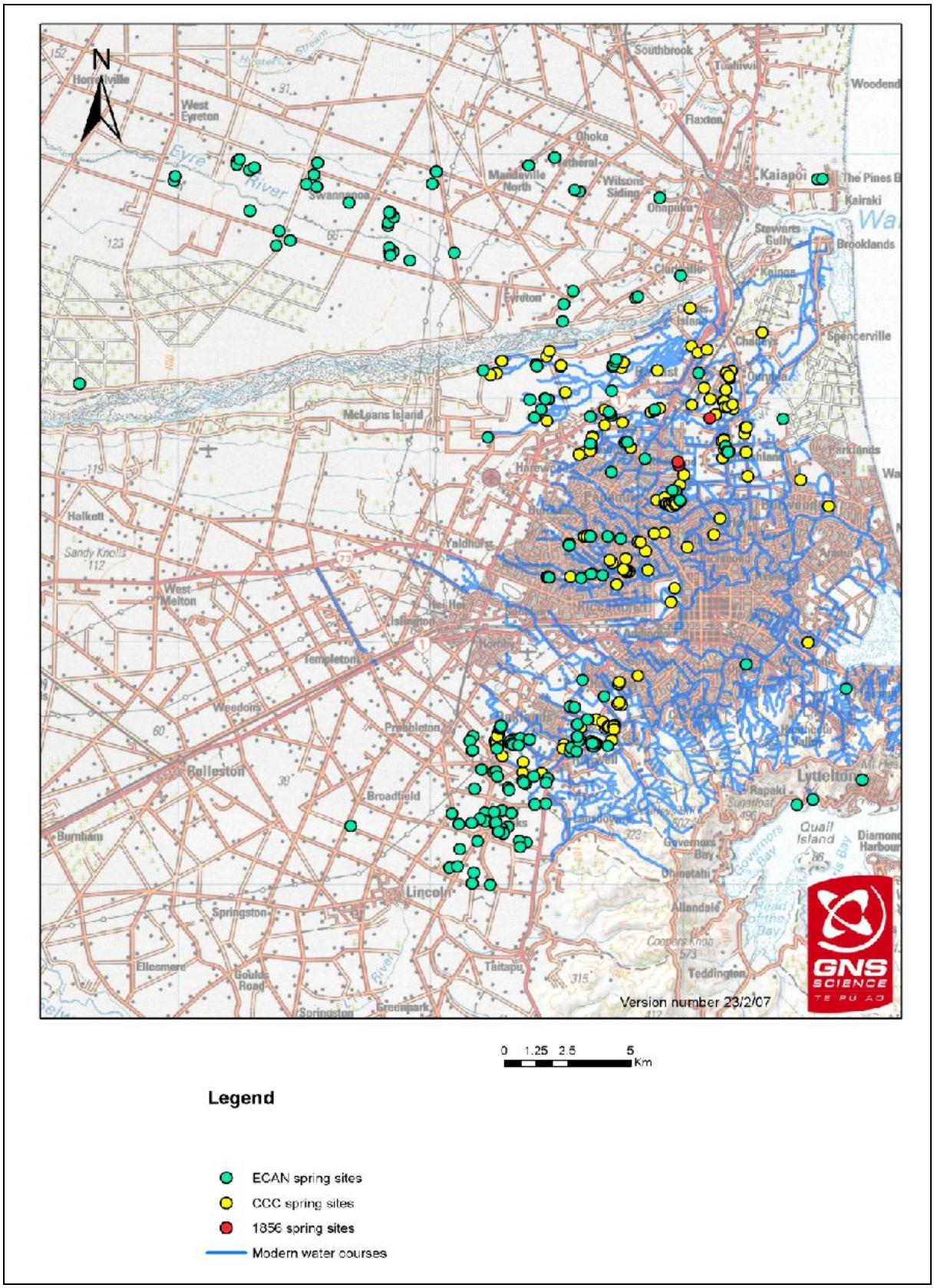


Figure 11. Springs mapped by Environment Canterbury, Christchurch City Council and the Sibly 1856 map (Wilson, 1989), with modern water courses (White et al. 2007).

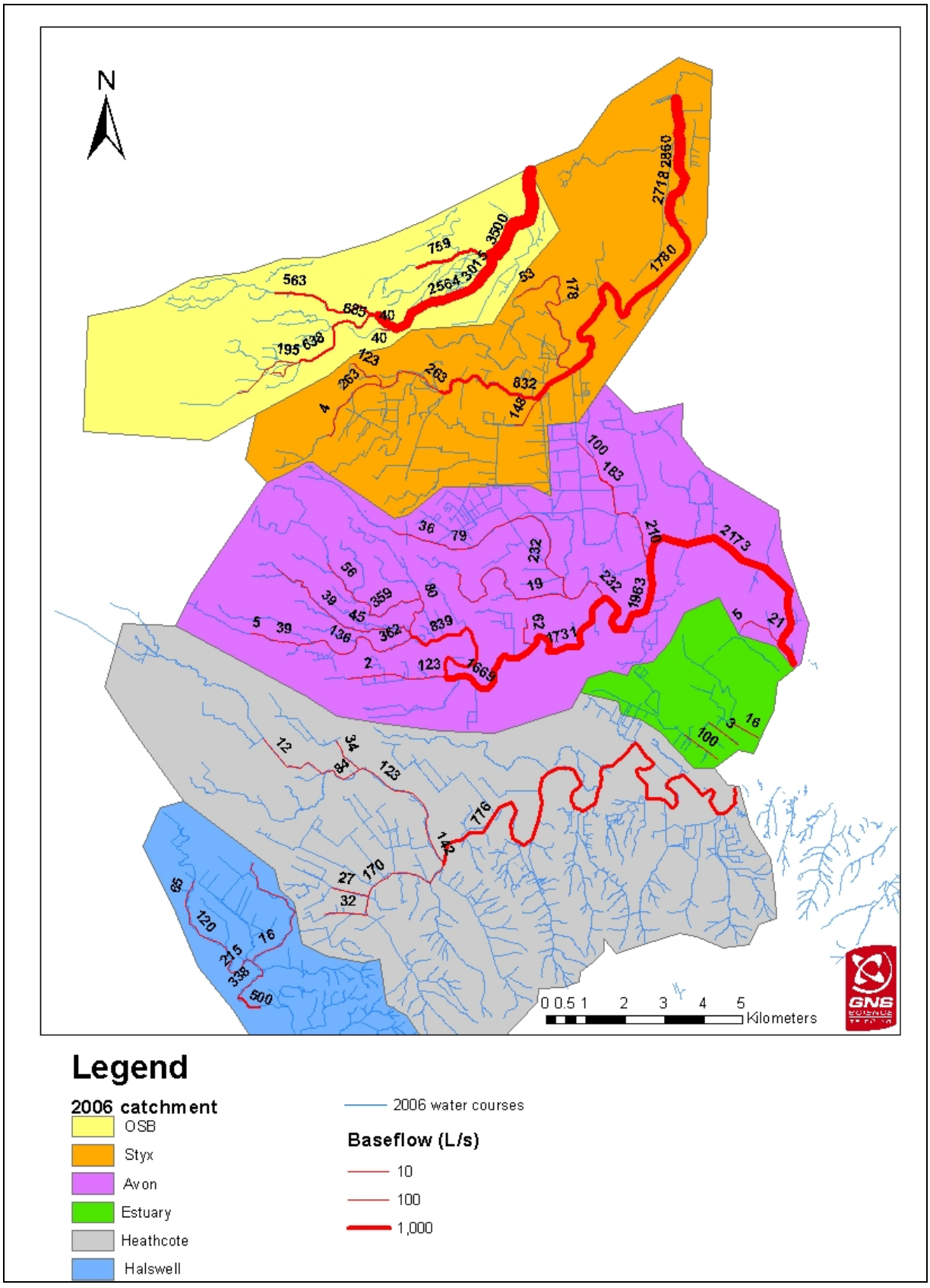


Figure 12. Estimated discharge from groundwater to streams in Christchurch City.

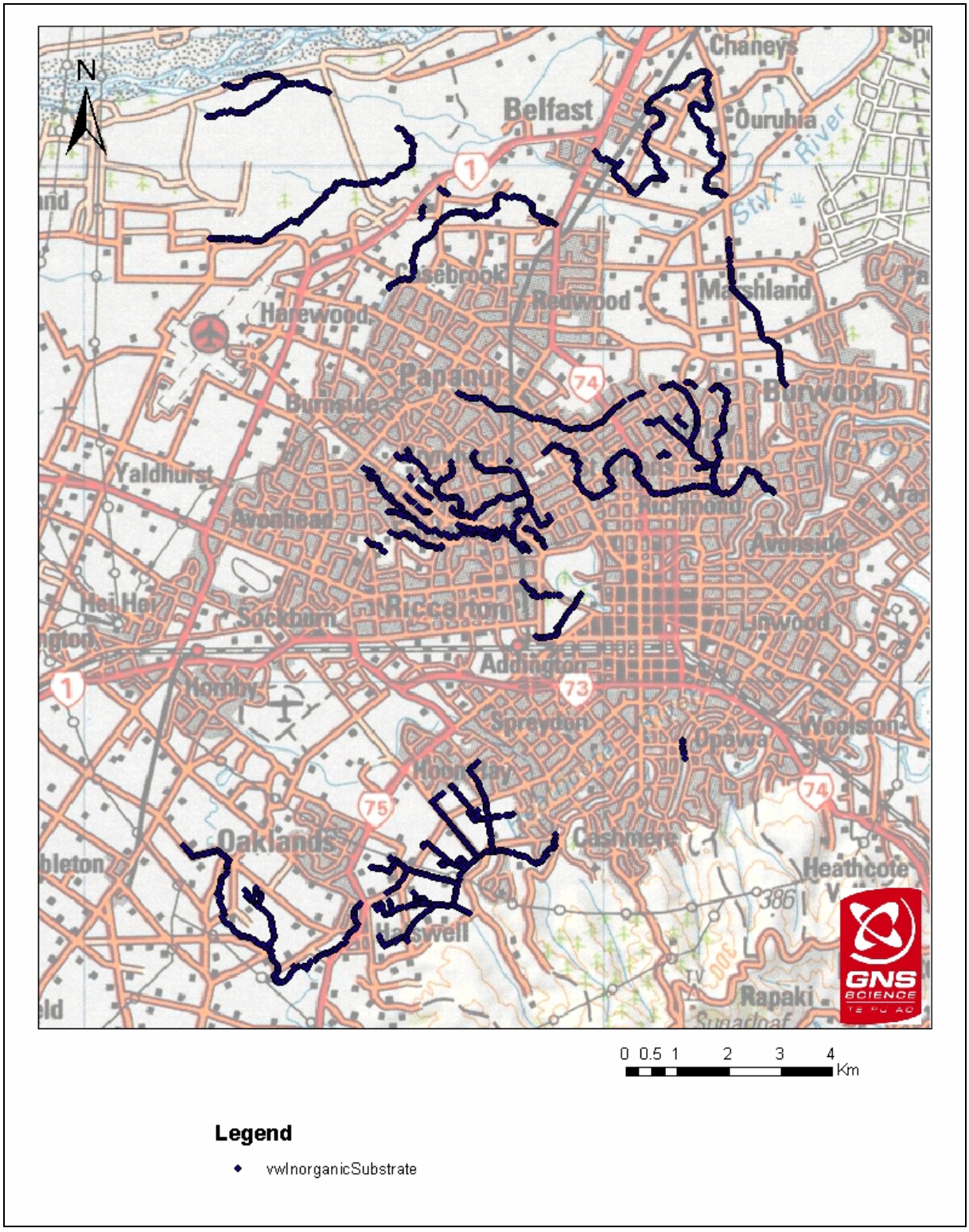


Figure 13. Locations of measurements of stream and river bed sediment type (Christchurch City Council, Van Nieuwpoort pers. Comm.).

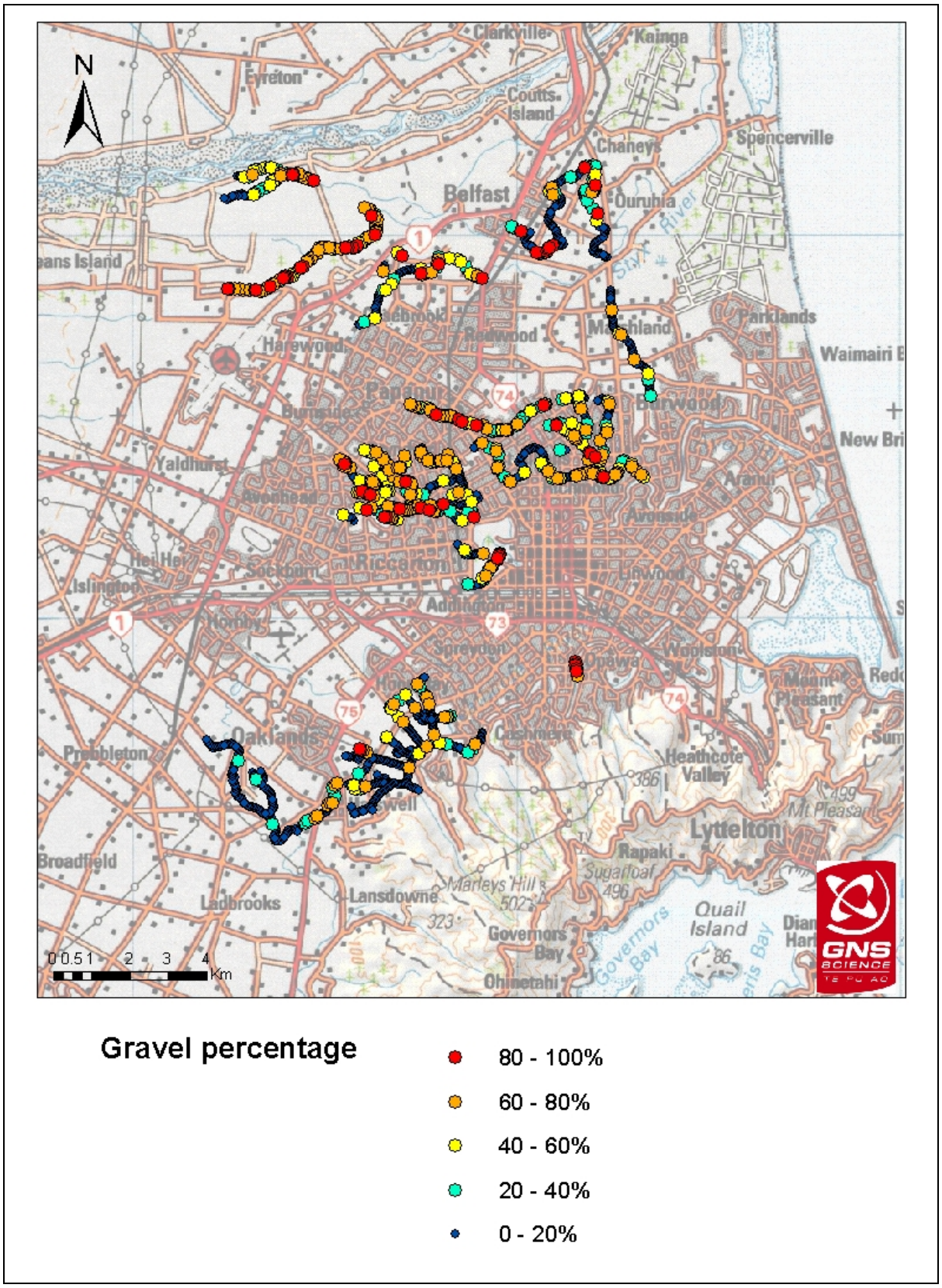


Figure 14. Gravel percentage in Christchurch stream beds.

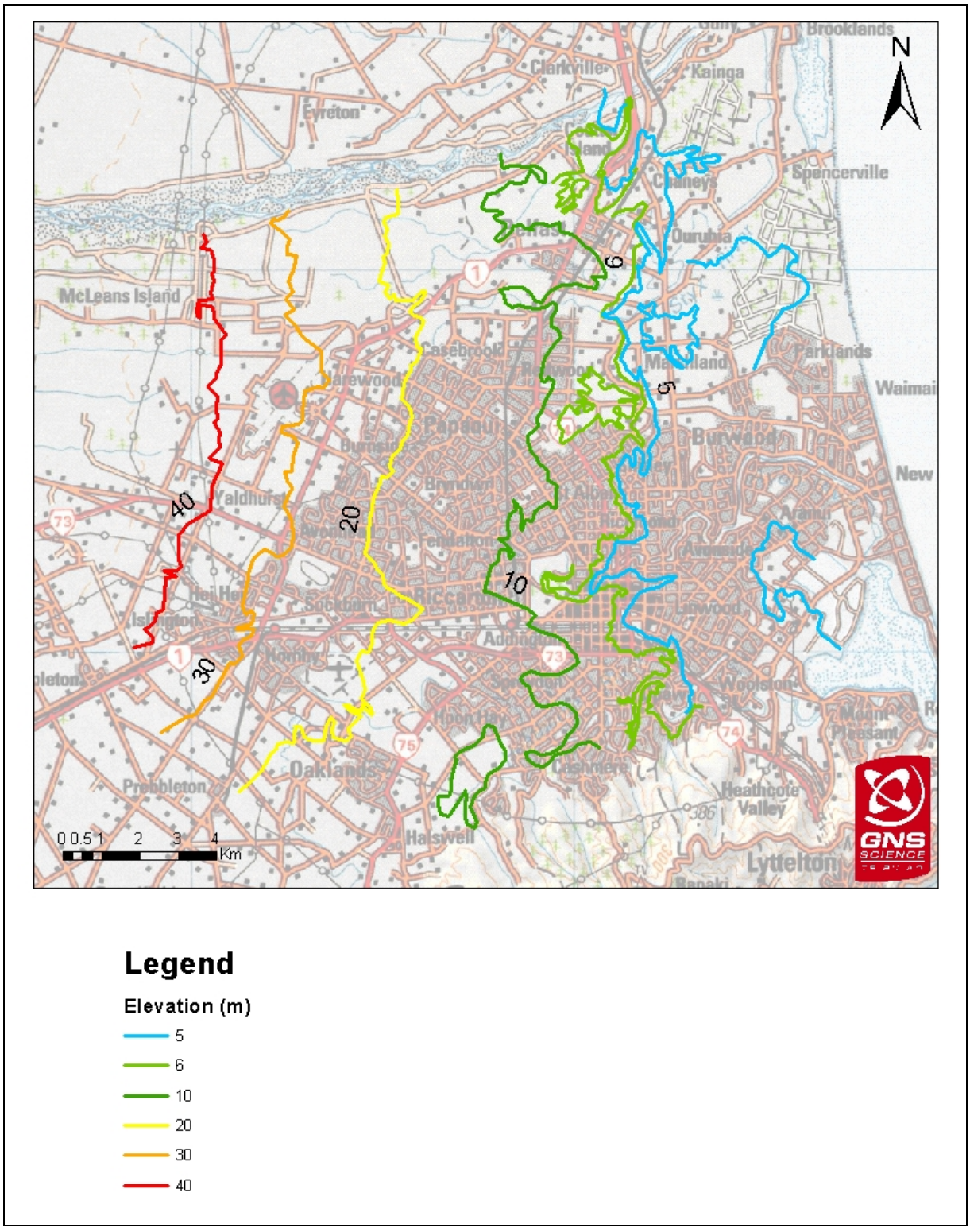


Figure 15. Ground elevation in Christchurch, digitised from Wilson (1989).

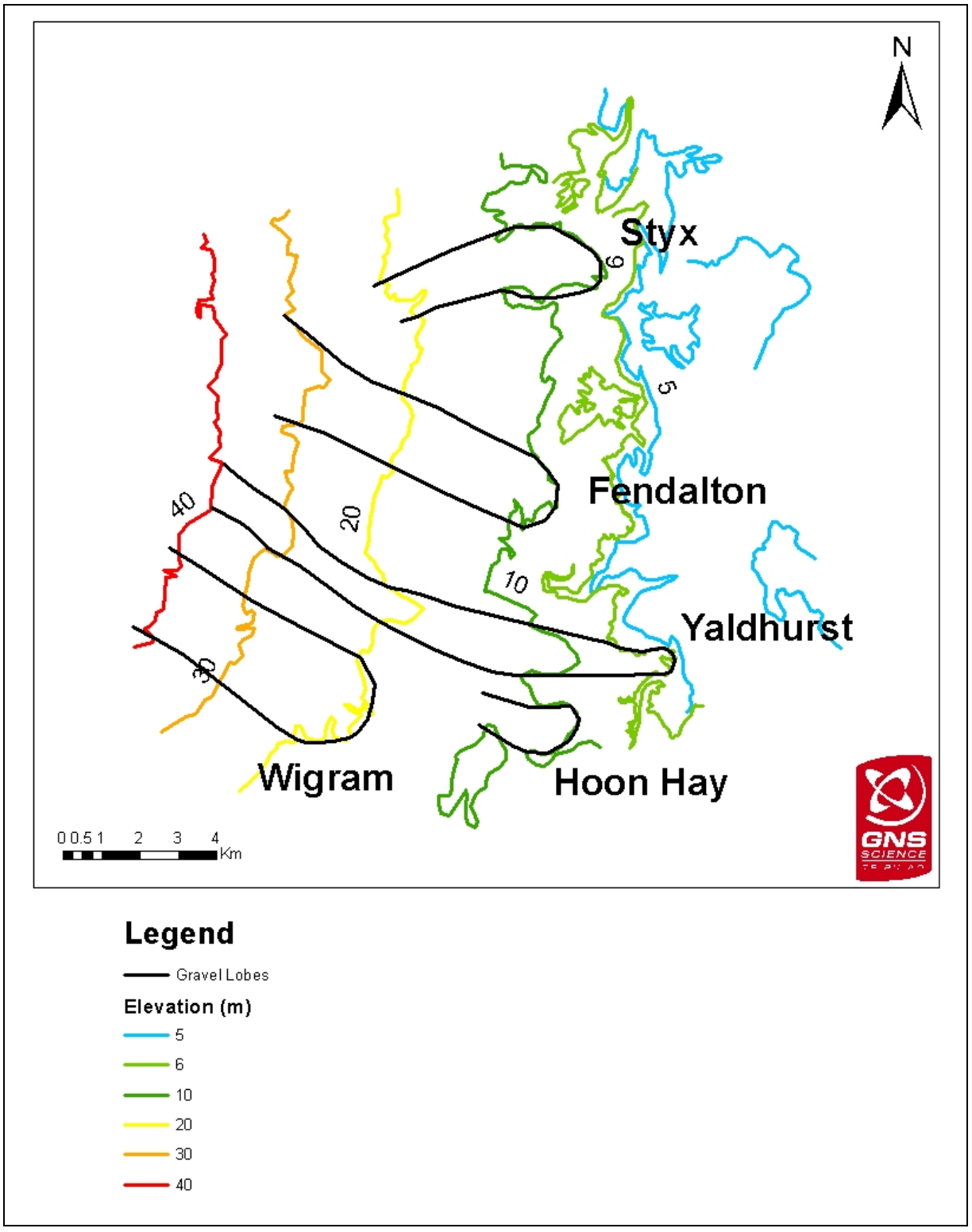


Figure 16. Interpretation of surface elevation map with proposed lobes.

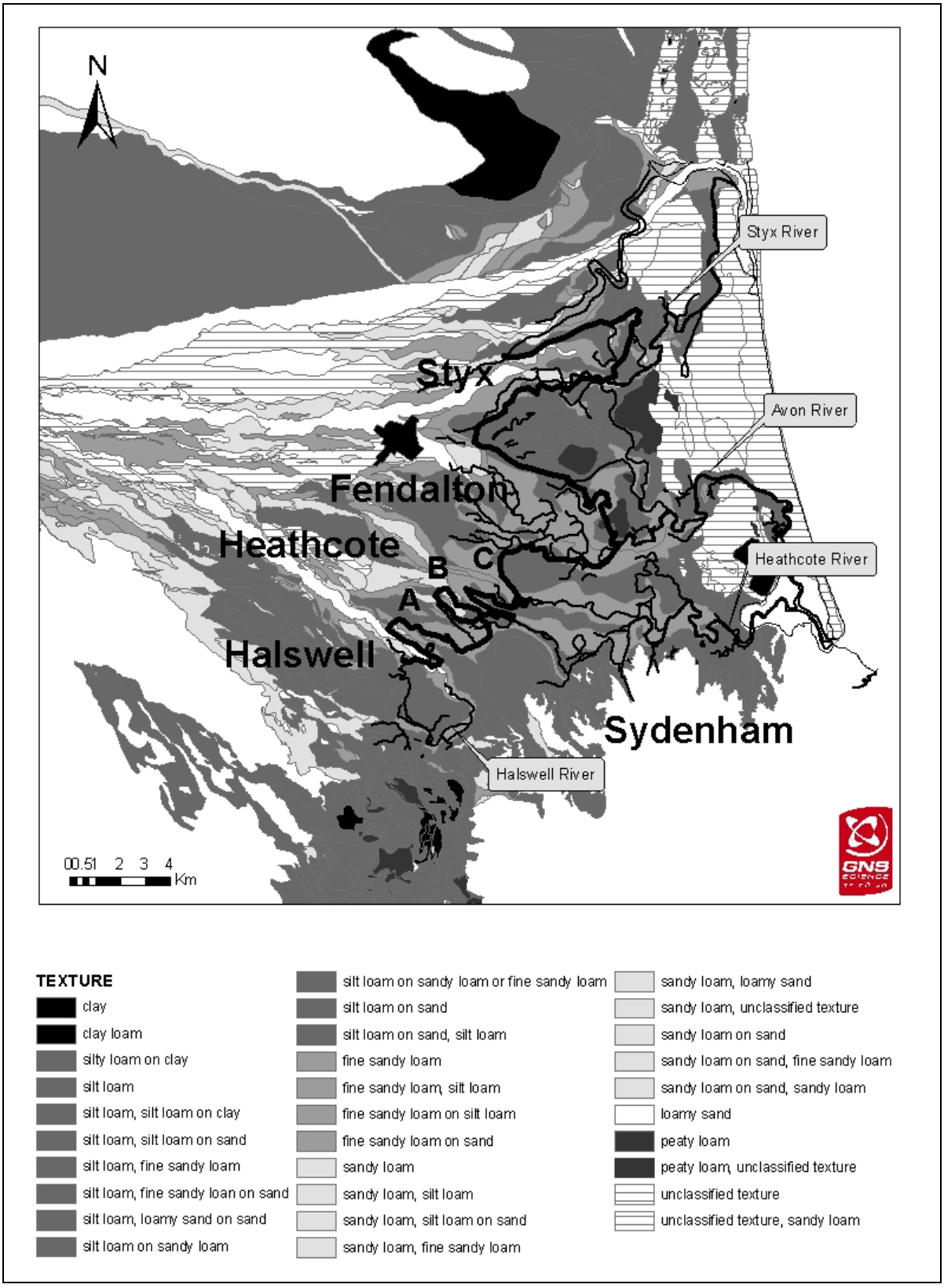


Figure 17. Lobes identified from the 1856 map and soil texture.

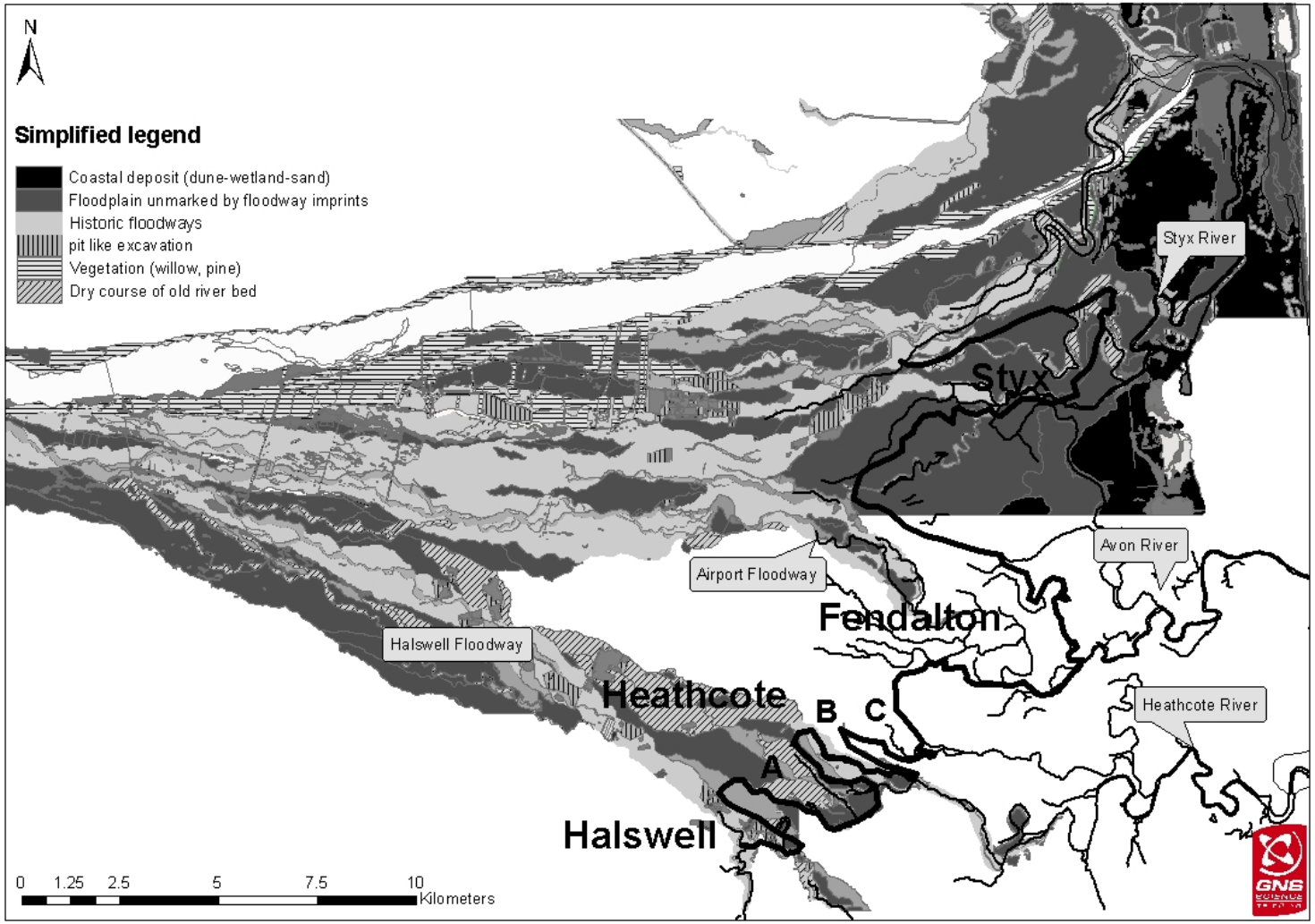


Figure 18. Lobes identified from the 1856 map and geomorphic features.

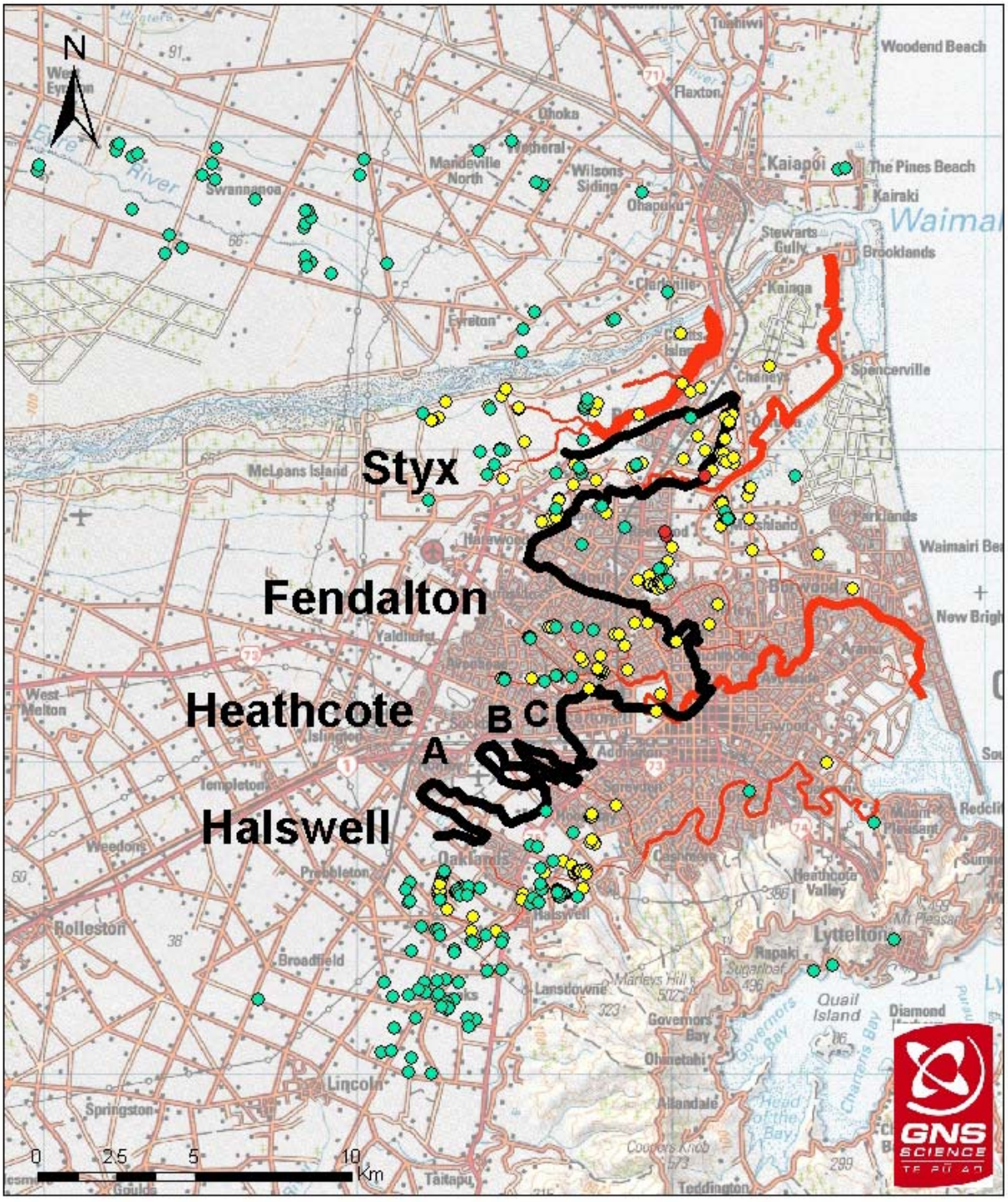


Figure 19. Lobes identified from the 1856 map with baseflow and spring location.

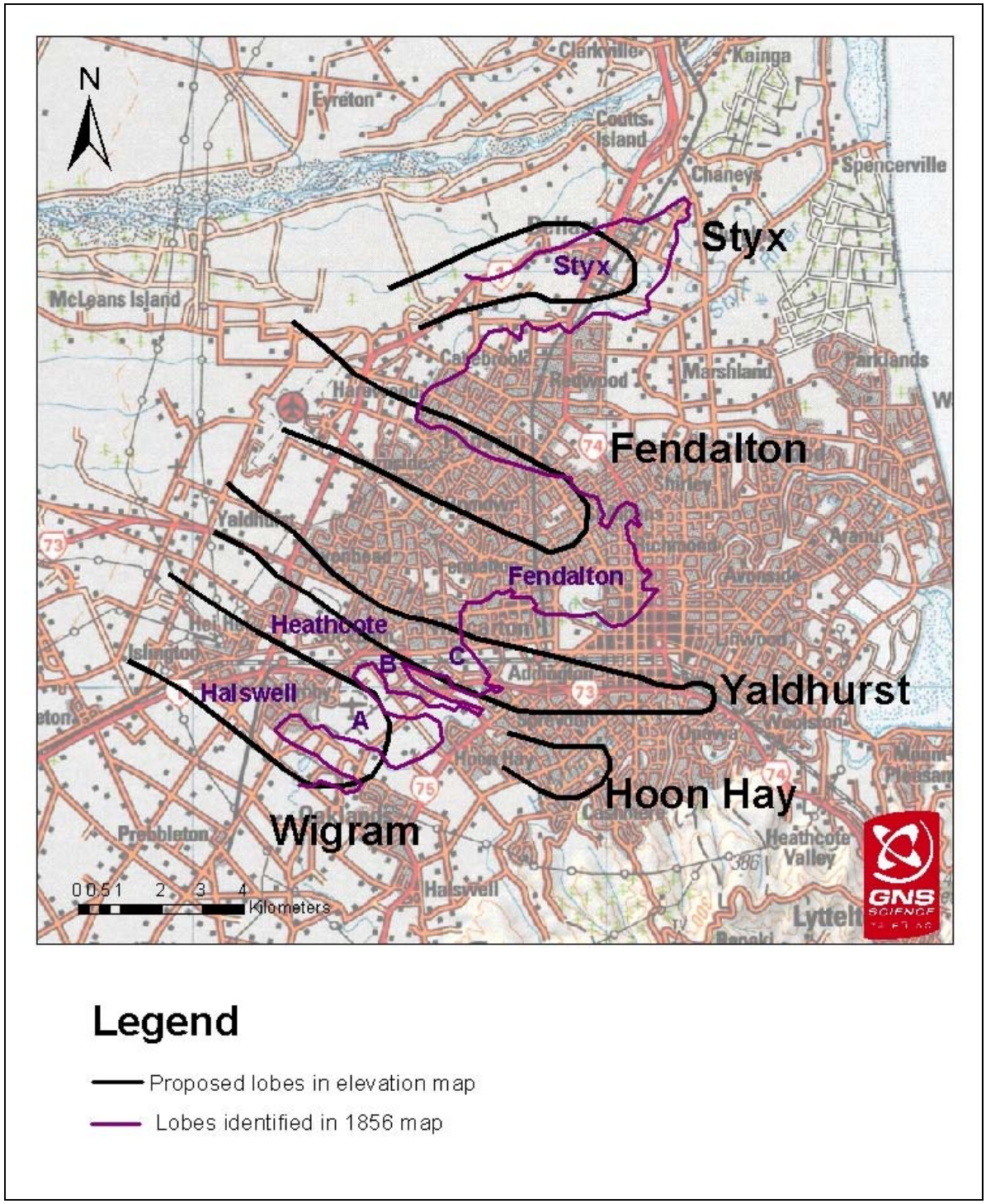


Figure 20. Lobes identified from the 1856 map with proposed lobes from the ground elevation map.

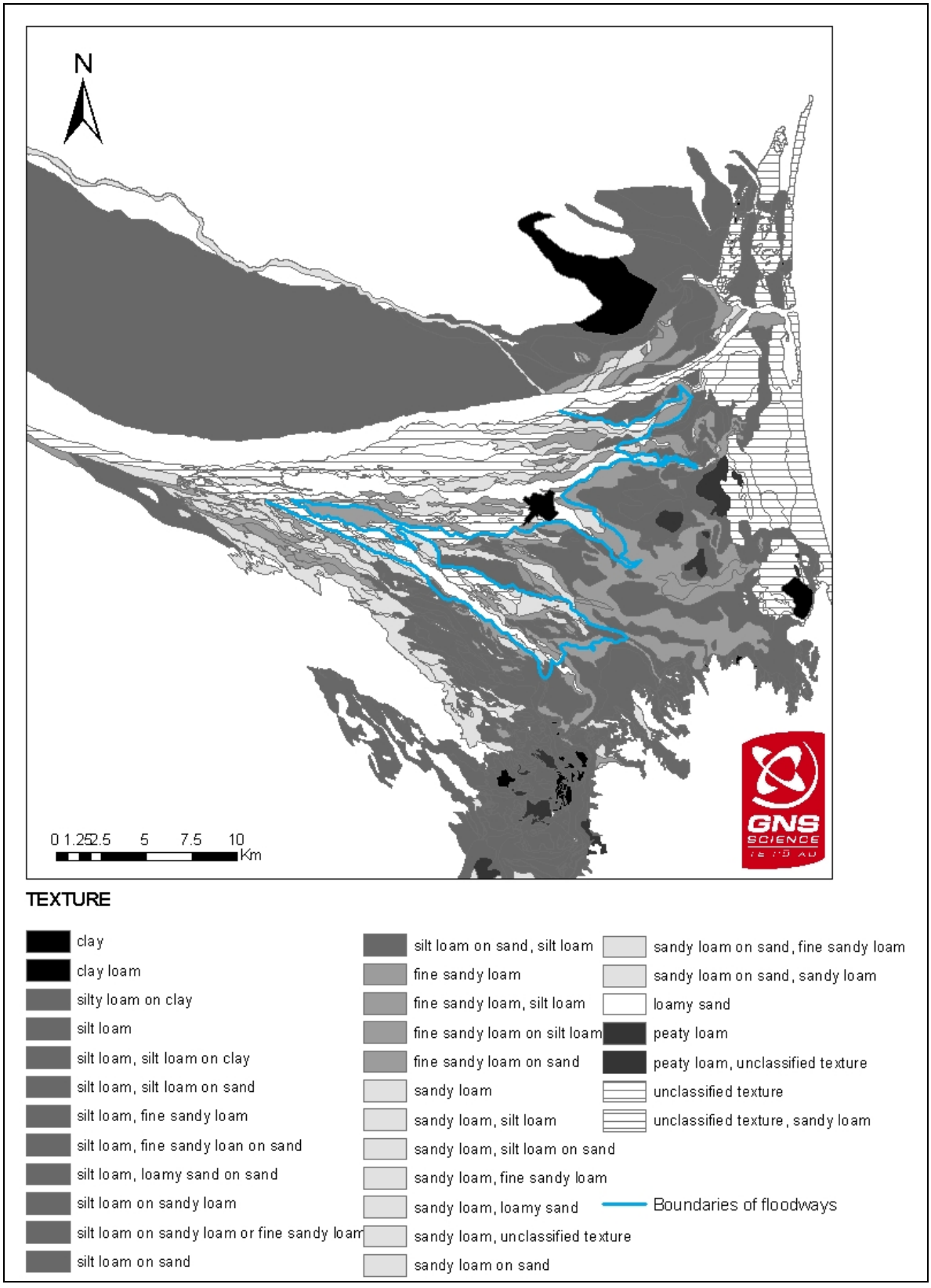


Figure 21. Floodways from the geomorphic map and soil texture.

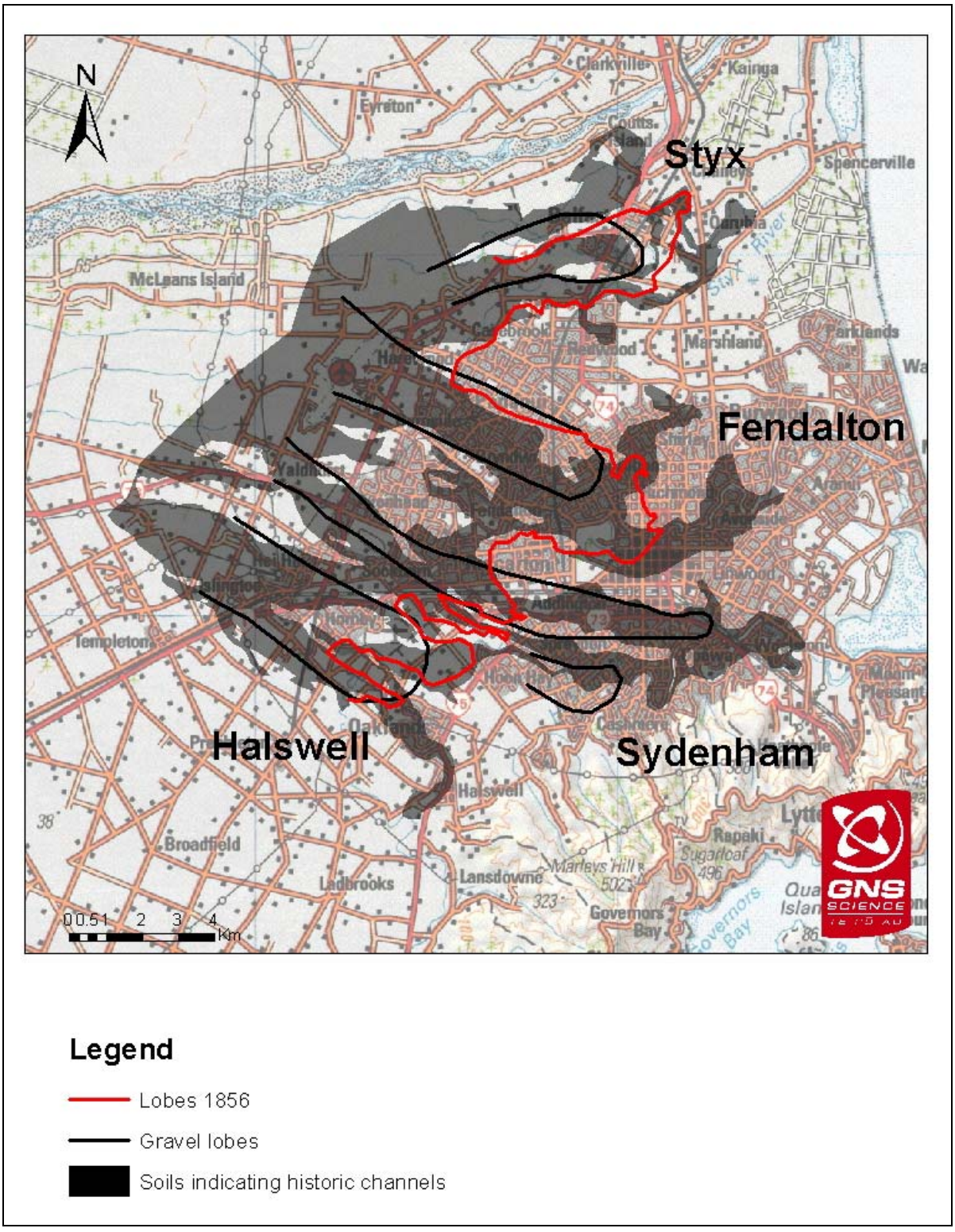


Figure 22. Floodways from the geomorphic map, sandy loam soil texture and proposed lobes from the ground elevation map.

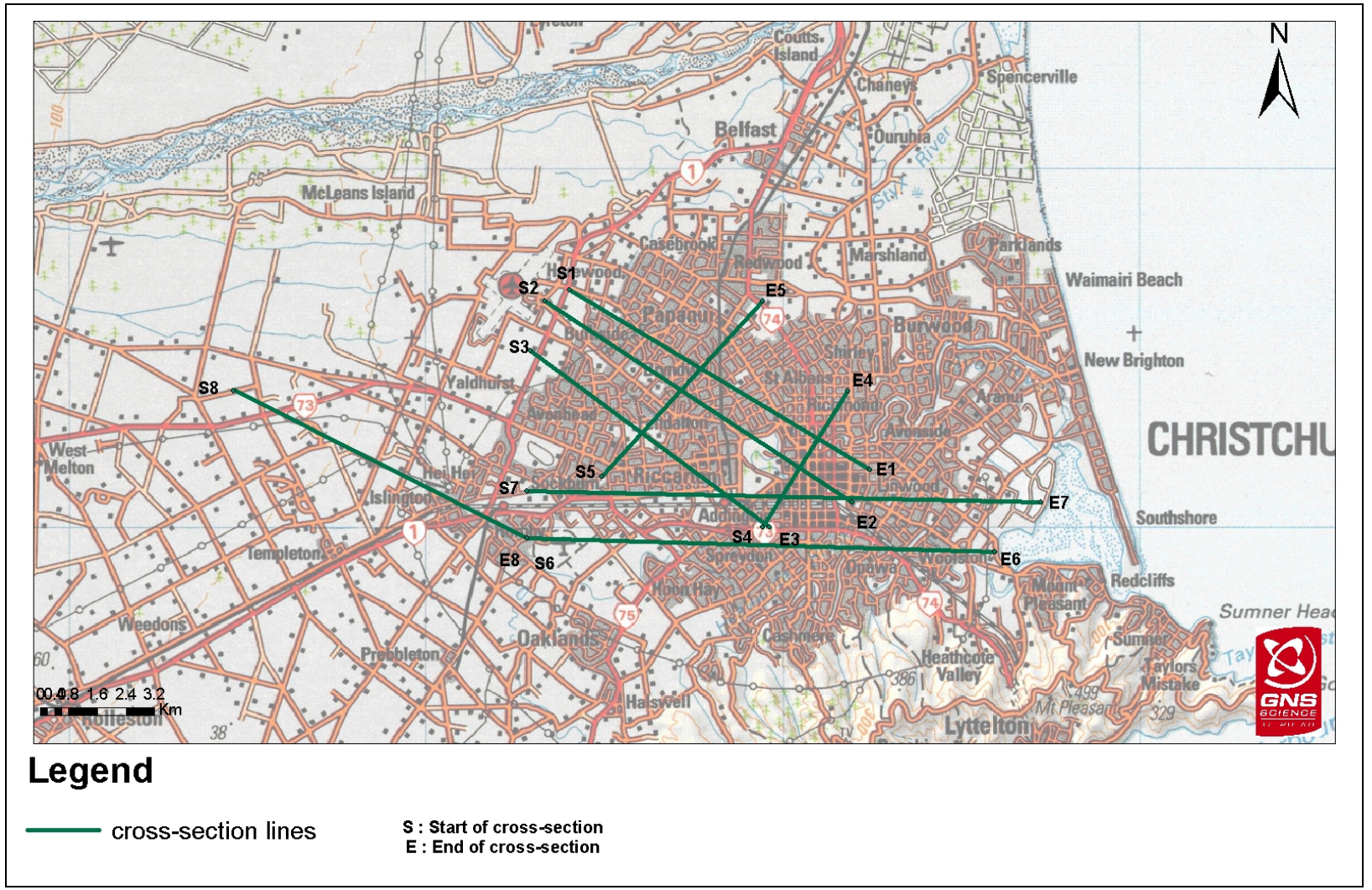


Figure 23. Location of eight geological cross-sections, Christchurch City.

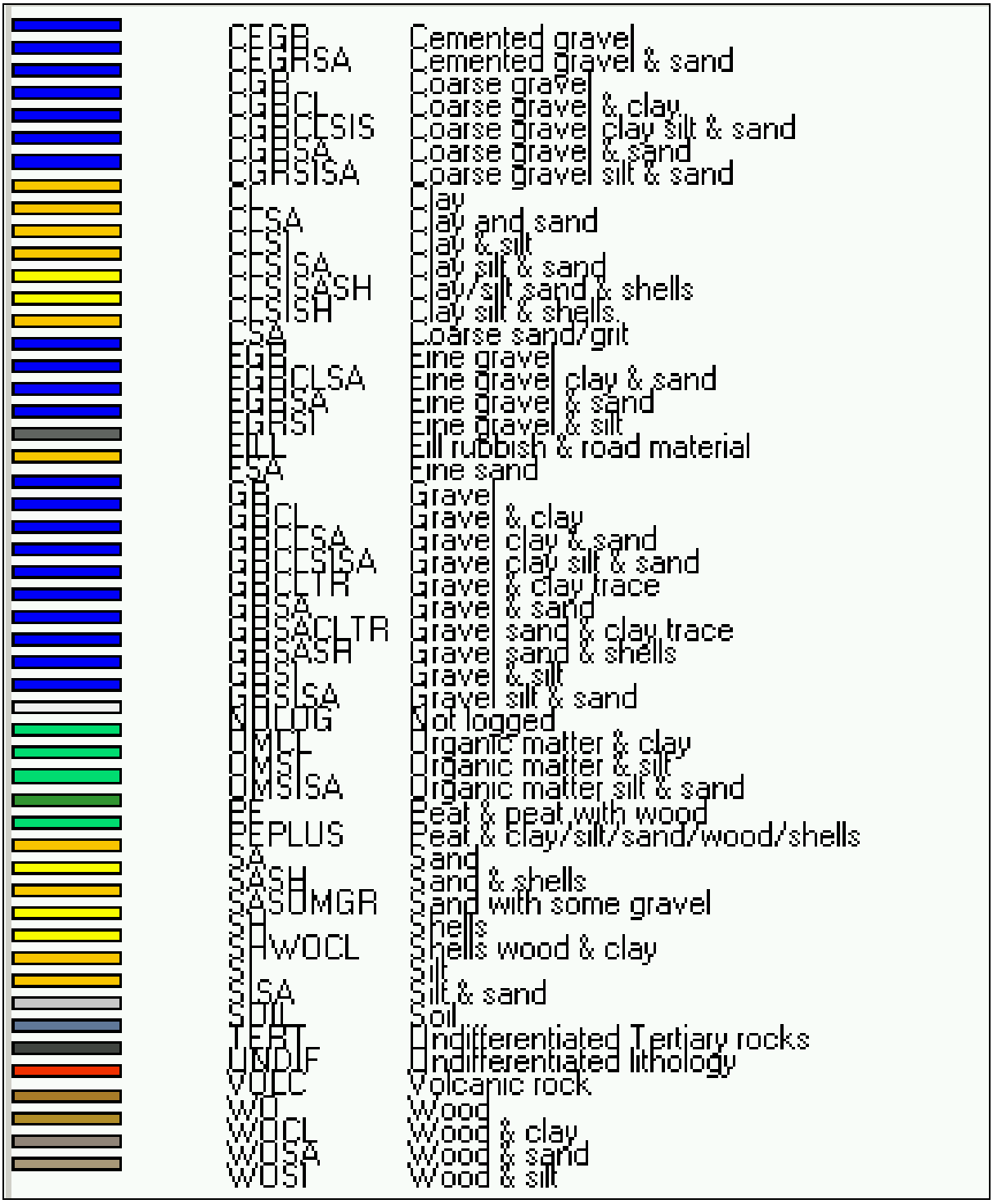


Figure 24. Legend for geological cross-sections of Christchurch City.

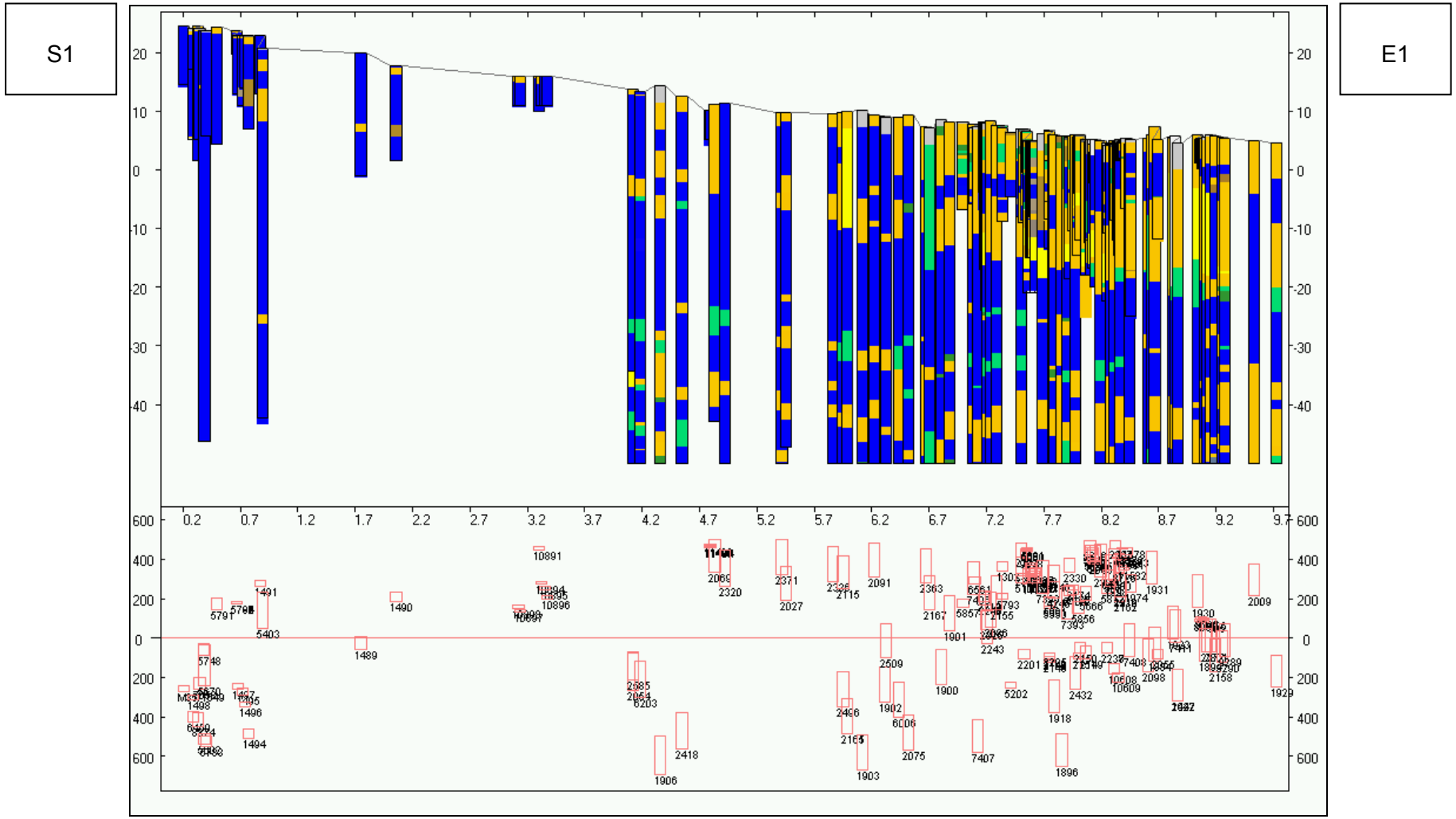


Figure 25. Geological cross-section one.

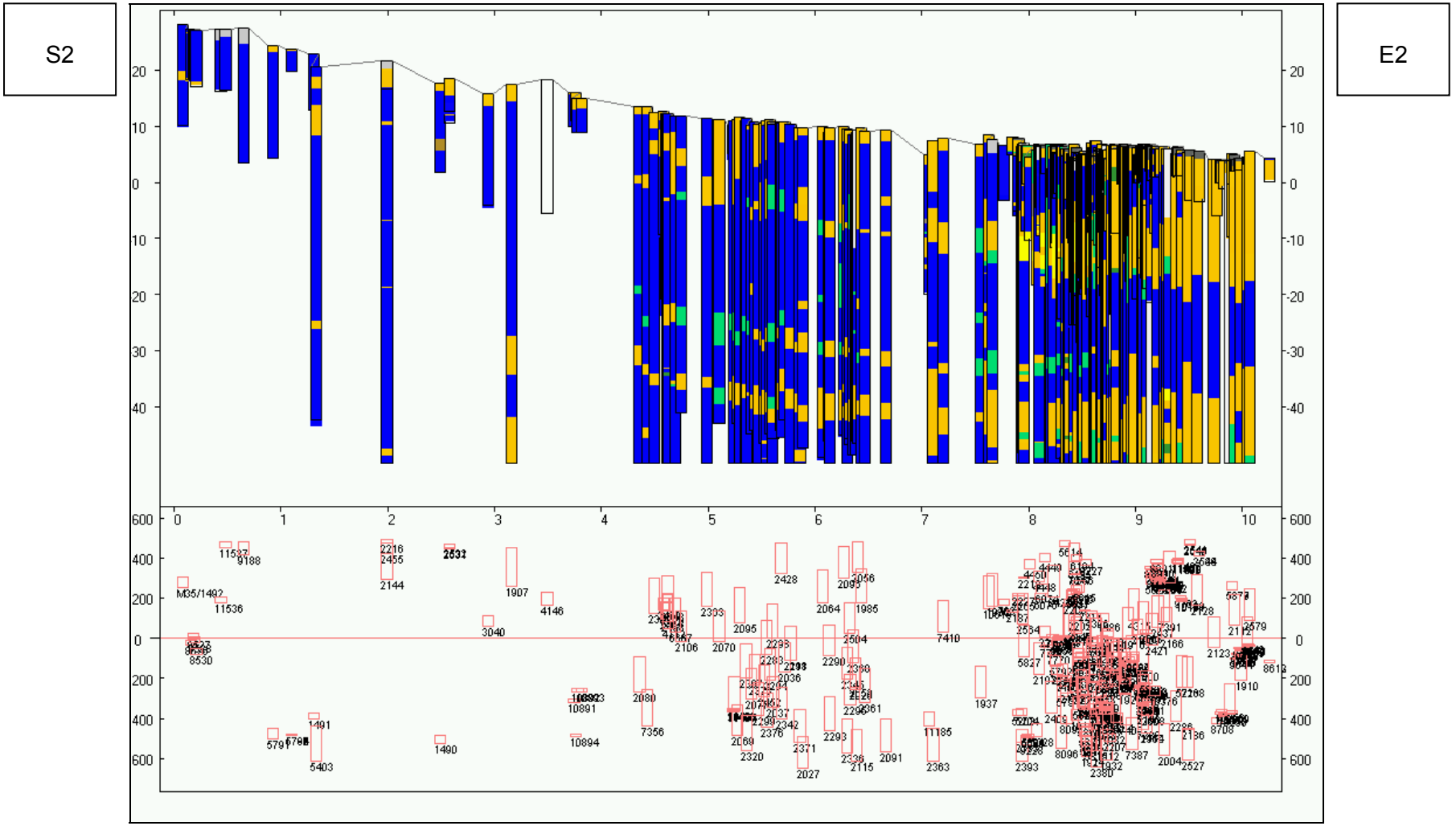


Figure 26. Geological cross-section two.

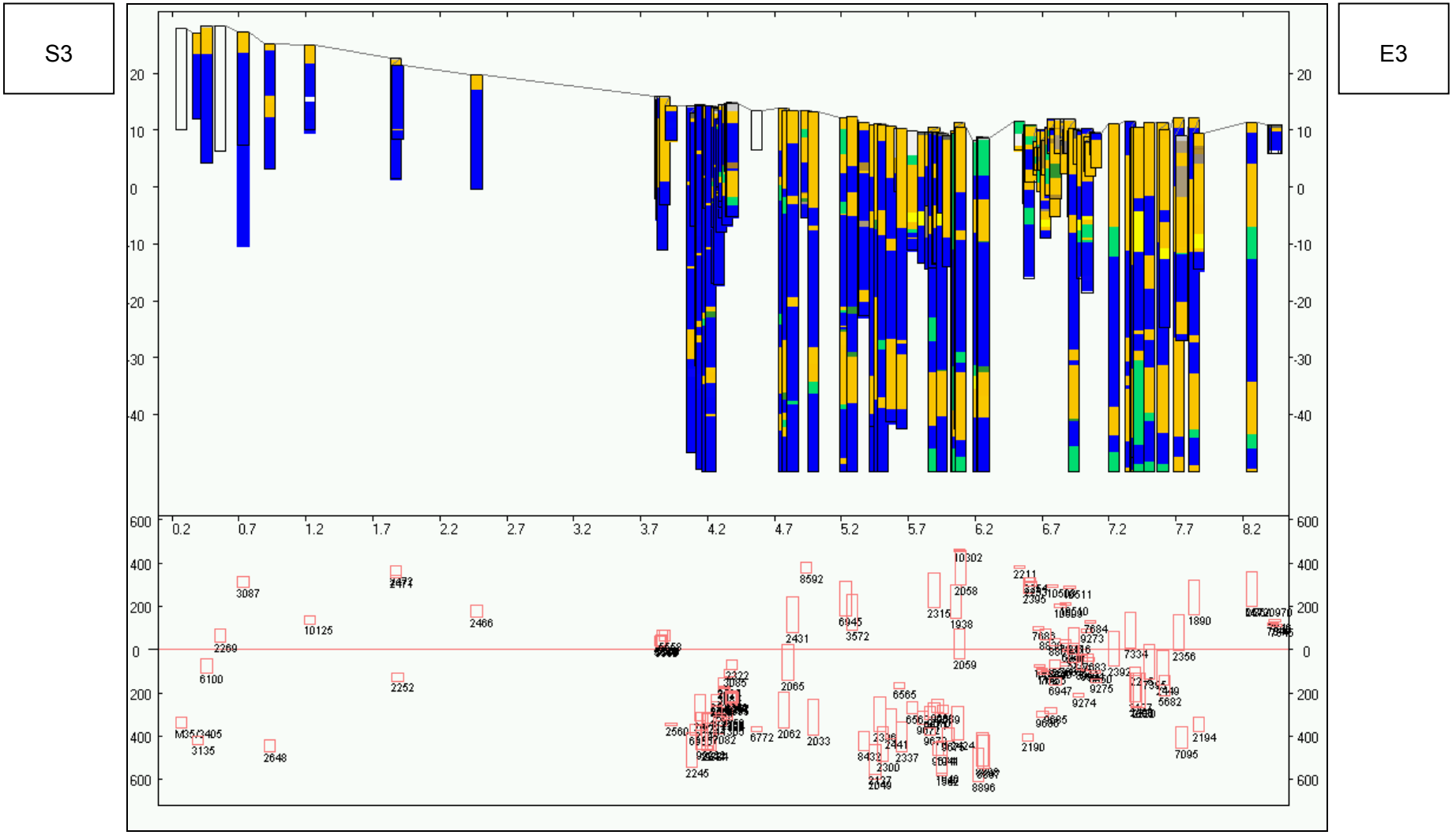


Figure 27. Geological cross-section three.

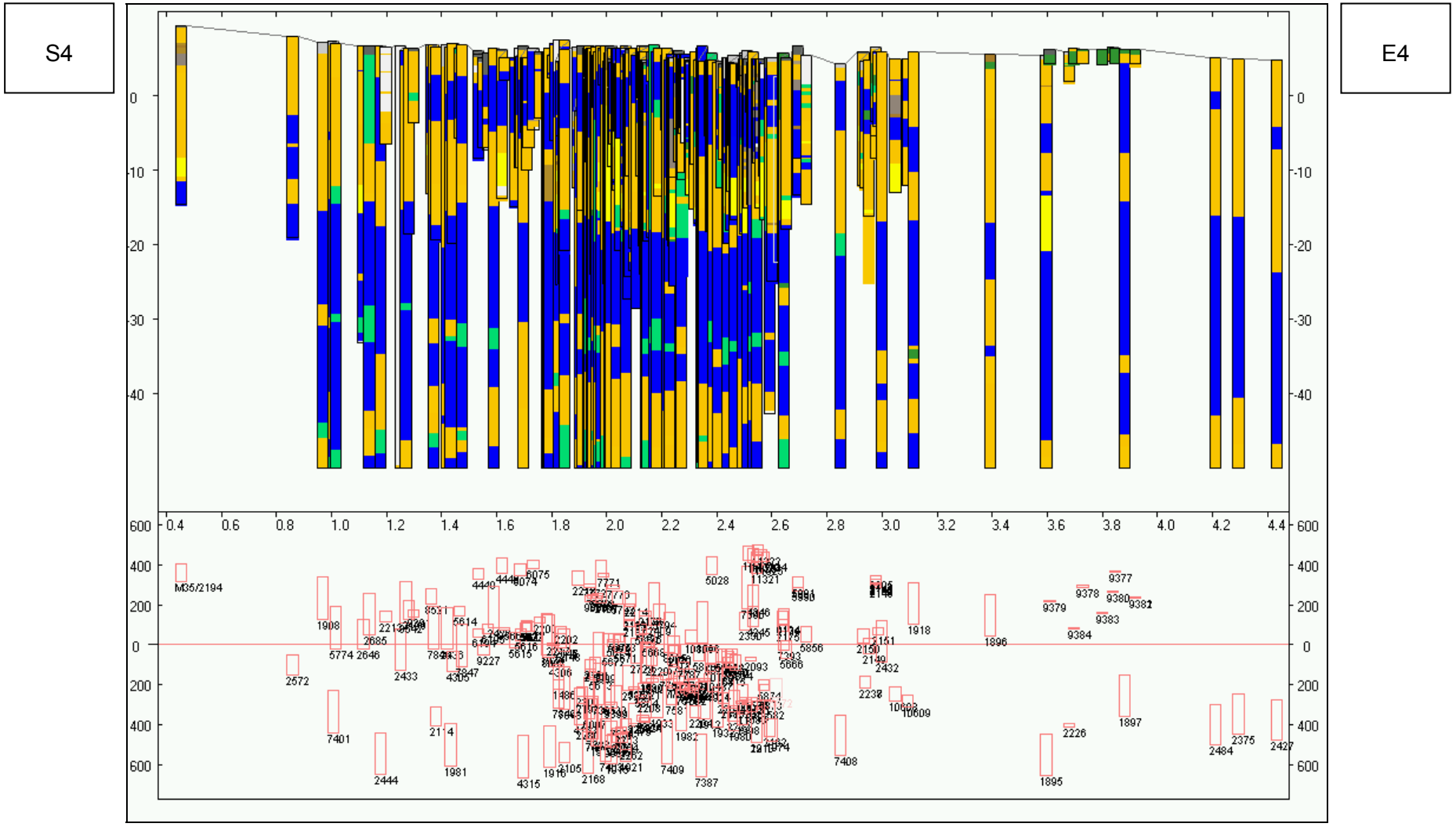


Figure 28. Geological cross-section four.

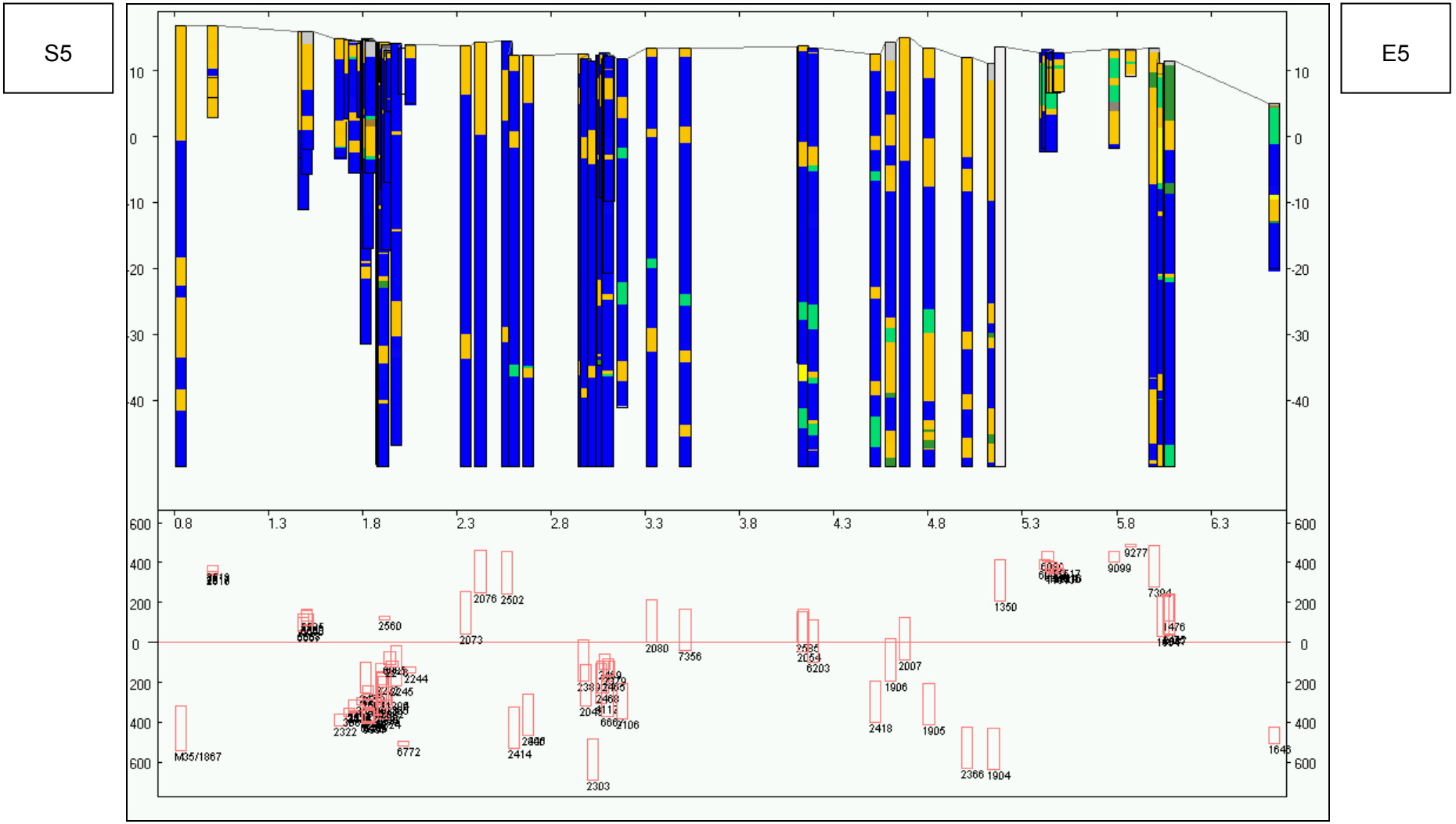


Figure 29. Geological cross-section five.

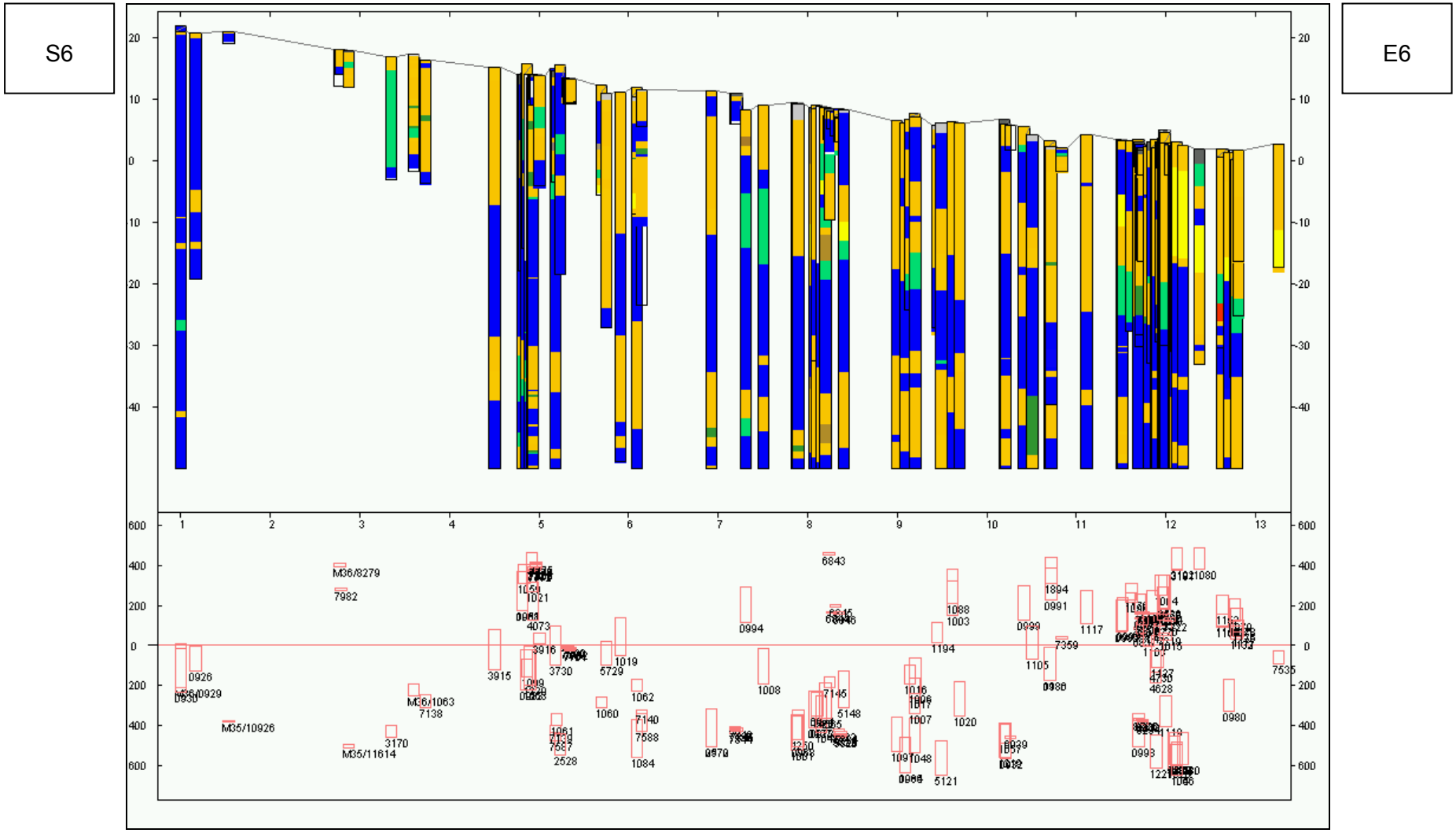


Figure 30. Geological cross-section six.

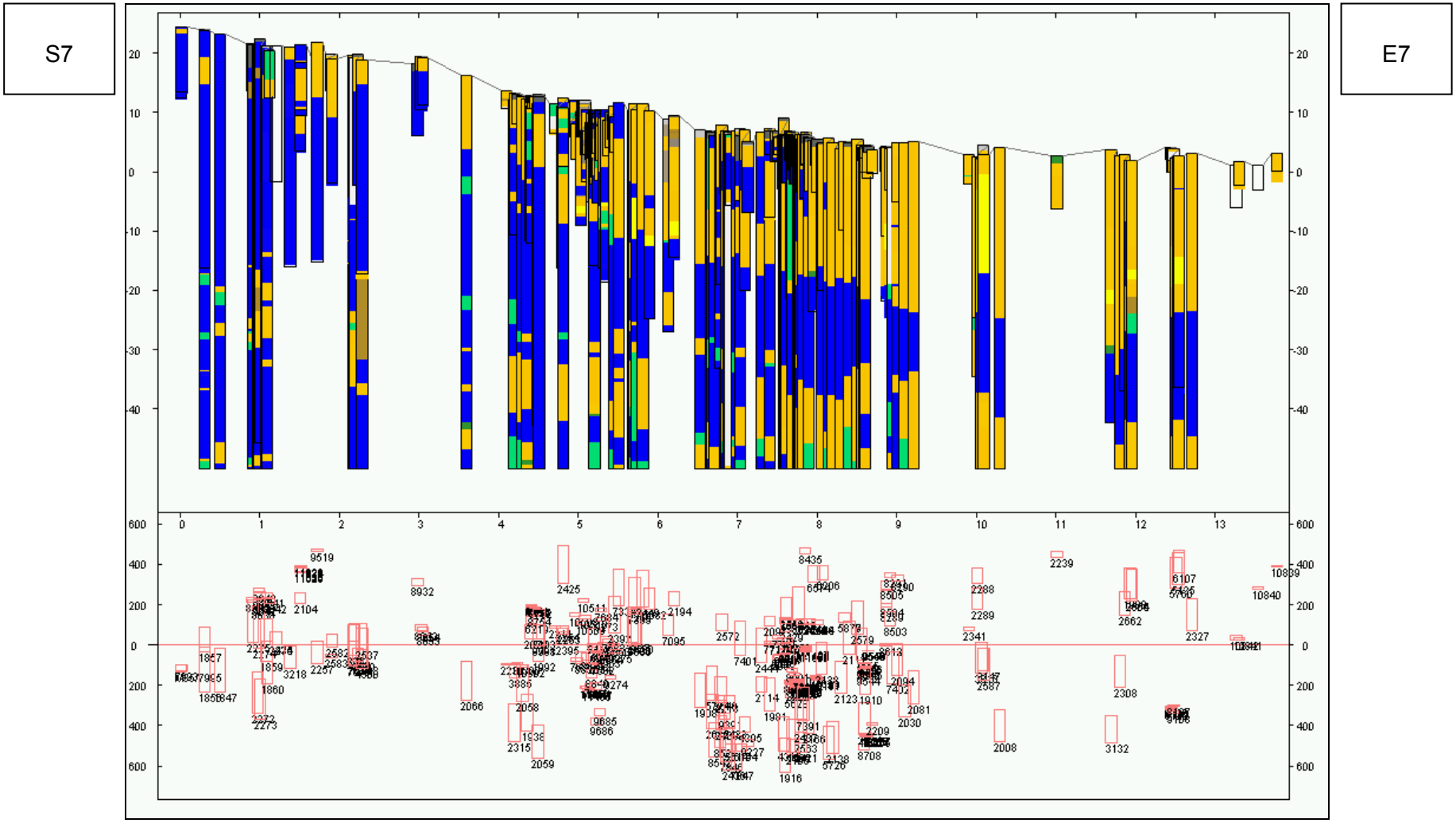


Figure 31. Geological cross-section seven.

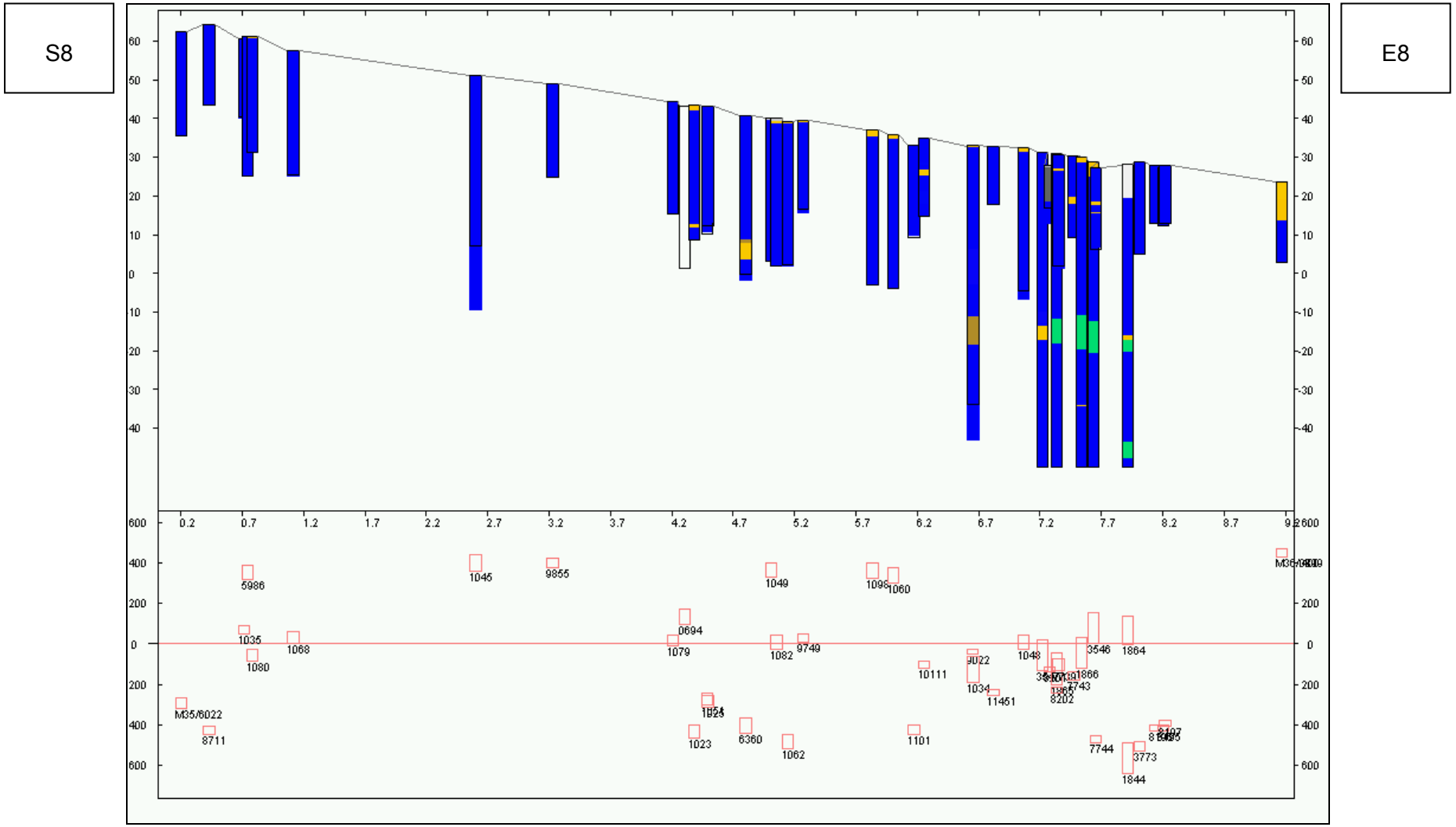


Figure 32. Geological cross-section eight.

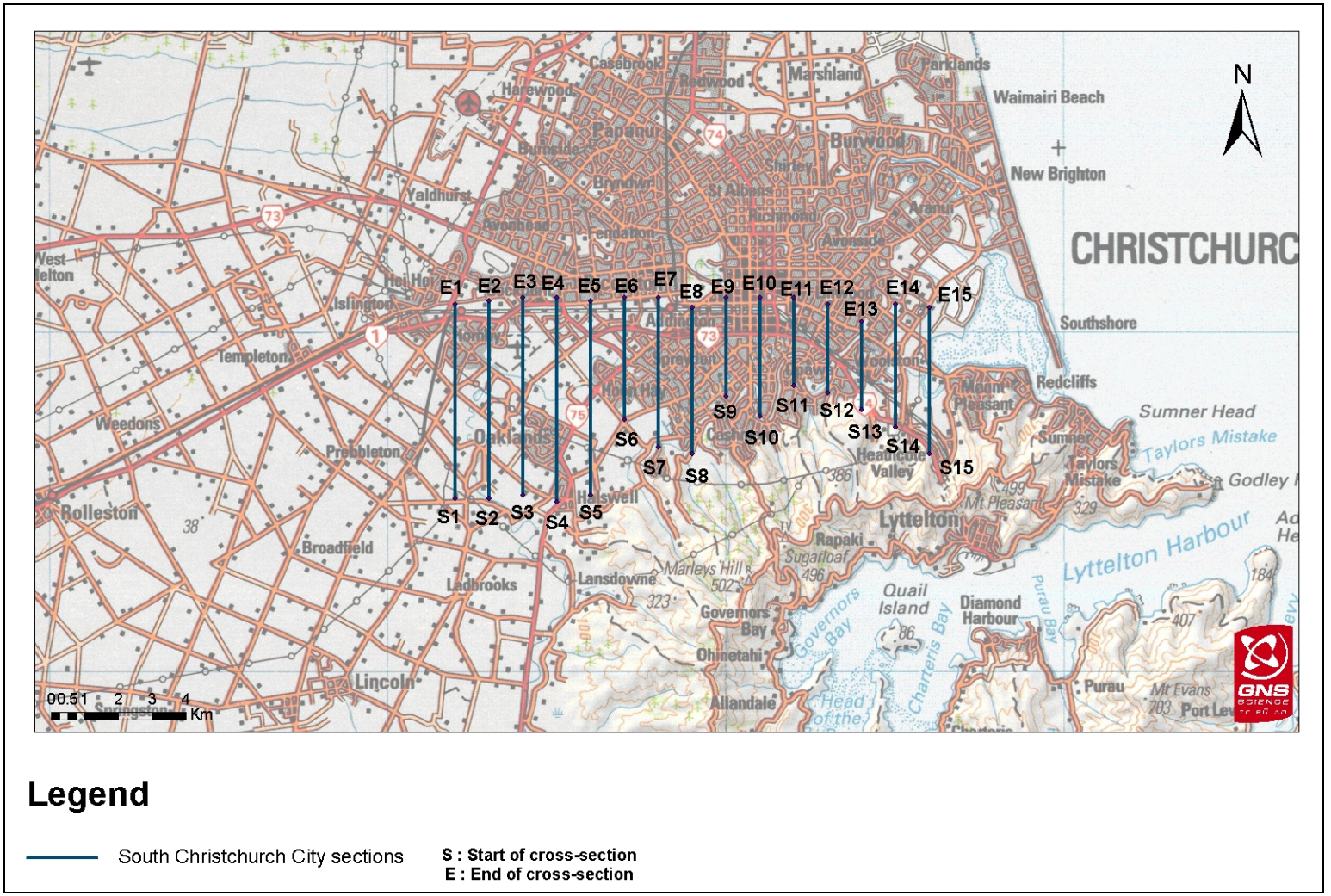


Figure 33. Location of geological sections in the south Christchurch area.

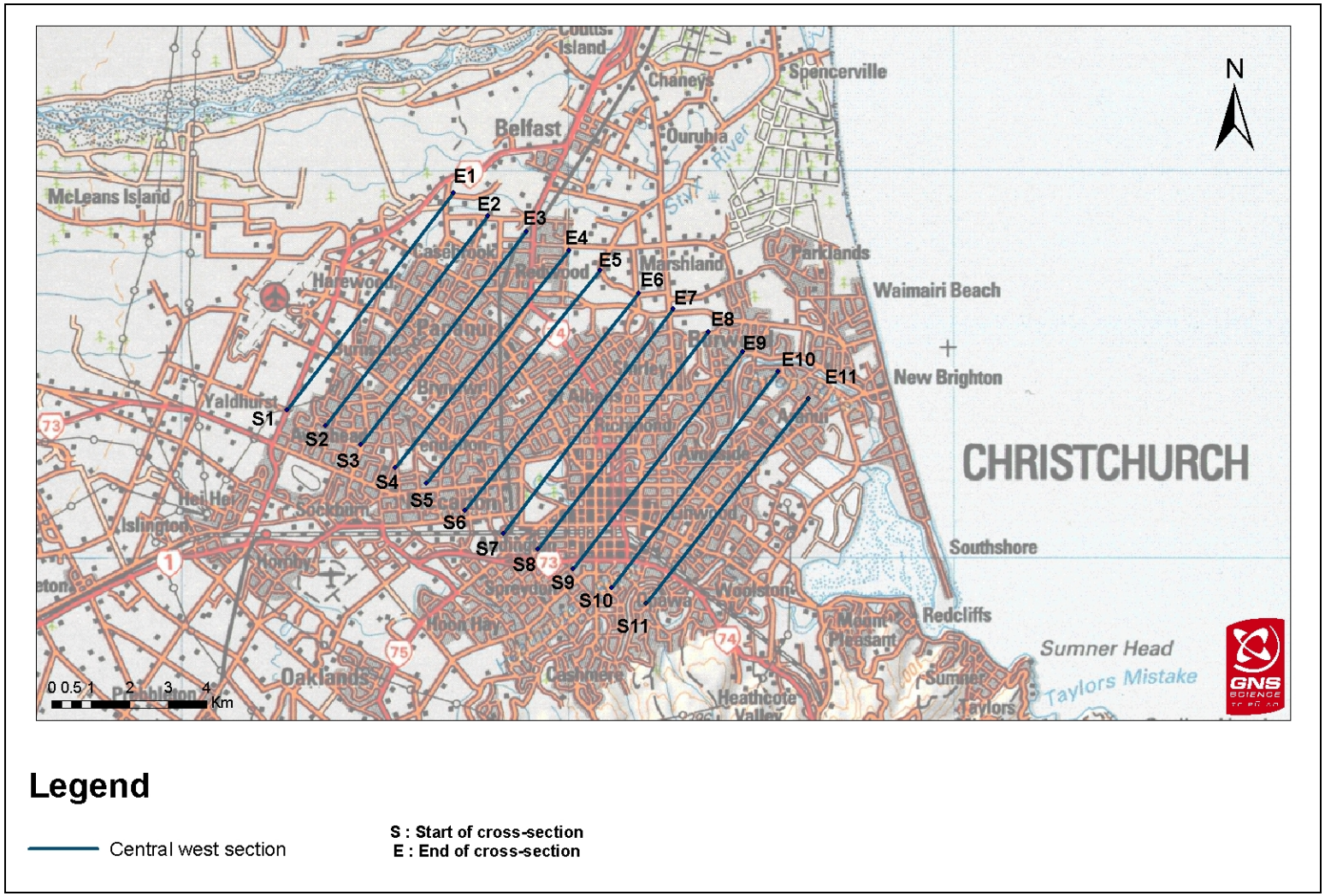


Figure 34. Location of geological sections in the central-west Christchurch area.

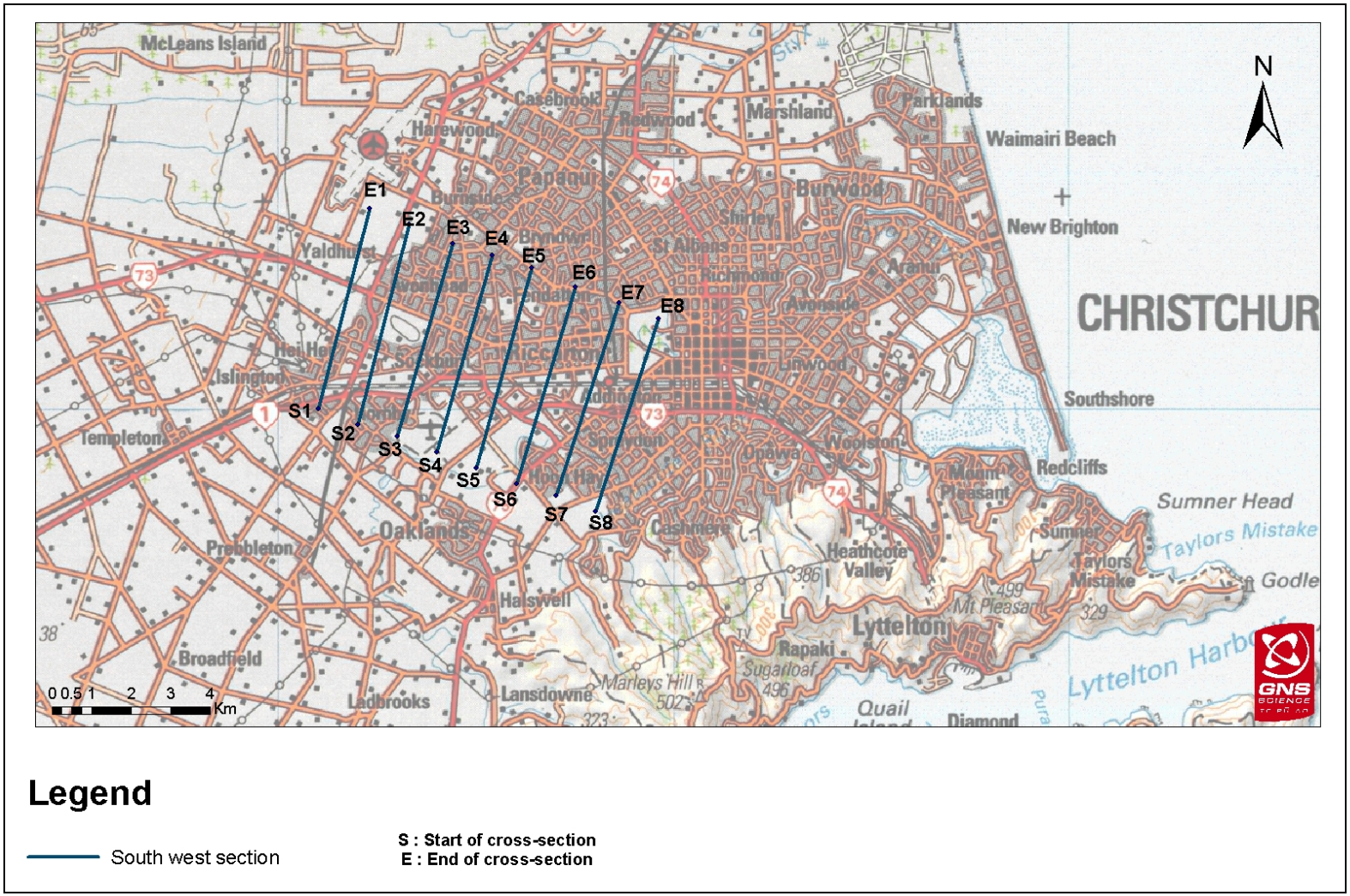


Figure 35. Location of geological sections in the south-west Christchurch area.

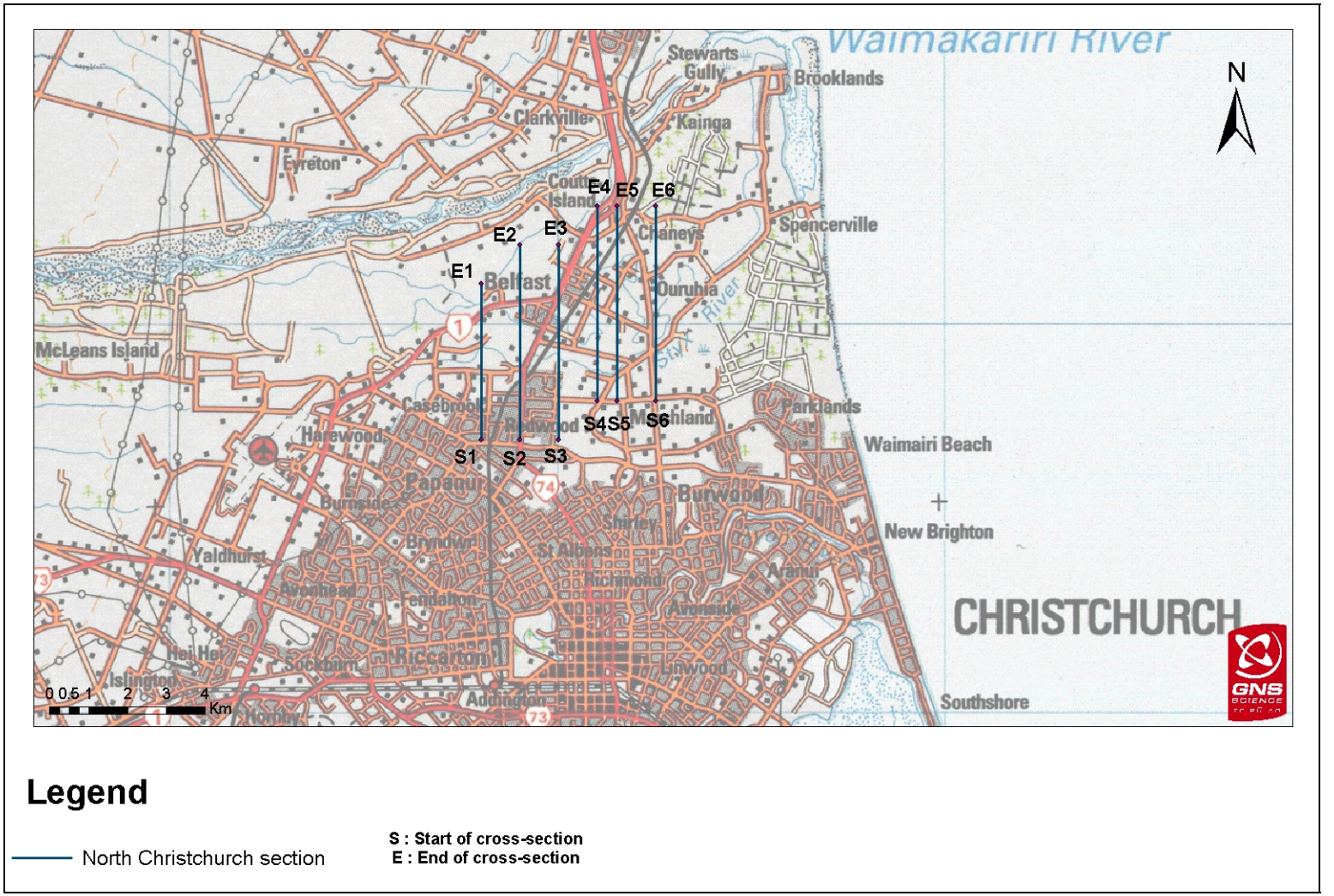


Figure 36. Location of geological sections in the north Christchurch area.

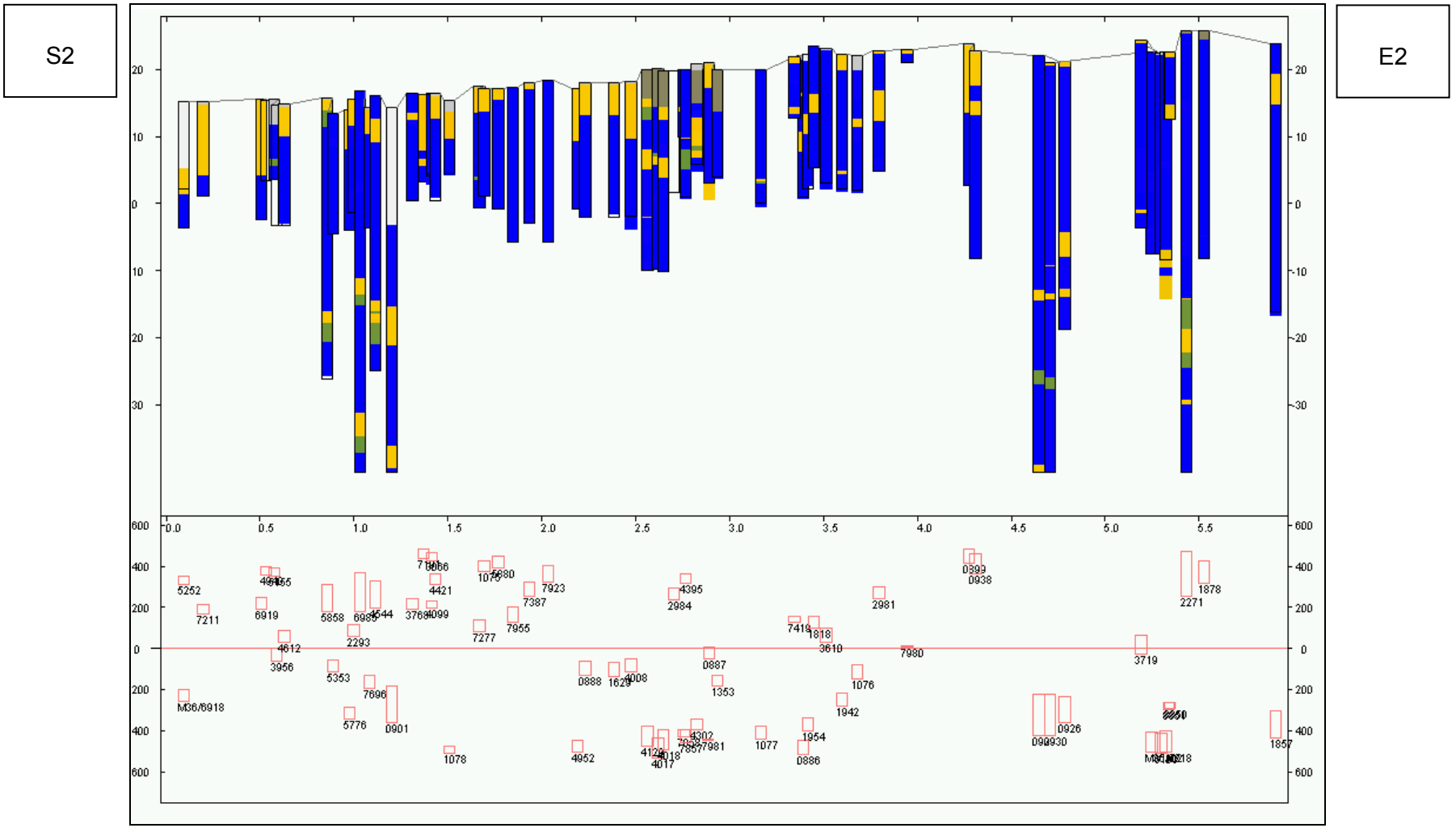


Figure 37. Geological logs in cross section S2 – E2 (Figure 33).

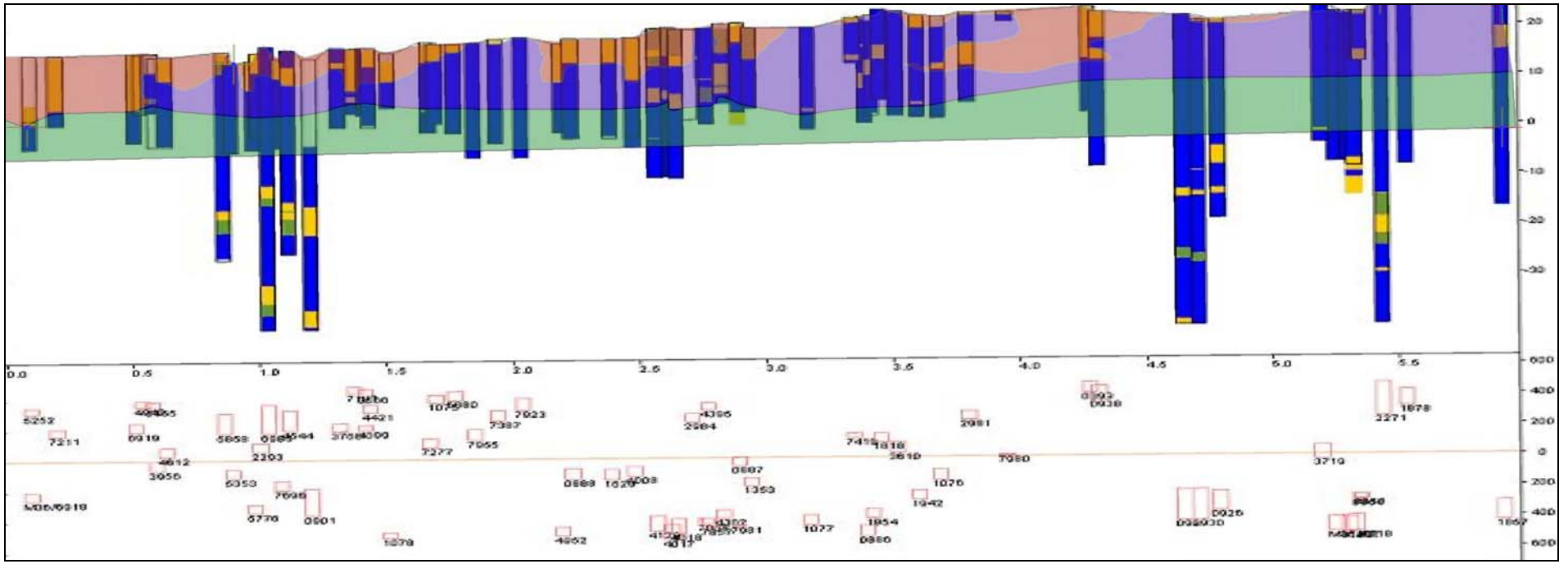


Figure 38. Geological logs in cross section S2 – E2 (Figure 37) and interpretation of cross section S2 – E2 as connected Springston Gravel (dark blue) and Riccarton Gravel (green).

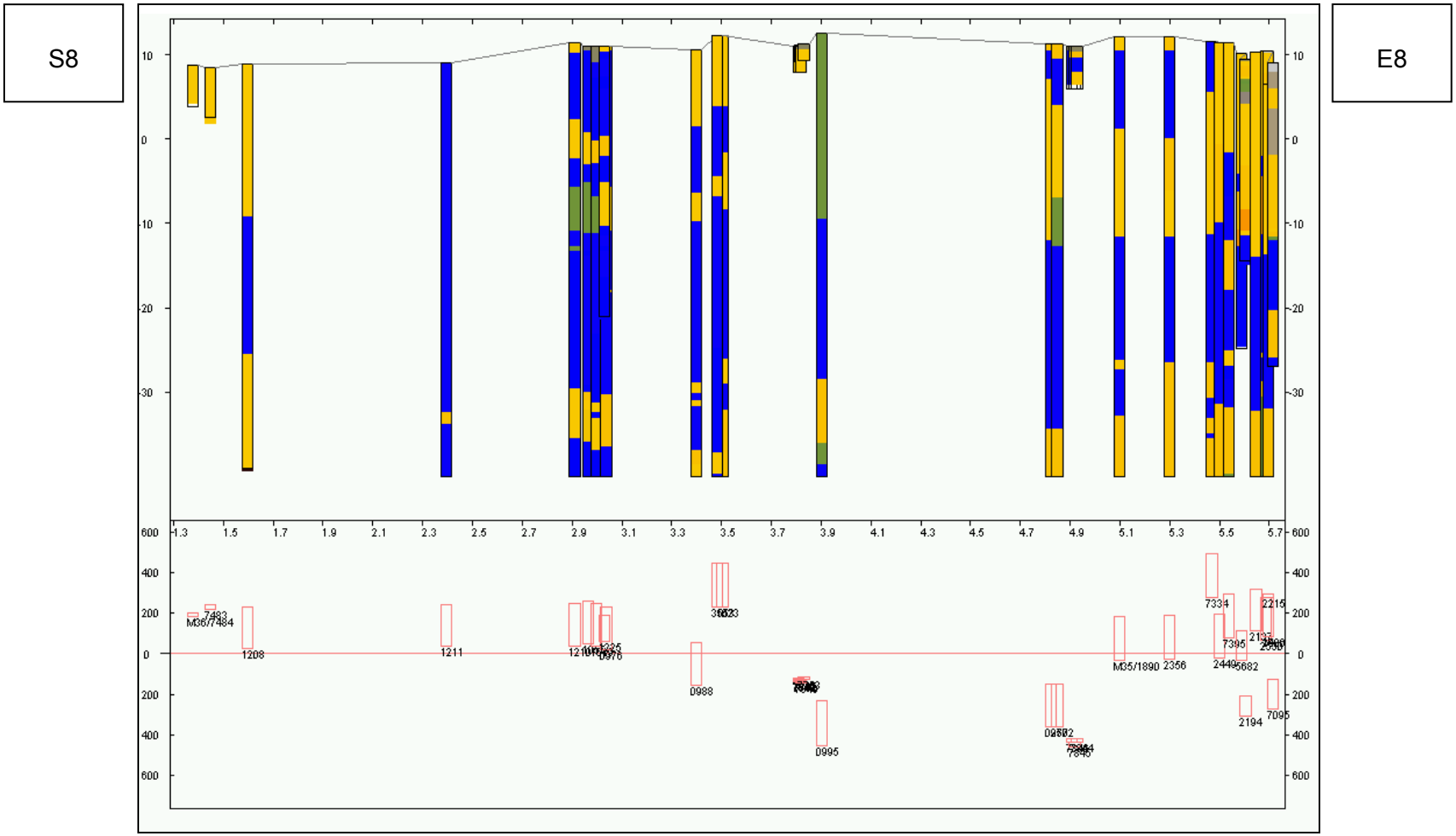


Figure 39. Geological logs in cross section S8 – E8 (Figure 33).

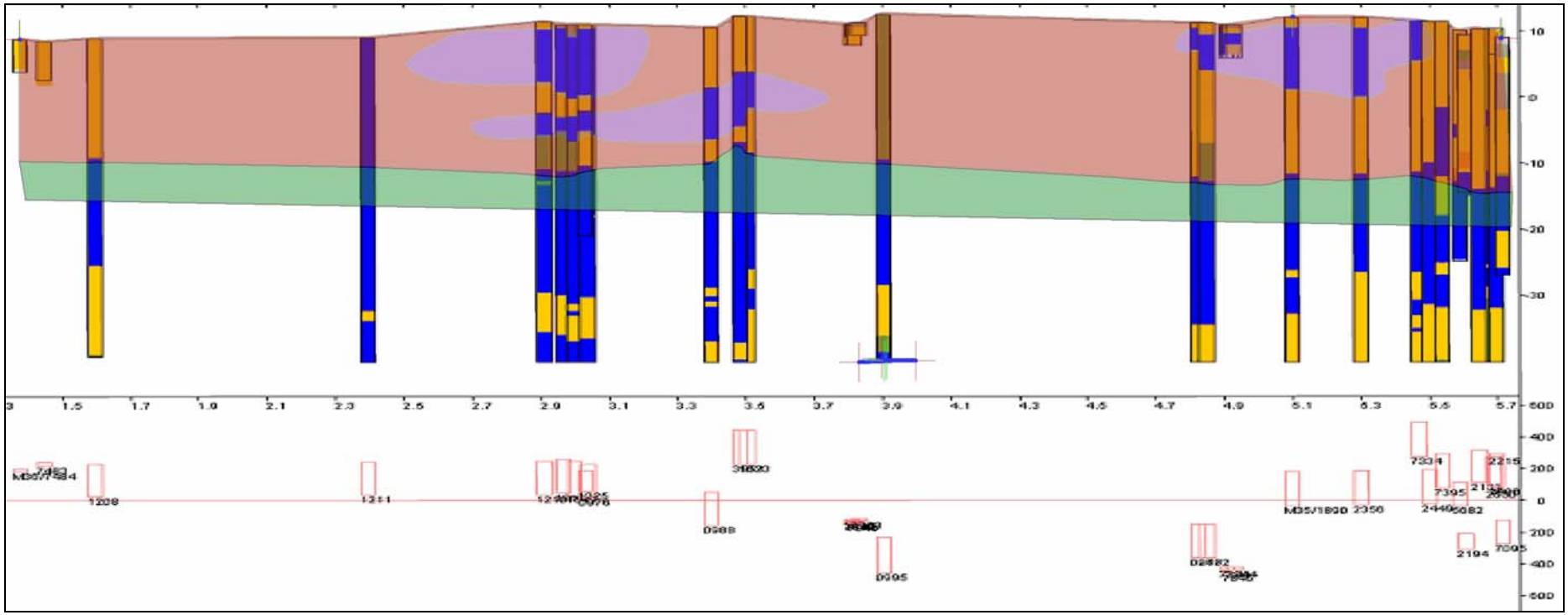


Figure 40. Geological logs in cross section S8 – E8 (Figure 39) and interpretation of cross section S8 – E8 as unconnected Springston Gravel (light blue) and Riccarton Gravel (green).

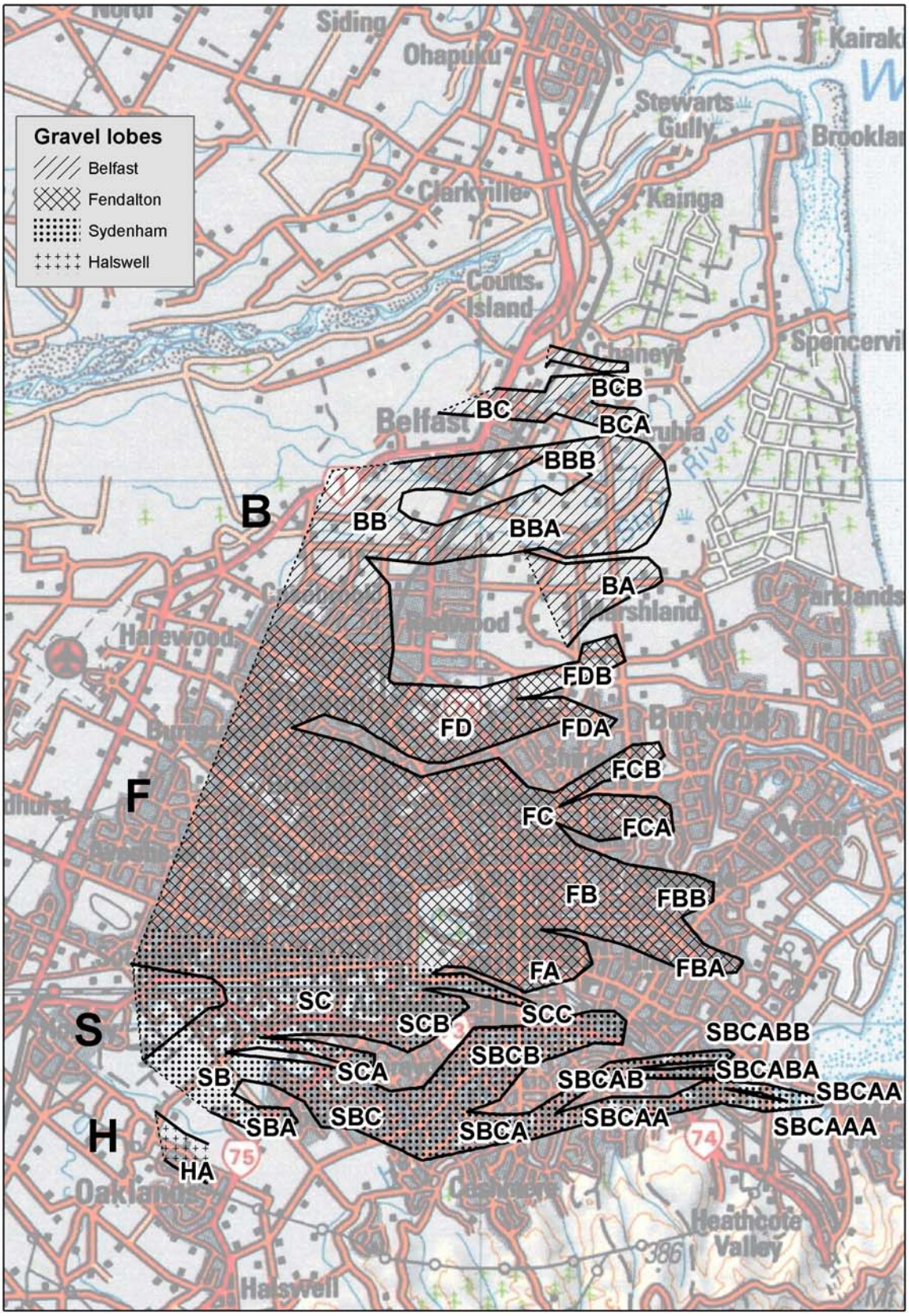


Figure 41. Location of unconnected Springston Gravel lobes. These gravel lobes are separated from Riccarton Gravel by non-gravel sediments in cross sections.

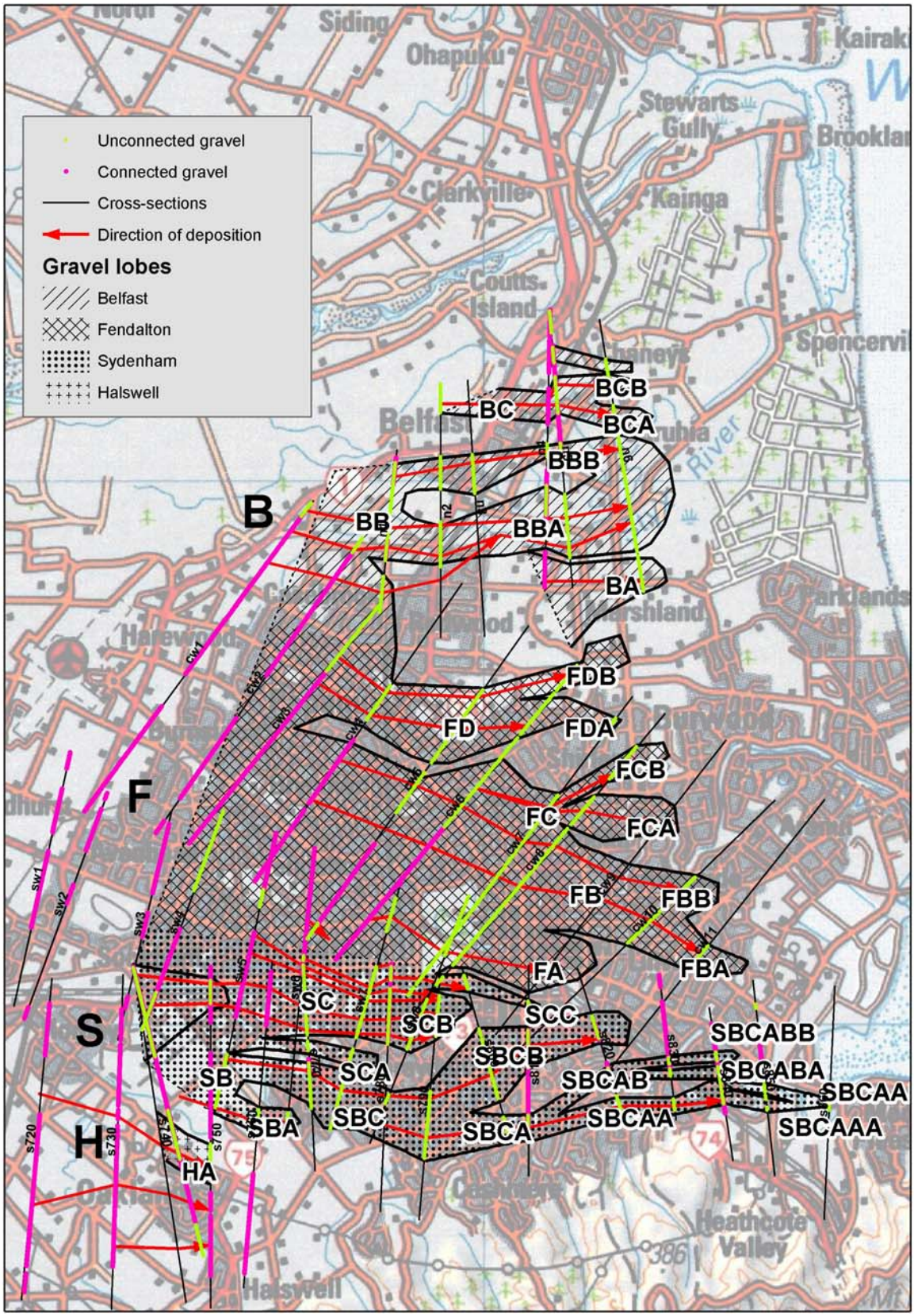


Figure 42. Unconnected gravel lobes and location of unconnected gravel on the geological cross sections.

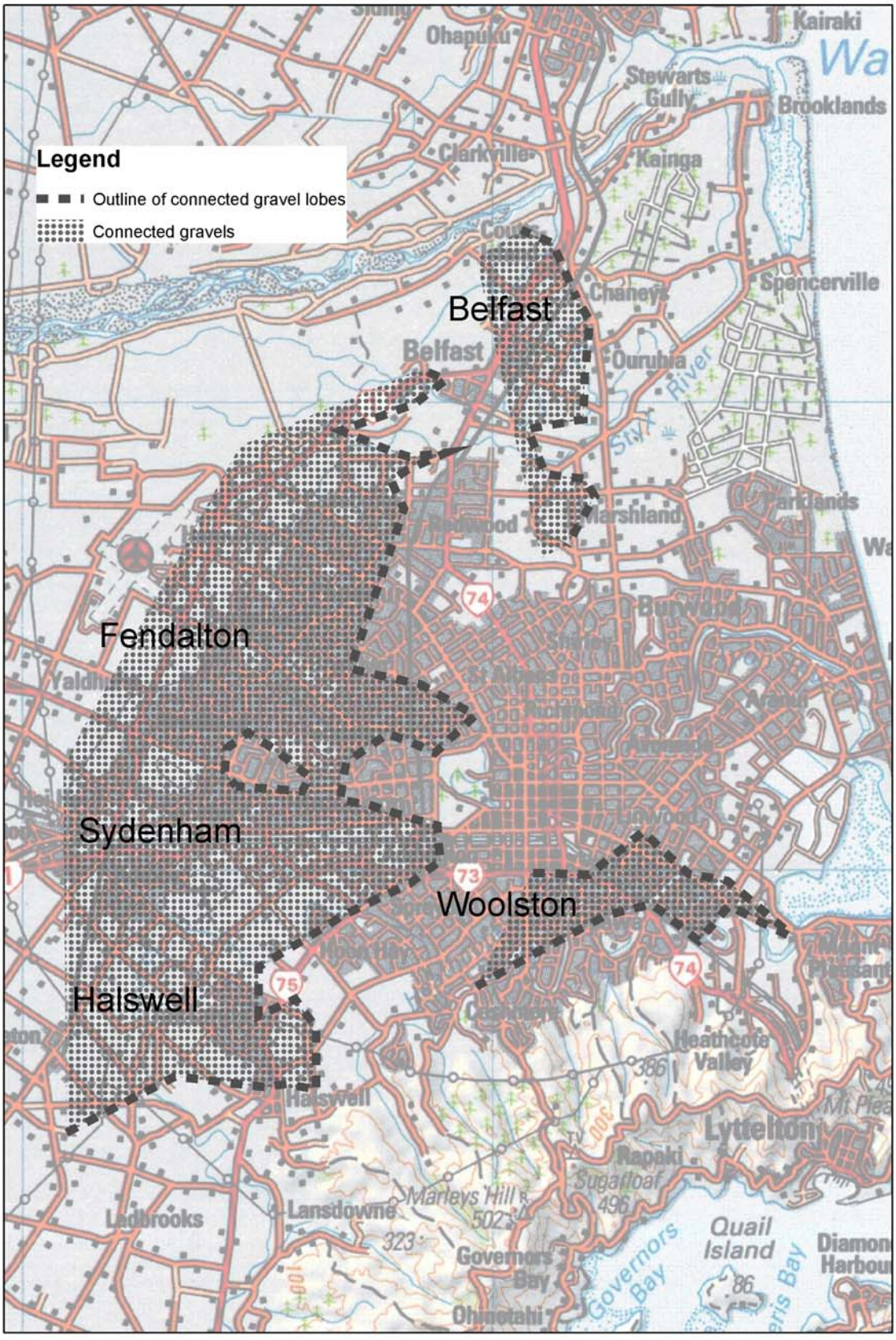


Figure 43. Location of "connected" Springston Gravel lobes. These gravel lobes are connected vertically with Riccarton Gravel by continuous gravel sedimentation.

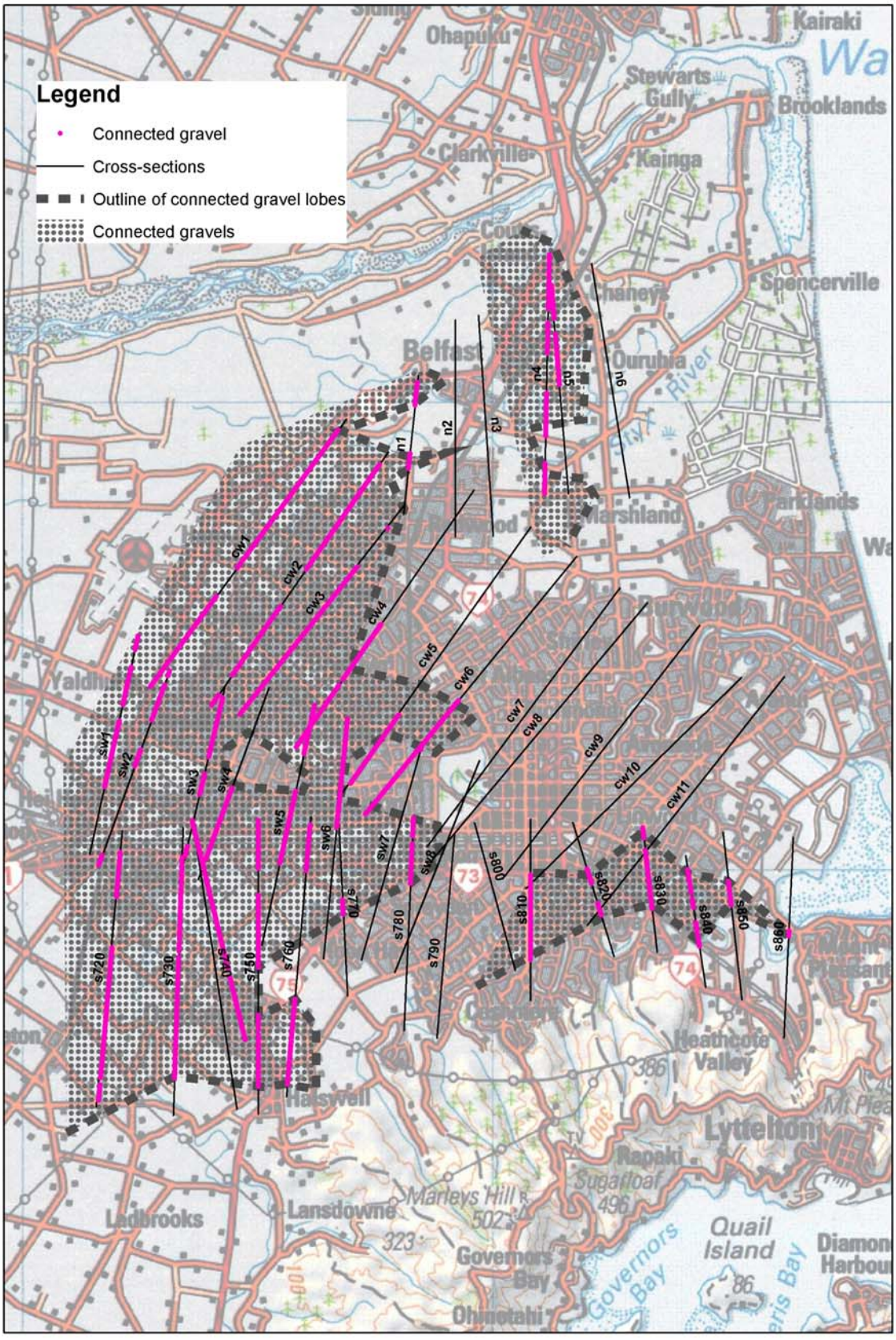


Figure 44. Connected gravel lobes and location of connected gravel on the geological cross sections.

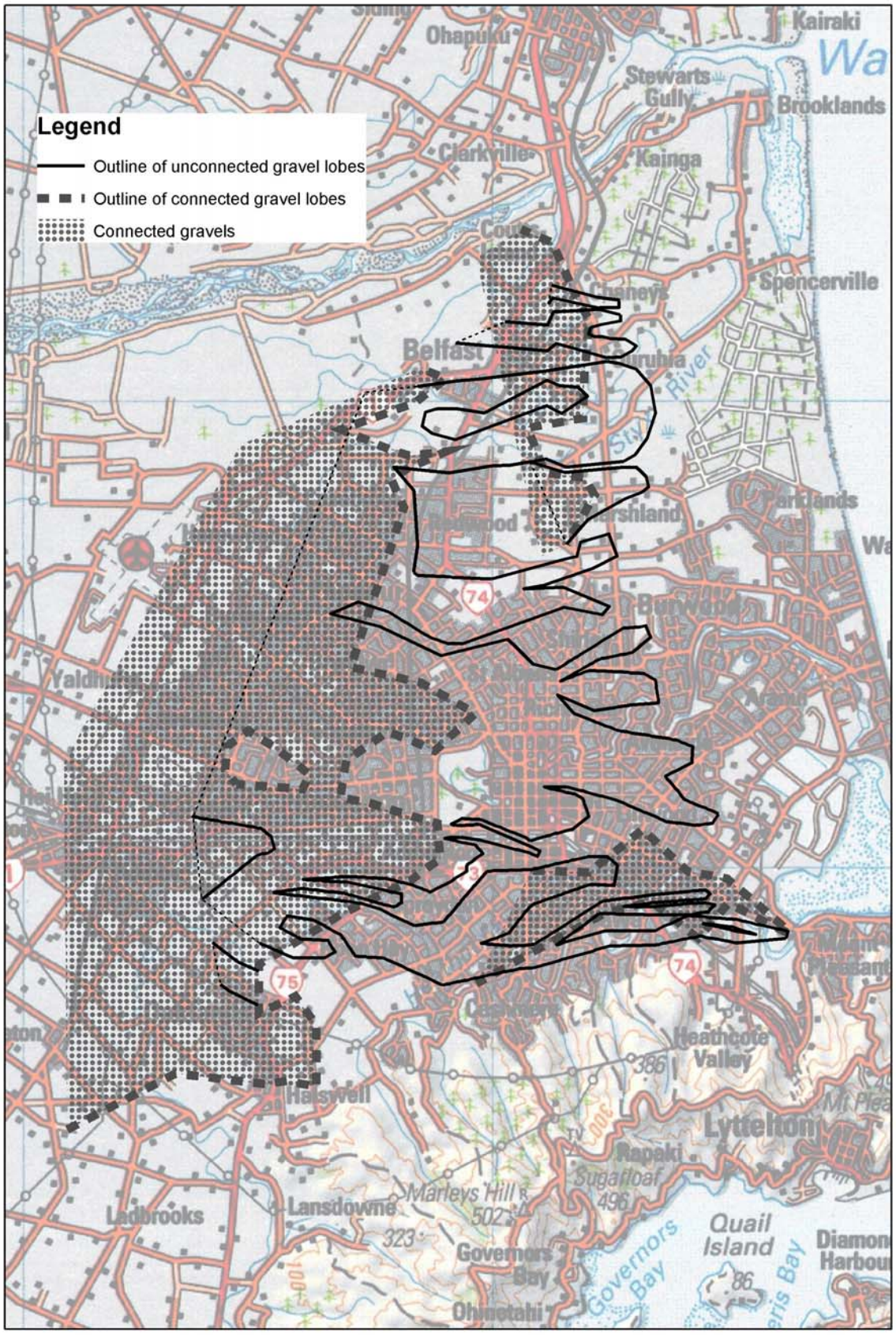


Figure 45. Extents of unconnected gravel lobes and connected gravel lobes.

Figure 46. Locations of wells with geological logs in the Christchurch City area (after White, 2007).

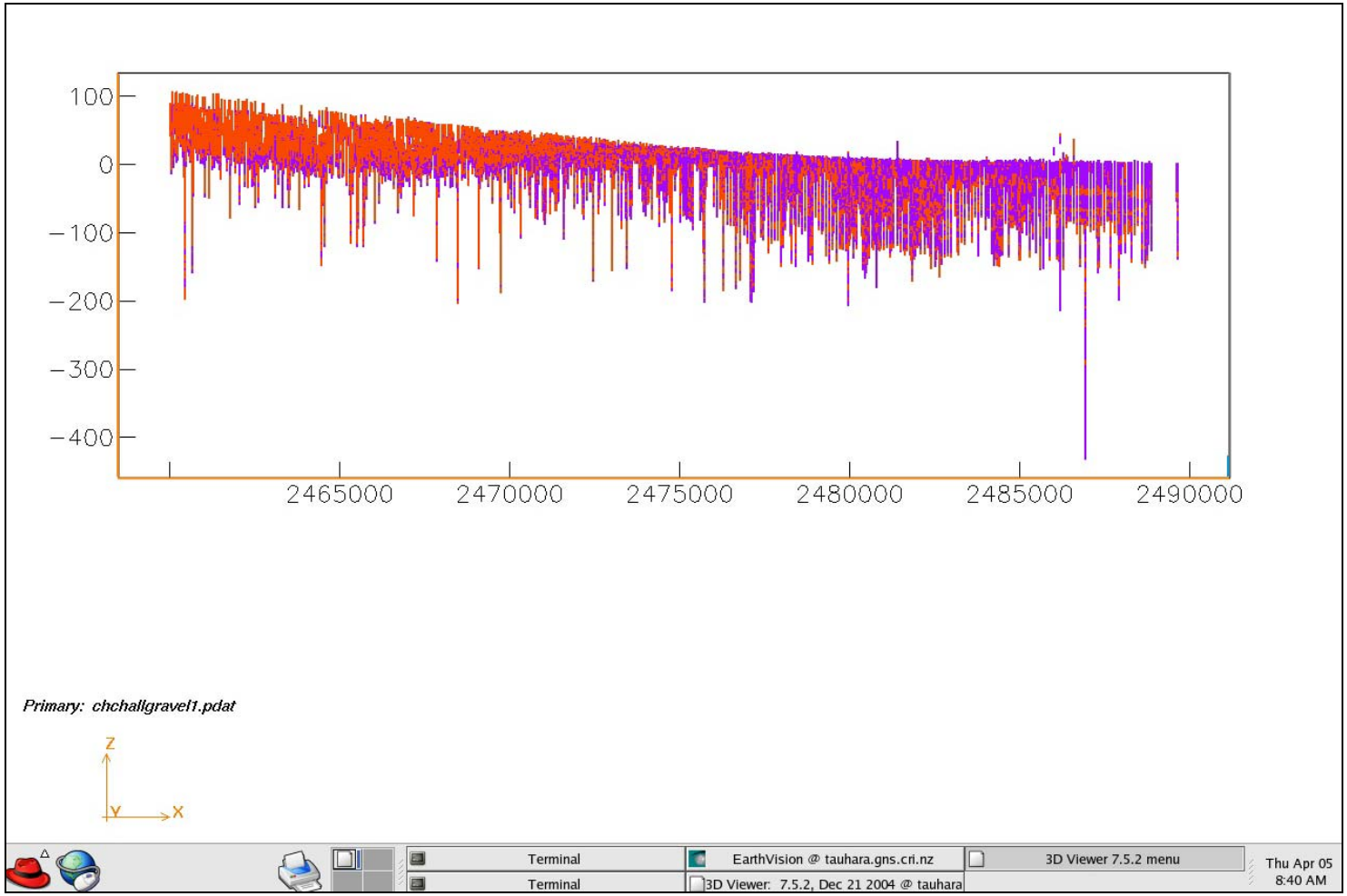


Figure 47. Lithological logs of wells in Christchurch showing gravel (red colour) and other sediments (blue colour) viewed towards the north (after White, 2007).

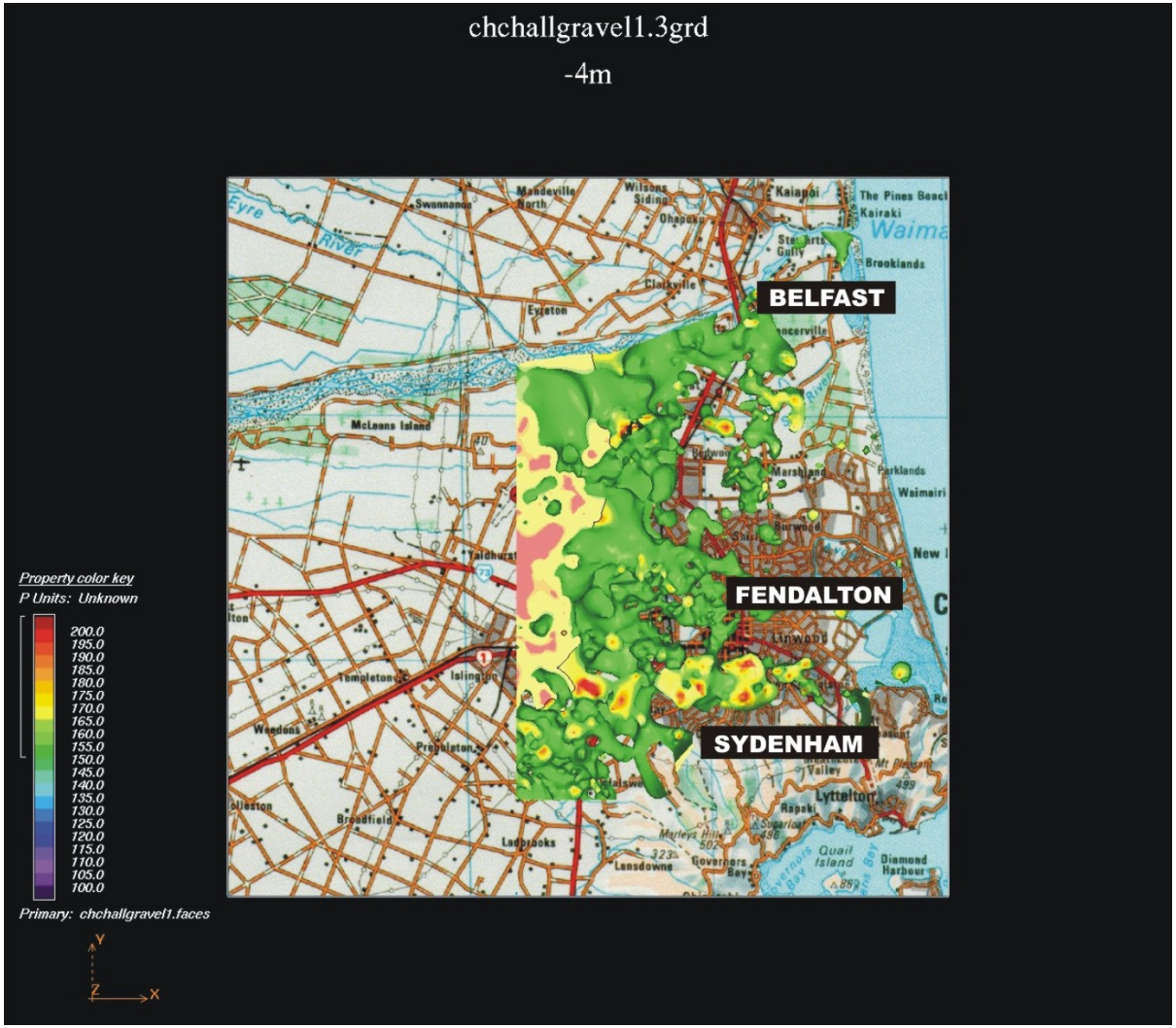


Figure 48. View of 3D model of gravel in the Christchurch City area indicating gravel lobes in the Belfast, Fendalton and Sydenham areas (White, 2007).

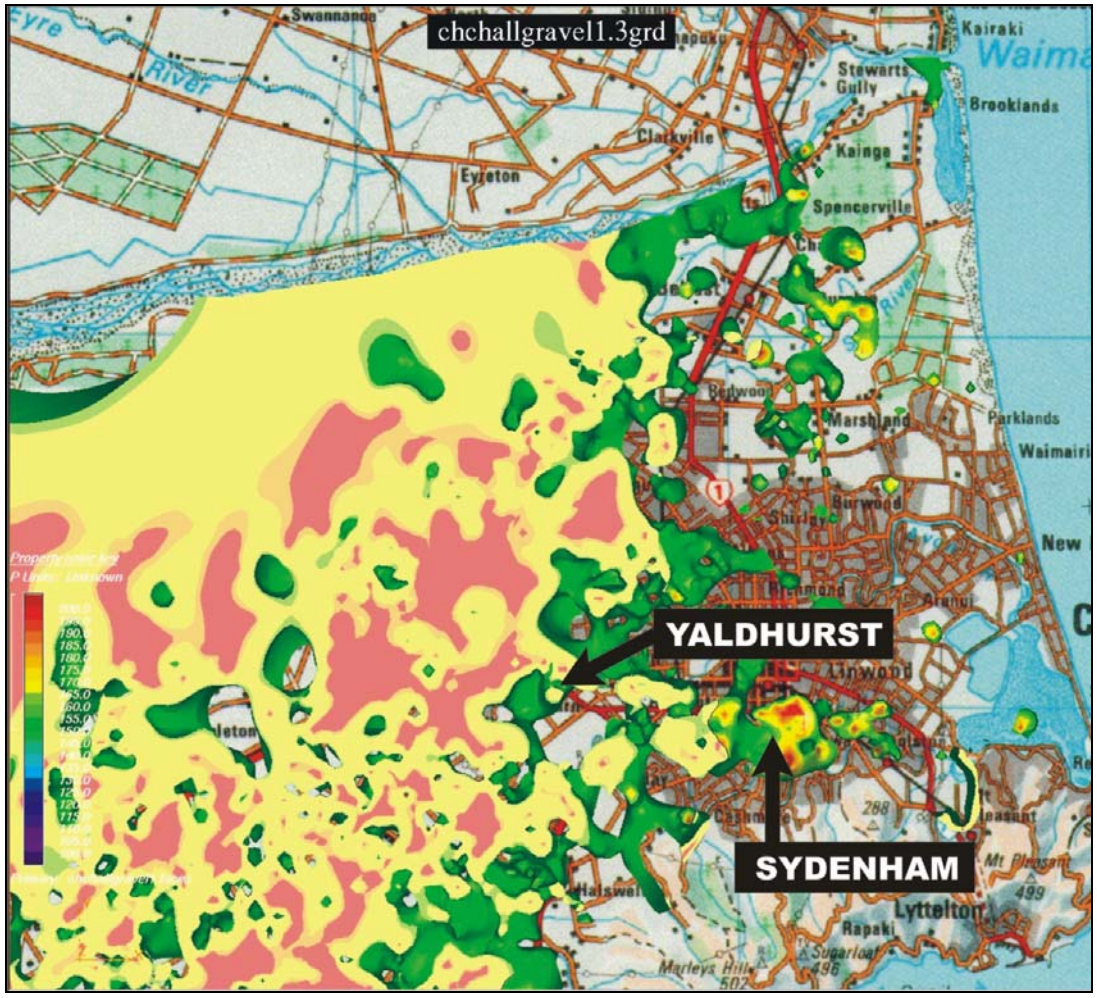


Figure 49. Interpretation of extents of gravel lobes in the Sydenham area from the 3D model (White, 2007).

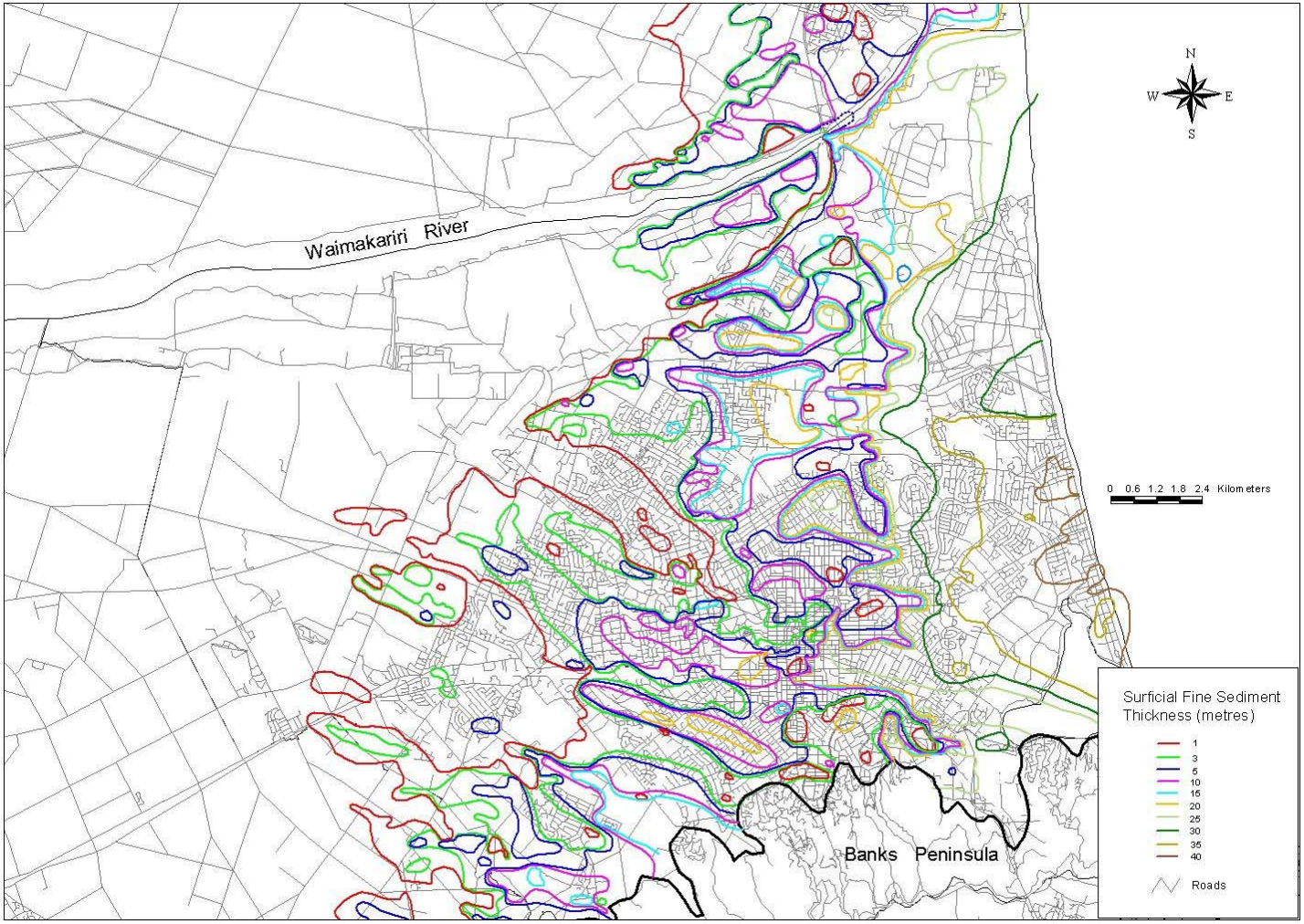


Figure 50. Thickness of fine sediments.

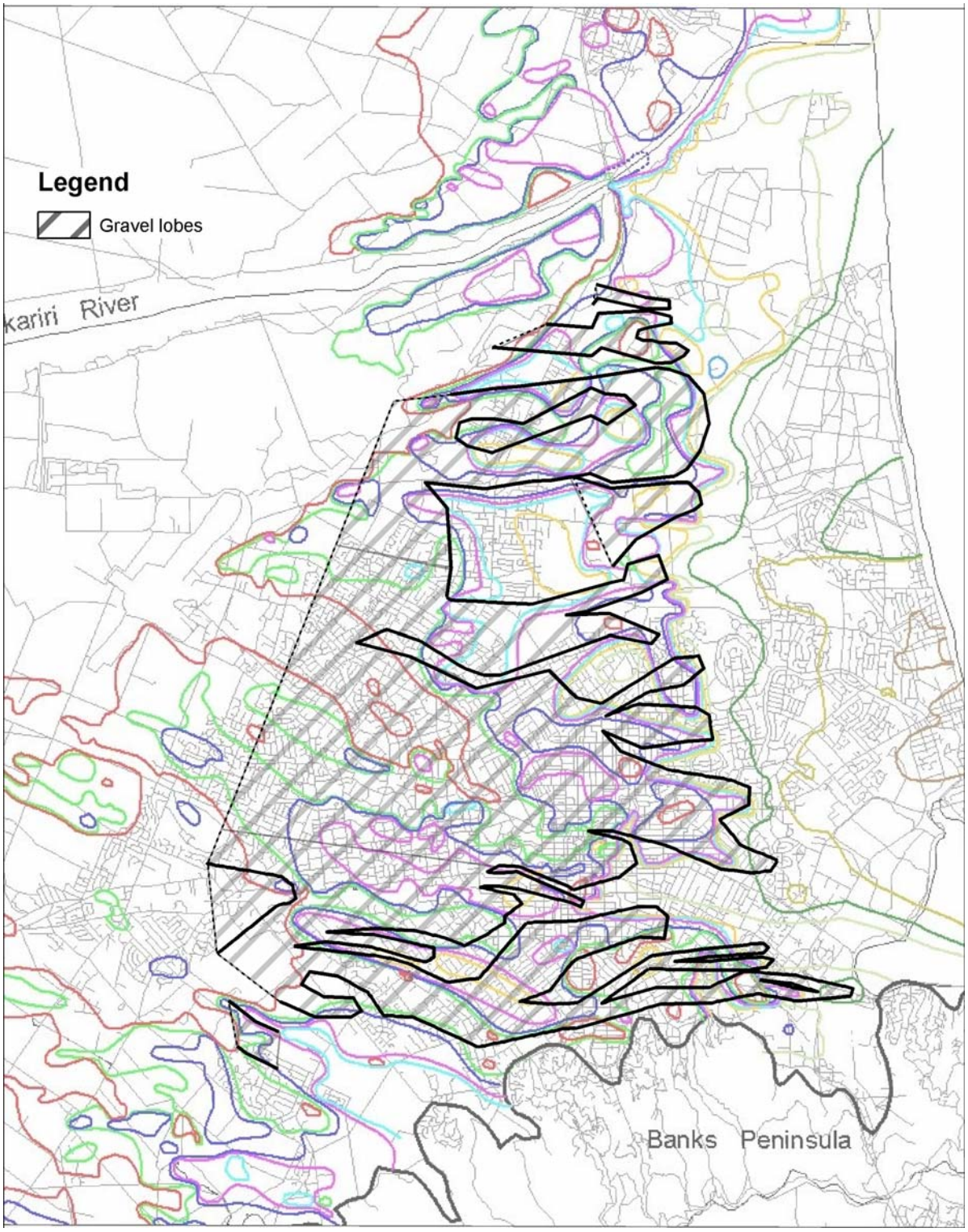


Figure 51. Thickness of fine sediments and location of unconnected gravel lobes.

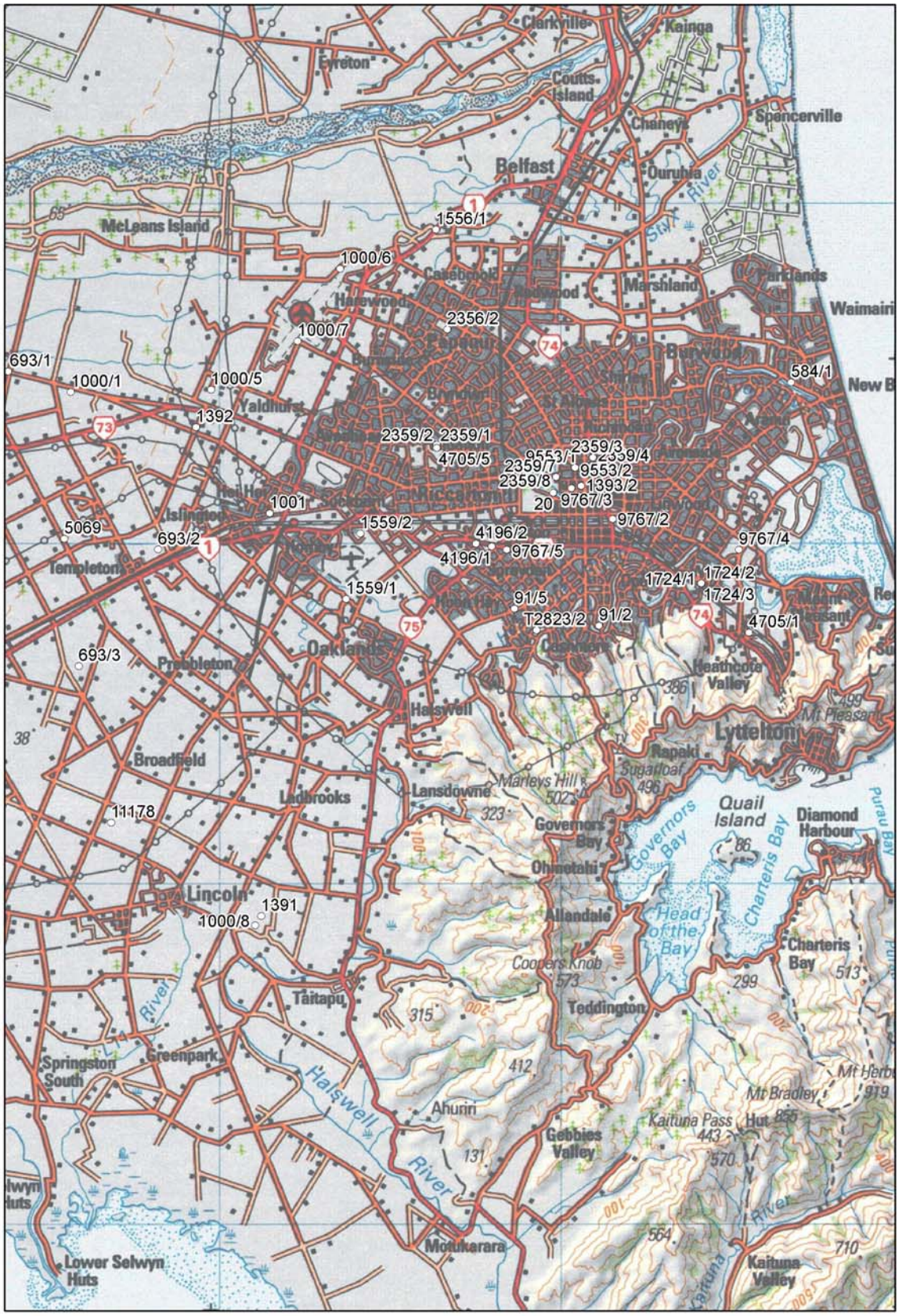


Figure 52. Radiocarbon analyses of shallow sediments; location and sample number.

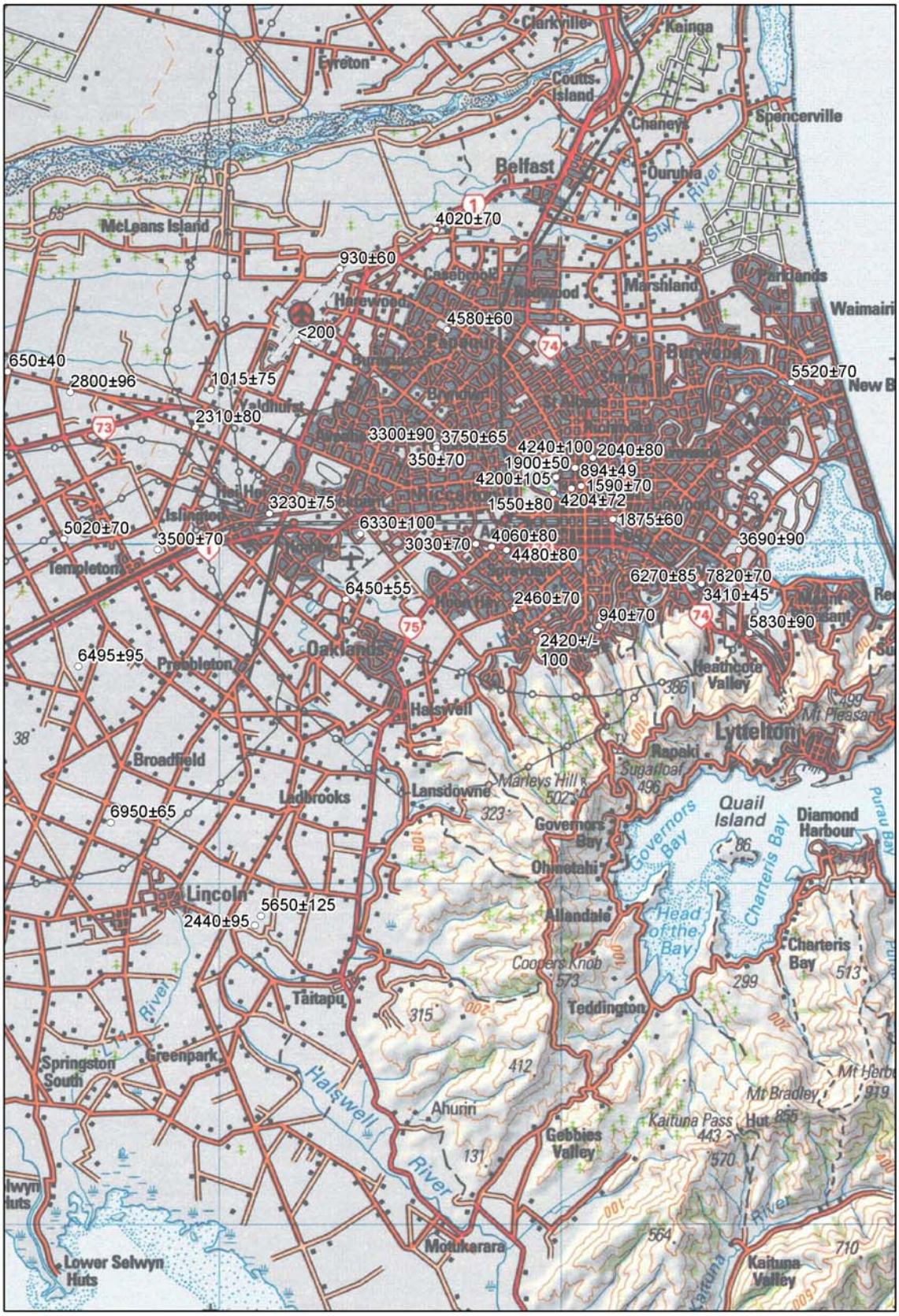


Figure 53. Radiocarbon analysis of shallow sediments: radiocarbon age and error in radiocarbon age.

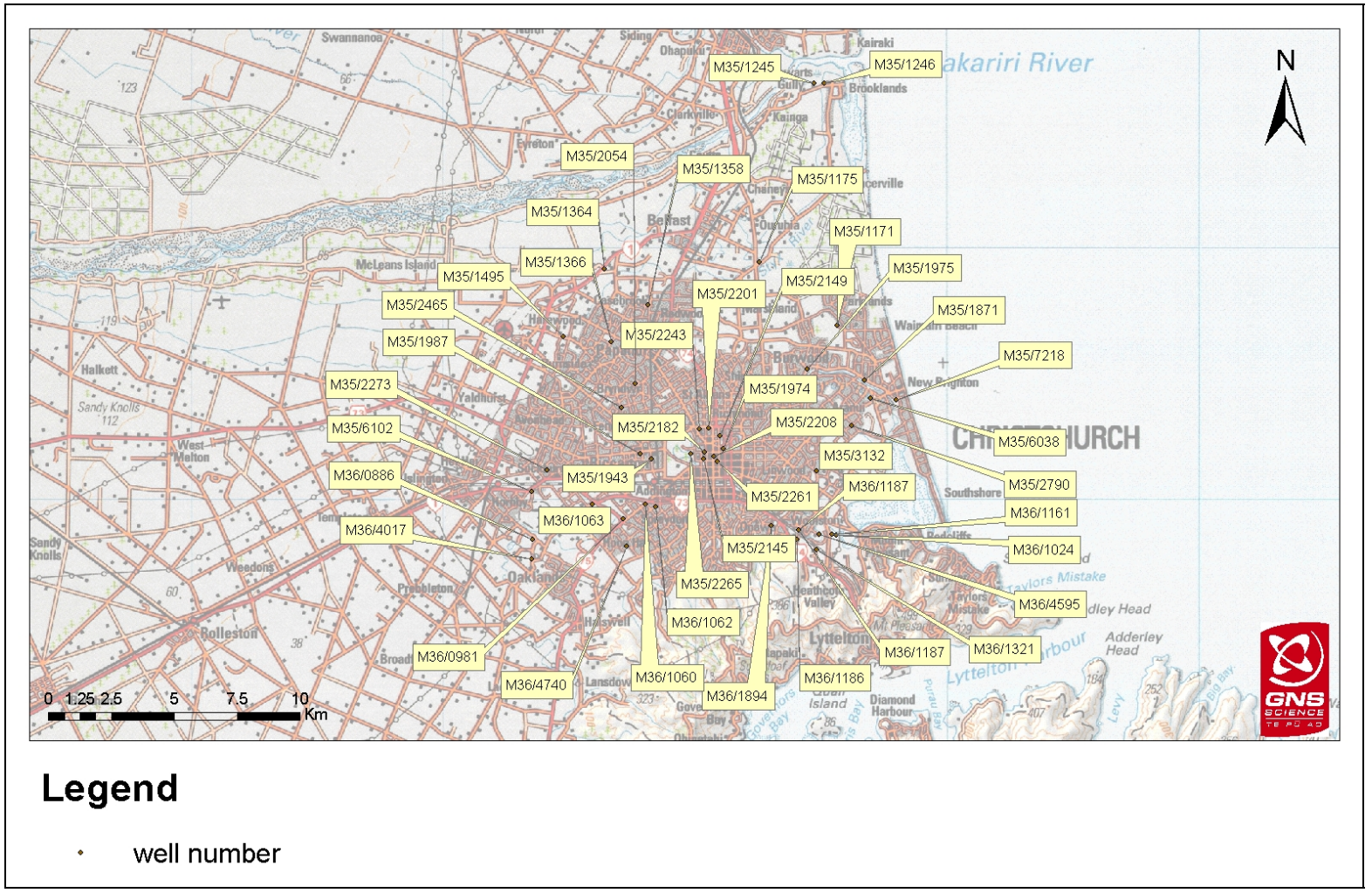


Figure 54. Wells in Christchurch City with radiocarbon analyses of sediments held in the Environment Canterbury database.

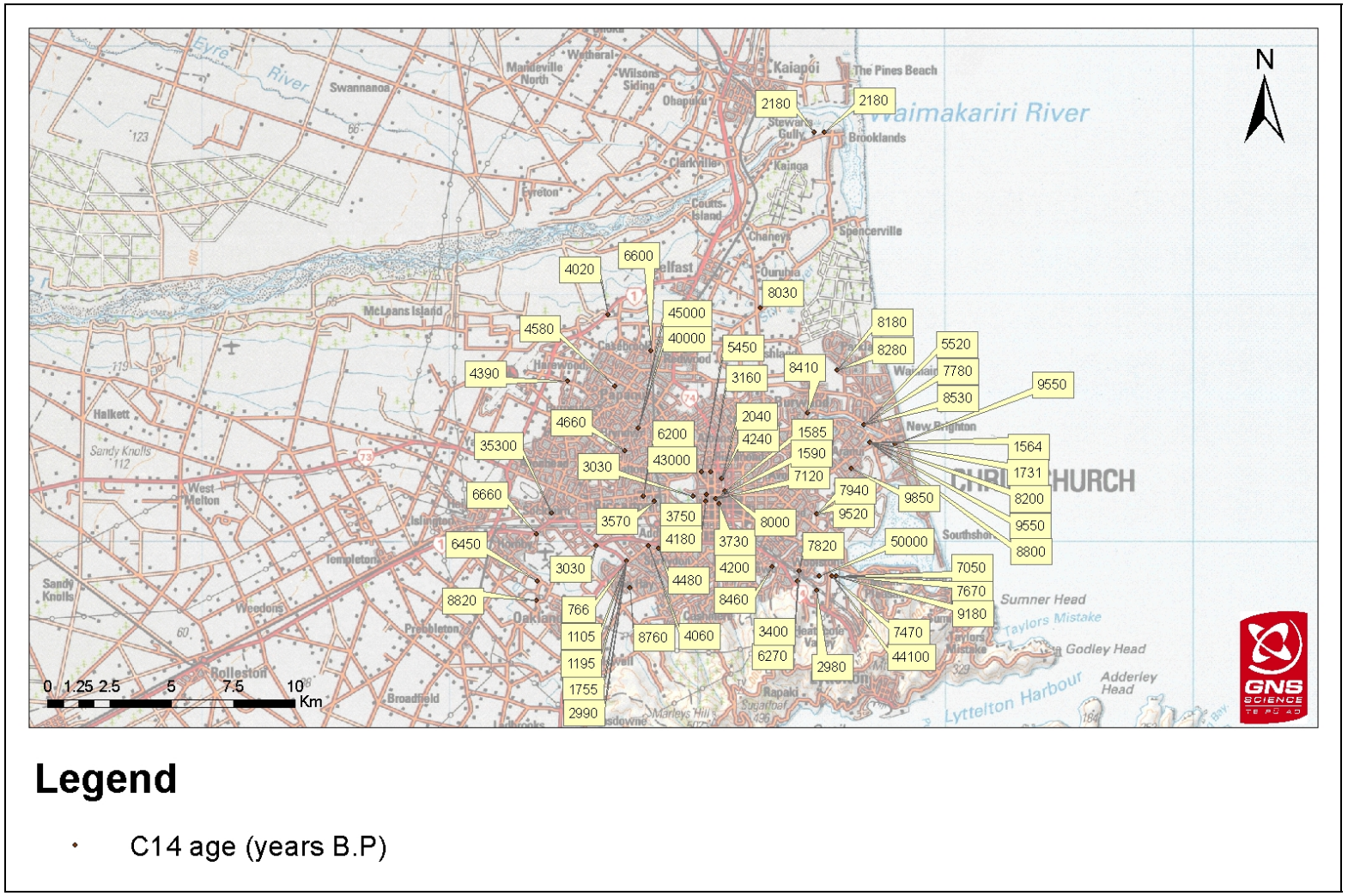
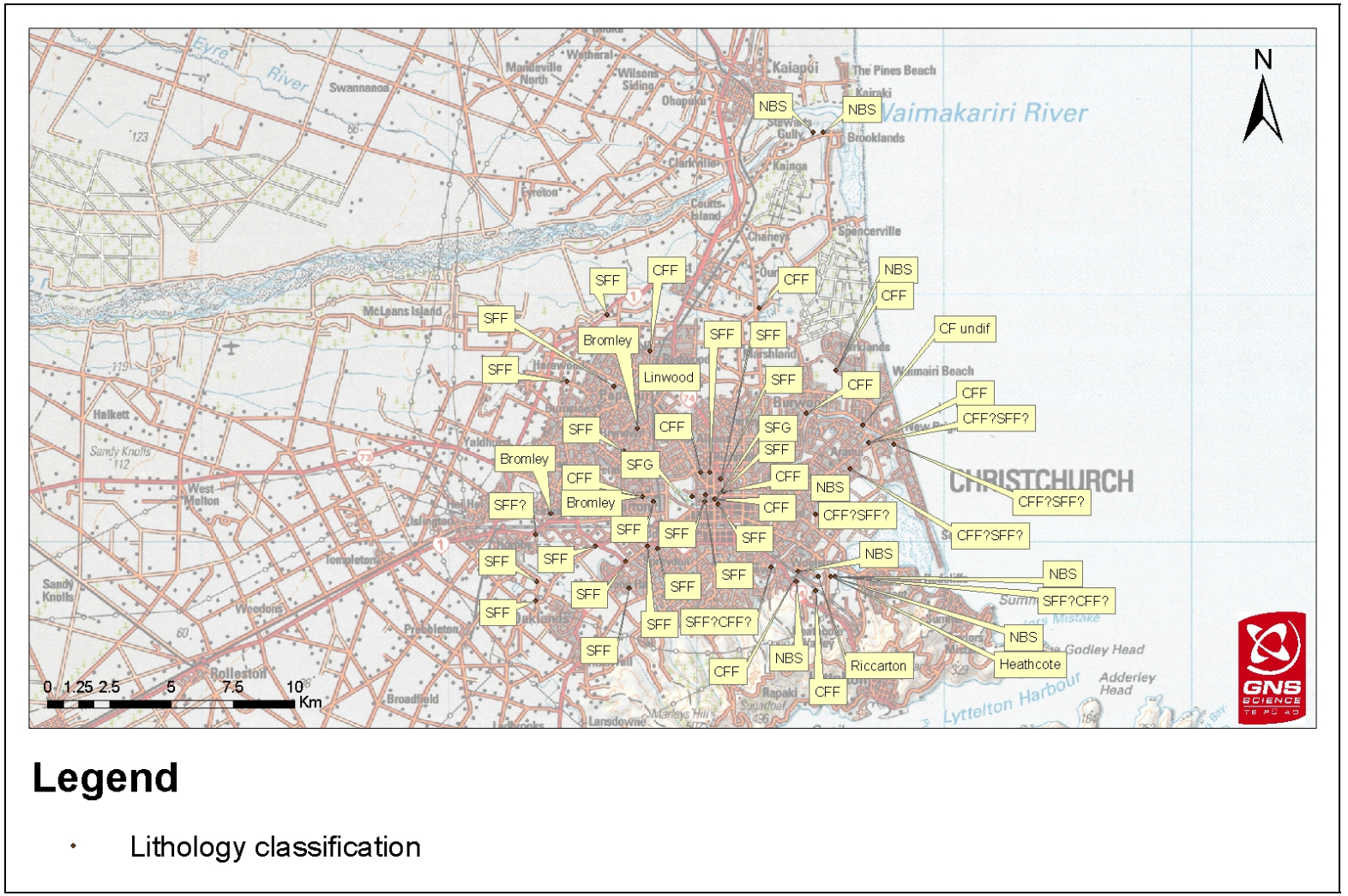


Figure 55. Ages of sediments in Christchurch City from radiocarbon analyses held in the Environment Canterbury database.



Legend

- Lithology classification

Figure 56. Formation classification of Christchurch City sediment radiocarbon analyses.

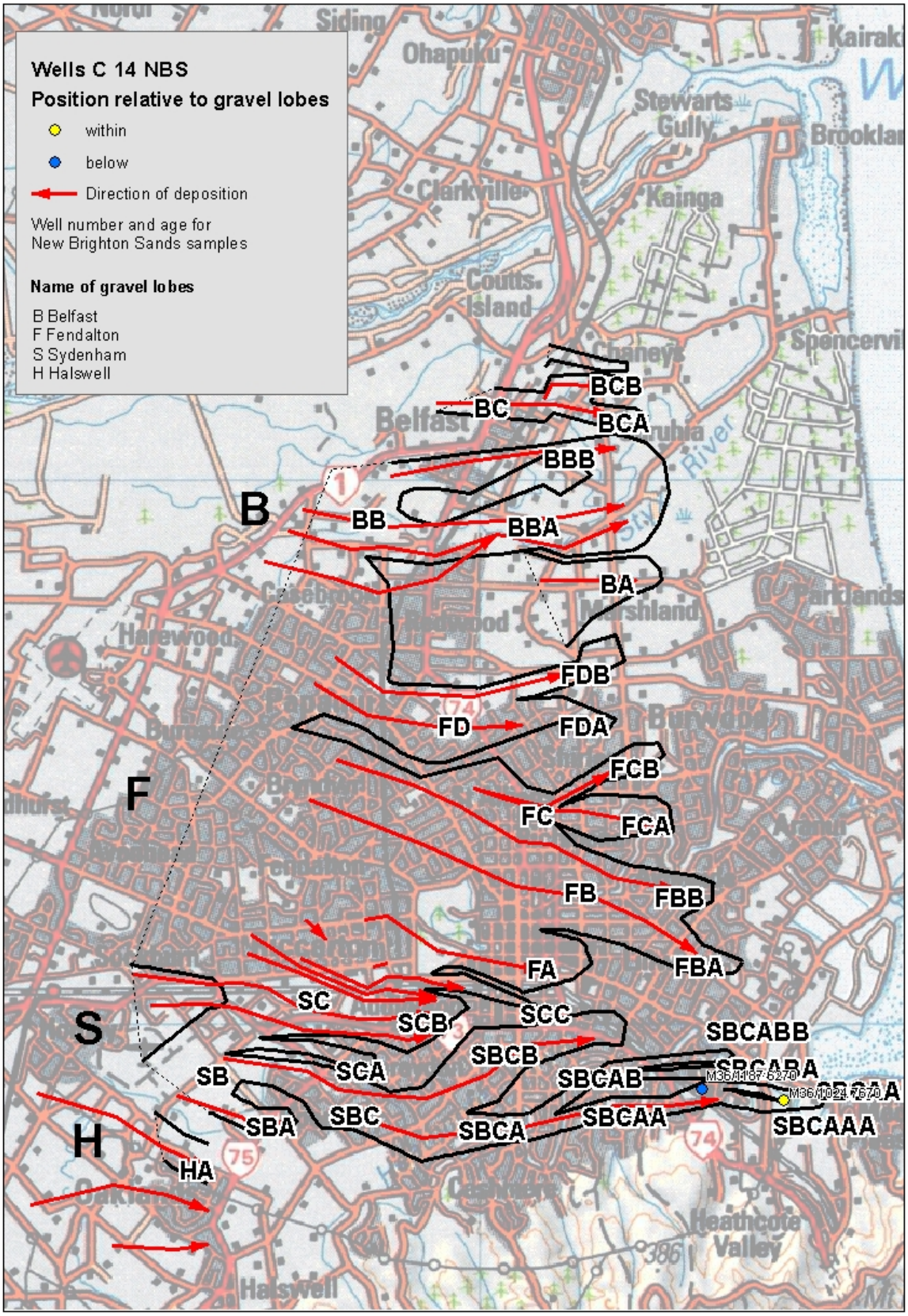


Figure 57. Location of wells with radiocarbon dates of New Brighton Sands. Wells are within the geographic boundaries of proposed gravel lobes.

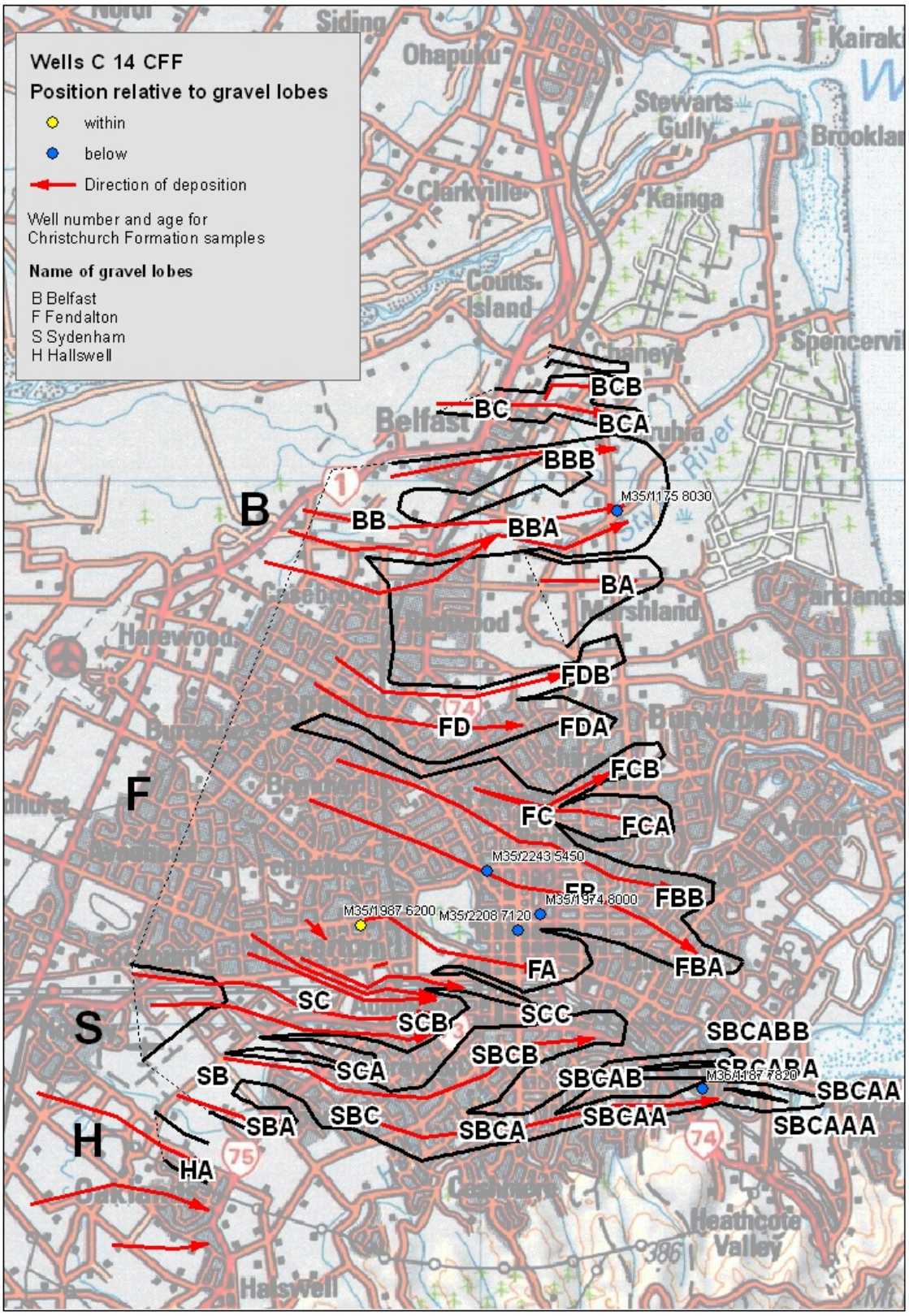


Figure 58. Location of wells with radiocarbon dates of Christchurch Formation fine sediments within the geographic boundaries of proposed gravel lobes.

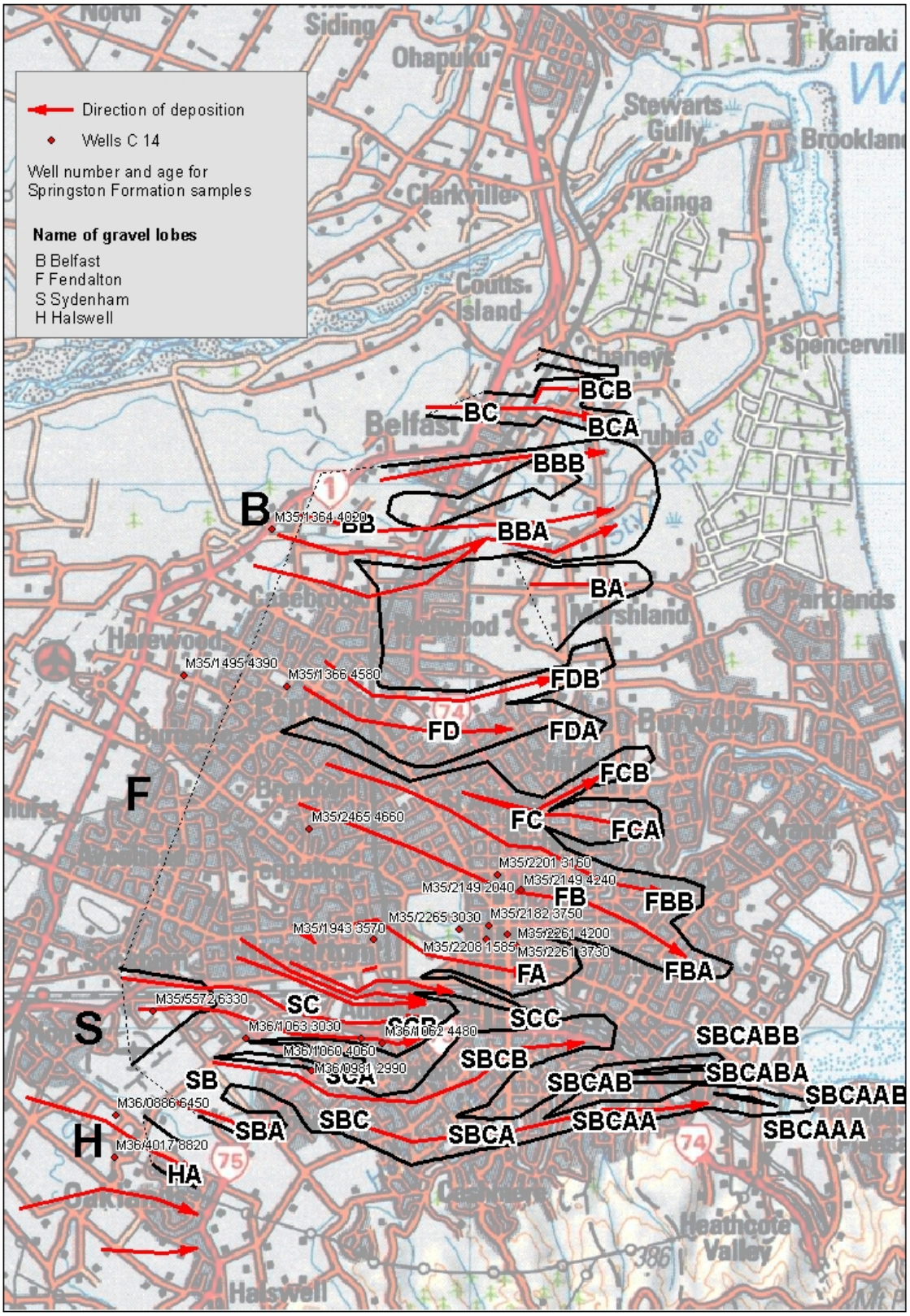


Figure 59. Location of wells with radiocarbon dates of Springston Formation sediments (SFF and SFG lithology codes).

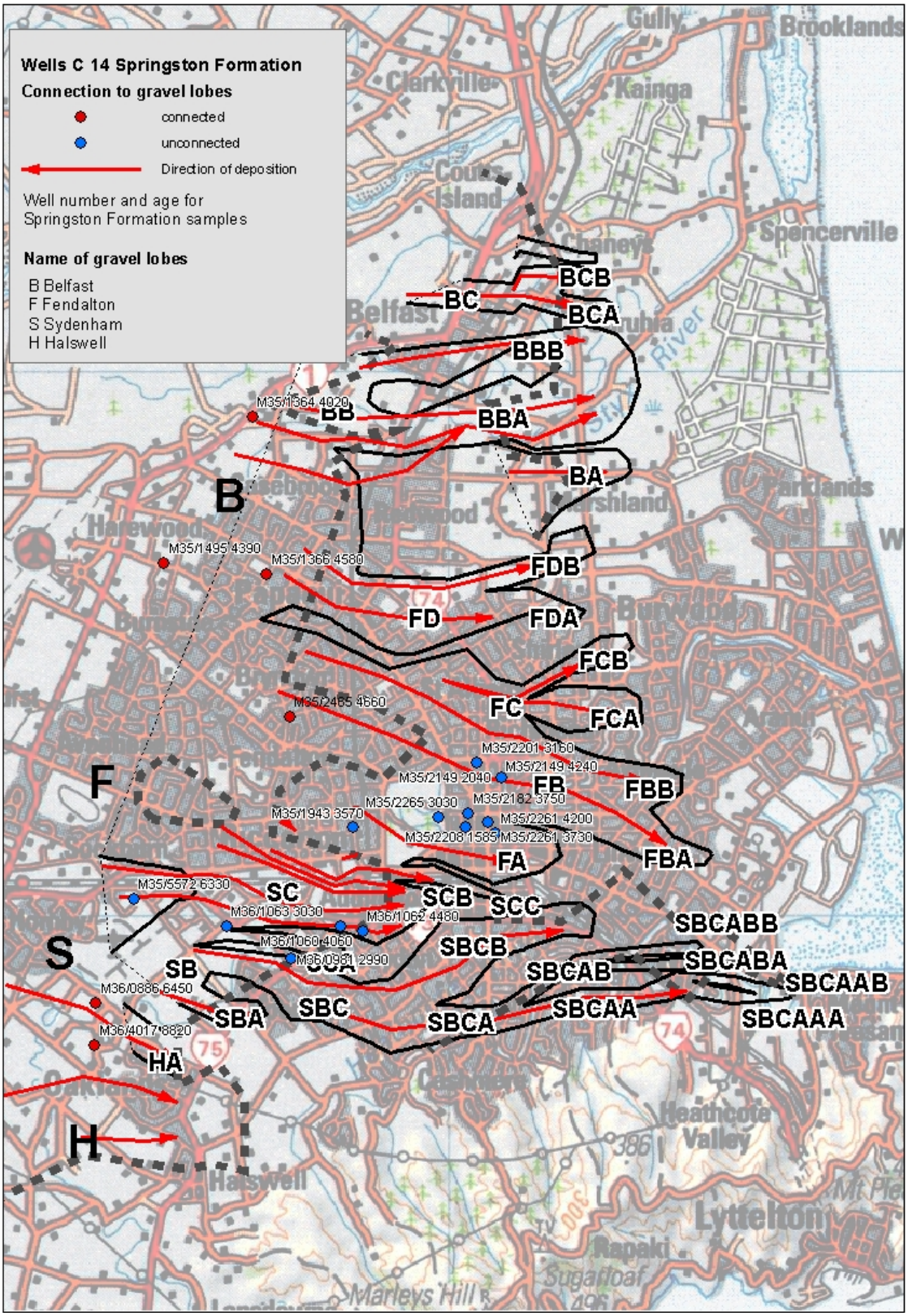


Figure 60. Radiocarbon ages of Springston Formation sediments (SFF and SFG lithology codes) in connected gravels and unconnected gravels.

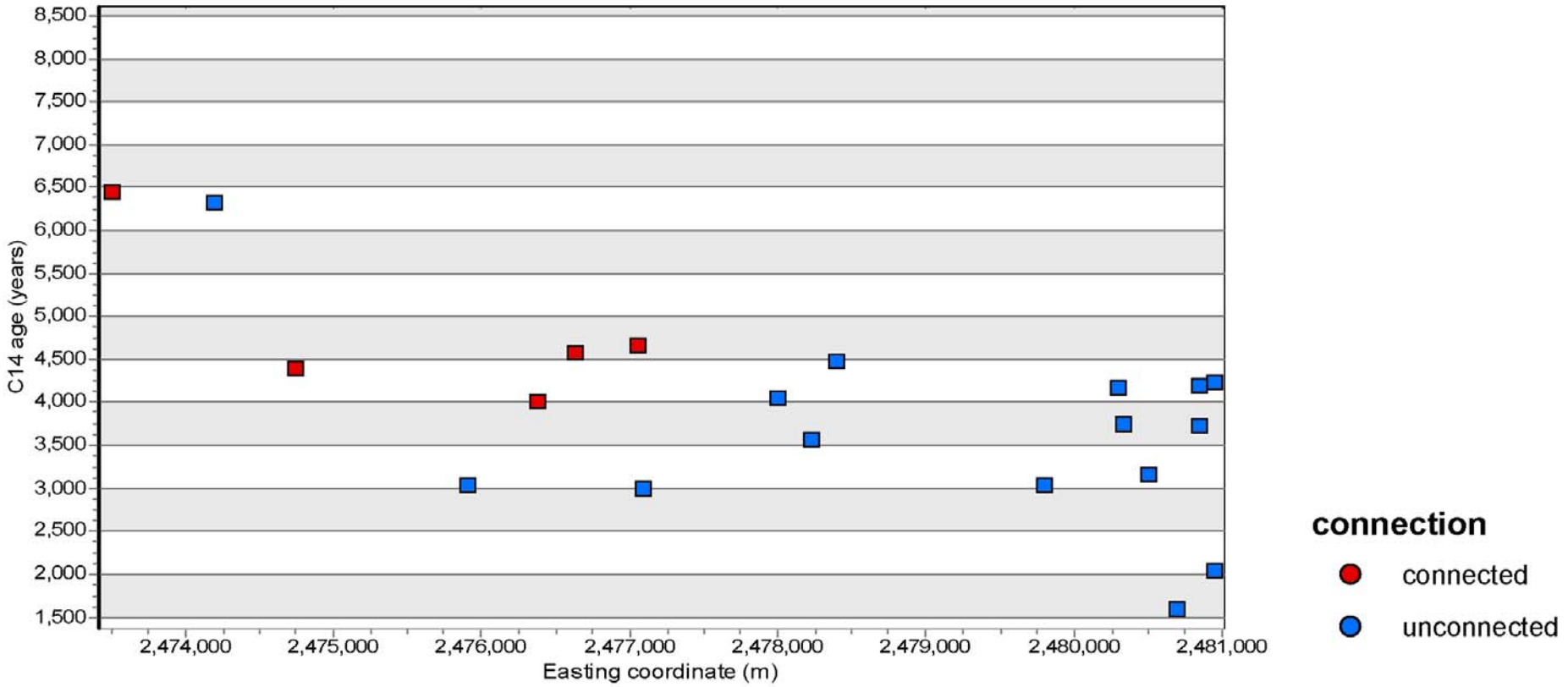


Figure 61. Radiocarbon ages of Springston Formation sediments by easting coordinate for connected and unconnected gravels. West Christchurch is towards the left of this figure.

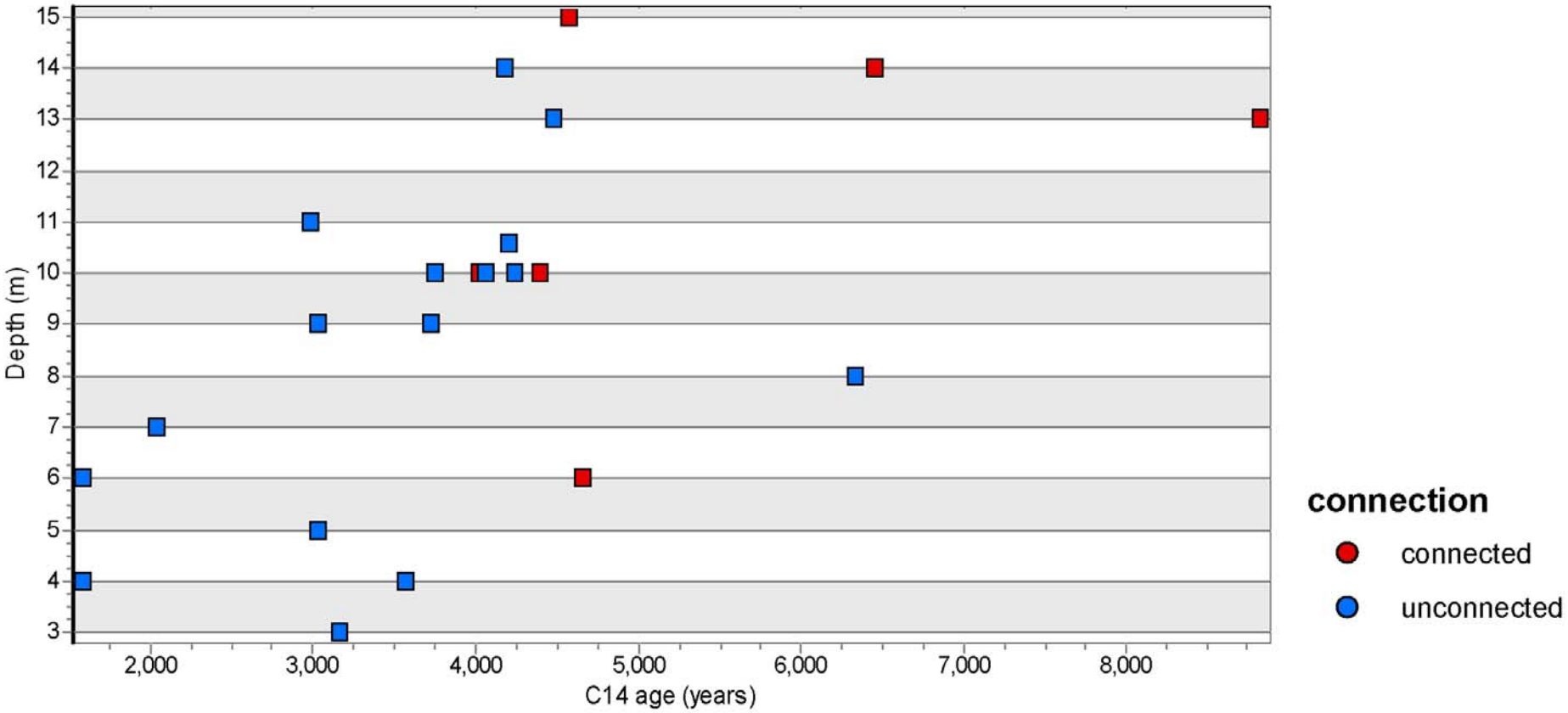


Figure 62. Radiocarbon ages of Springston Formation sediments and sample depth.

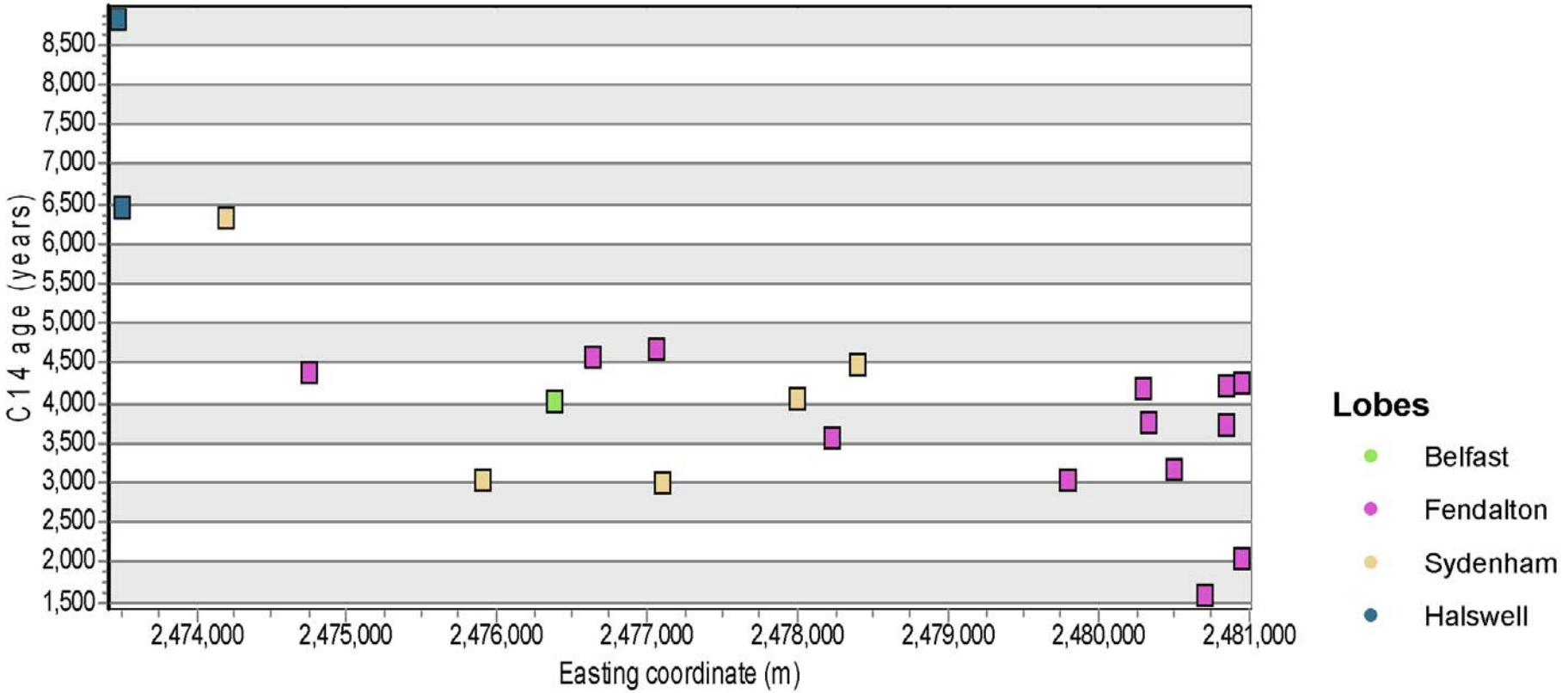


Figure 63. Radiocarbon ages of Springston Formation sediments by easting coordinate and by gravel lobe.

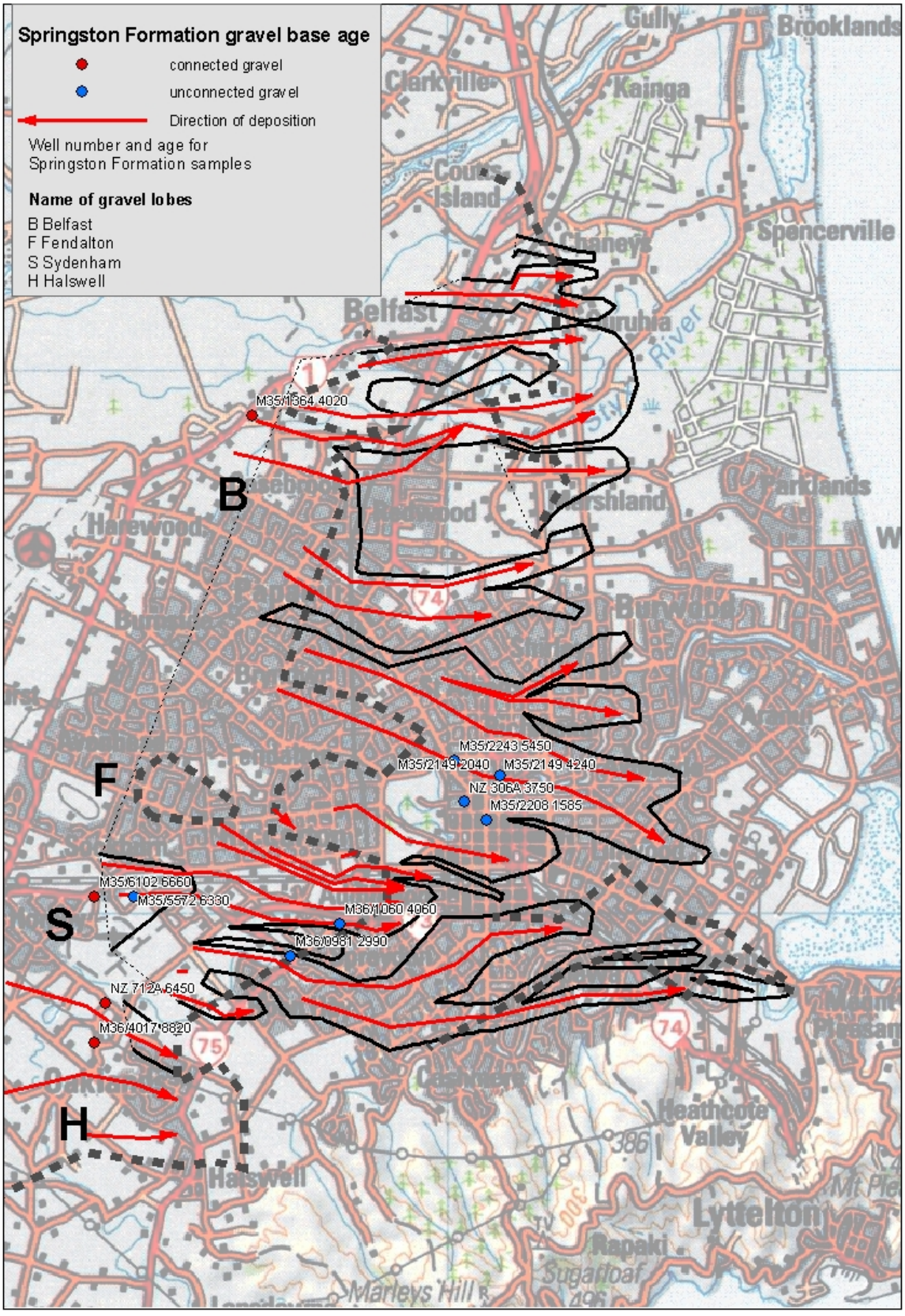


Figure 64. Estimates of the age of the base of Springston Formation gravels.

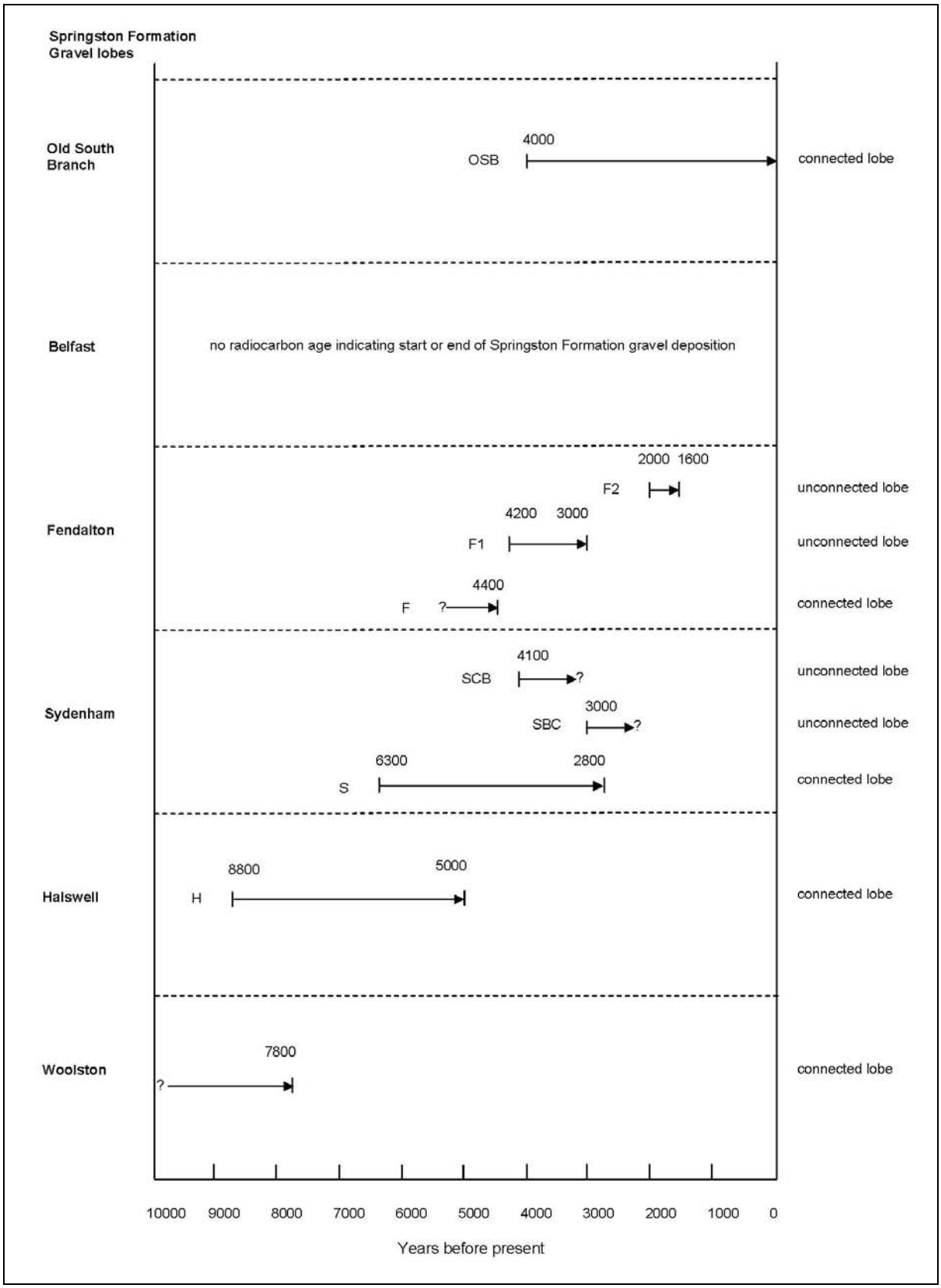


Figure 65 Schematic of Springston Formation gravel deposition in Christchurch City. The start and end of gravel deposition is indicated.

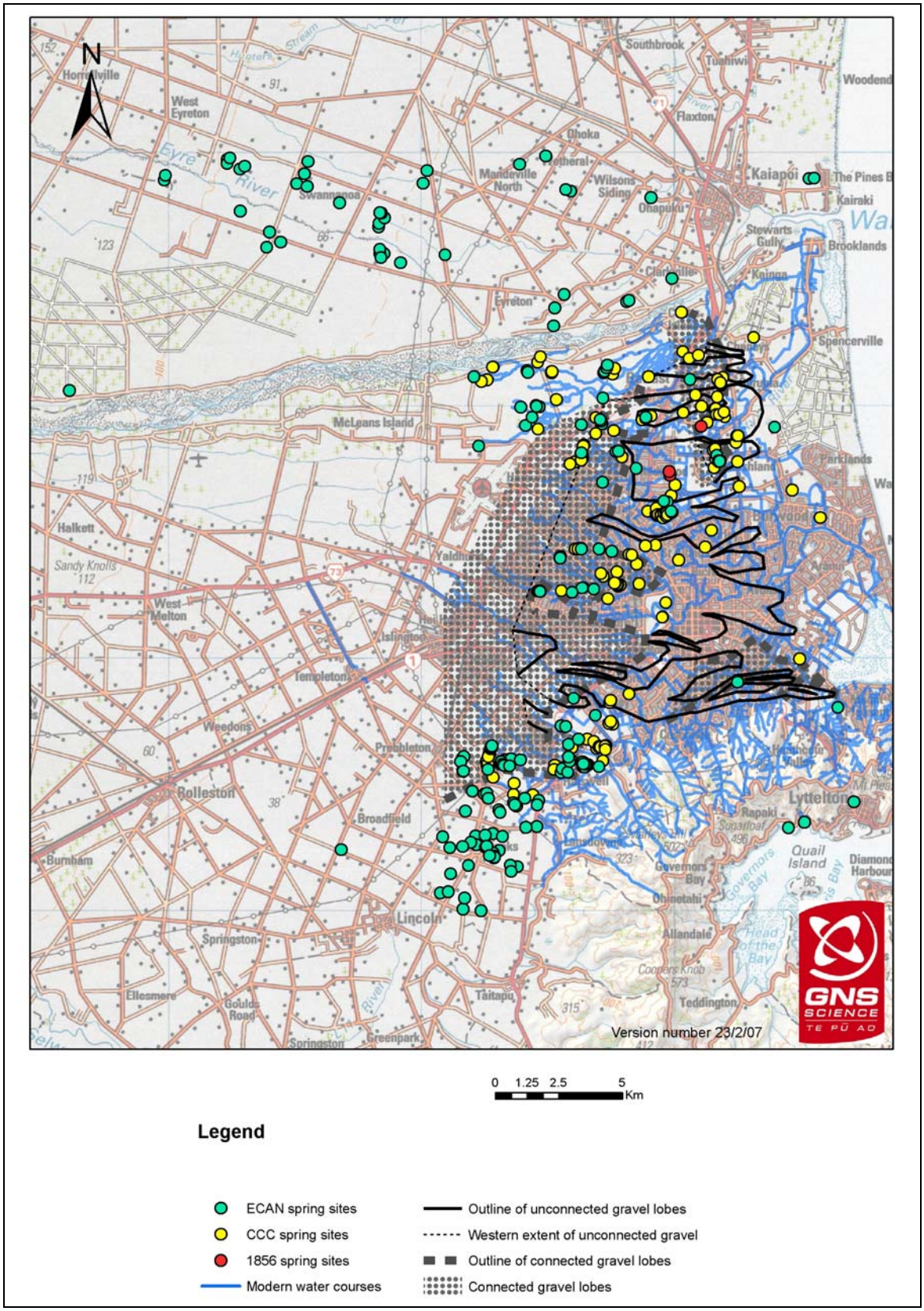


Figure 66. Location of: springs (White et al. 2007), modern water courses, unconnected gravel lobes and connected gravel lobes.

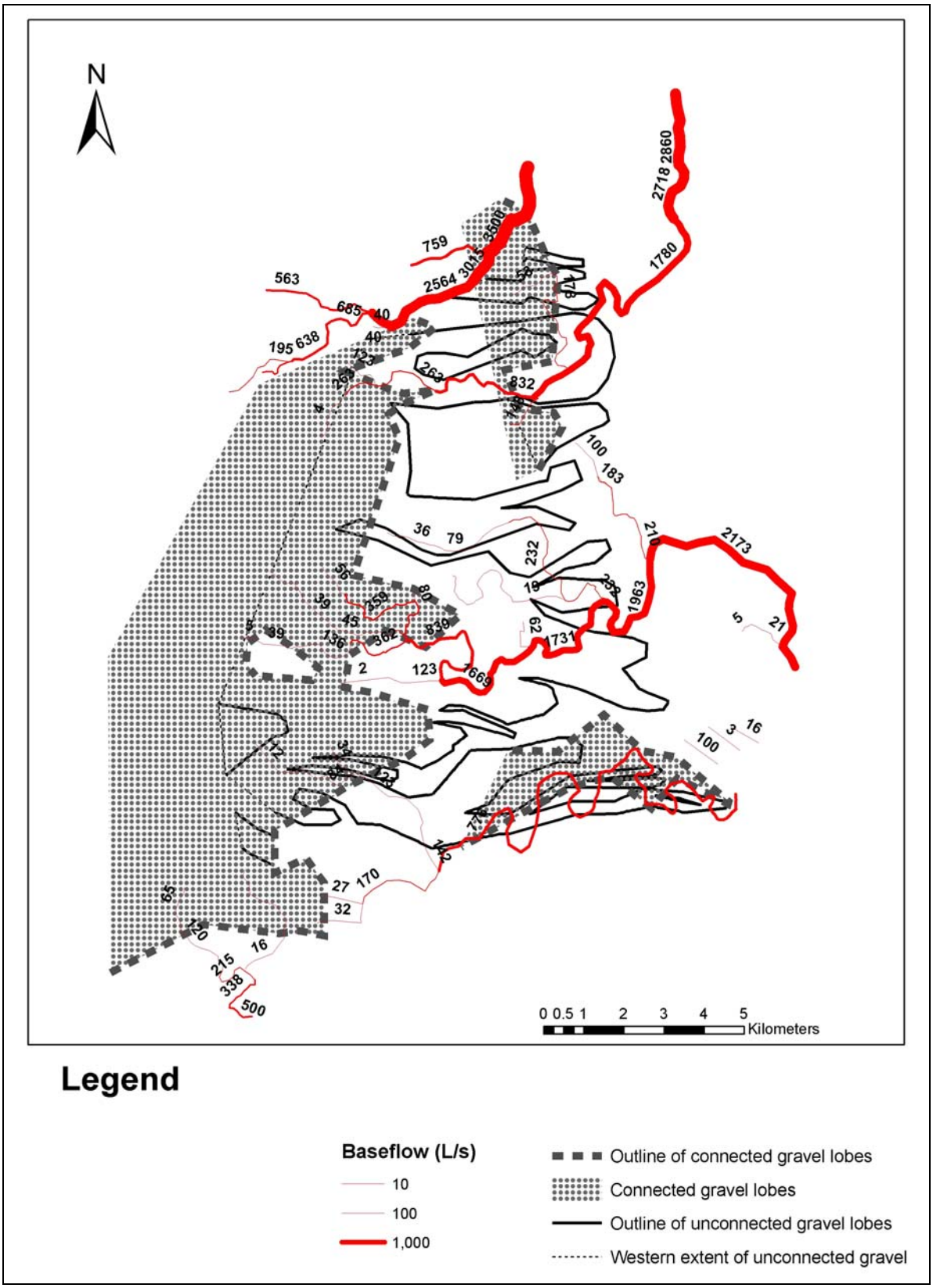


Figure 67. Baseflow discharge from Christchurch streams (White et al. 2007), location of unconnected gravel lobes and location of connected gravel lobes.

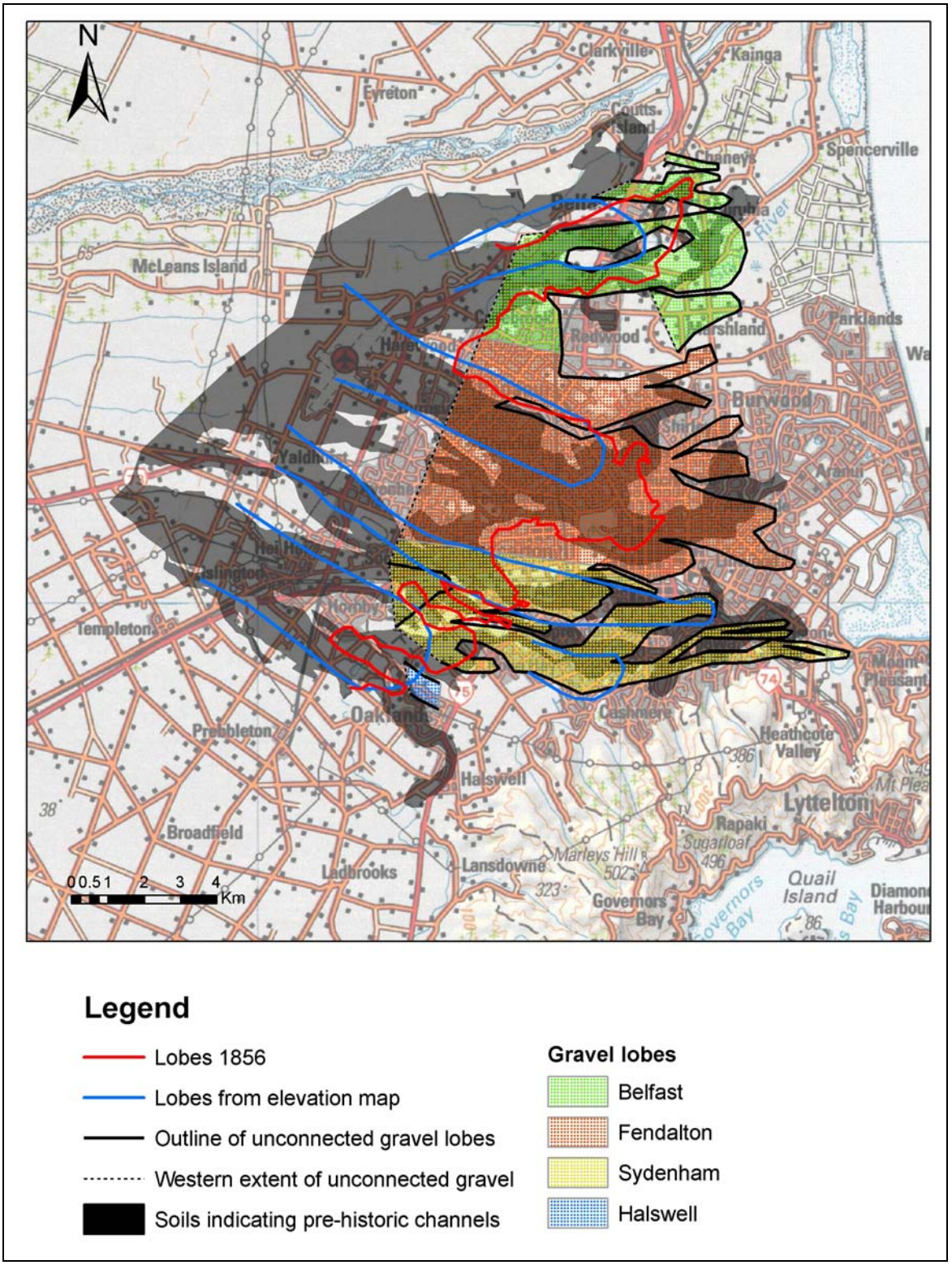


Figure 68. Unconnected gravel lobes and surface features indicating pre-historic channels: lobes from the 1856 map, proposed lobes from the elevation map and soils.

APPENDICES

APPENDIX 1 - GEOLOGICAL LOGS IN SOUTHERN CHRISTCHURCH CITY

Two conventions are used to plot the location of sections:

- S1 – E1 etc (Figure 33) being the start and end points of log selection zones for cross sections;
- S720 etc (Figure 44) being the location of wells at the ends of each section.

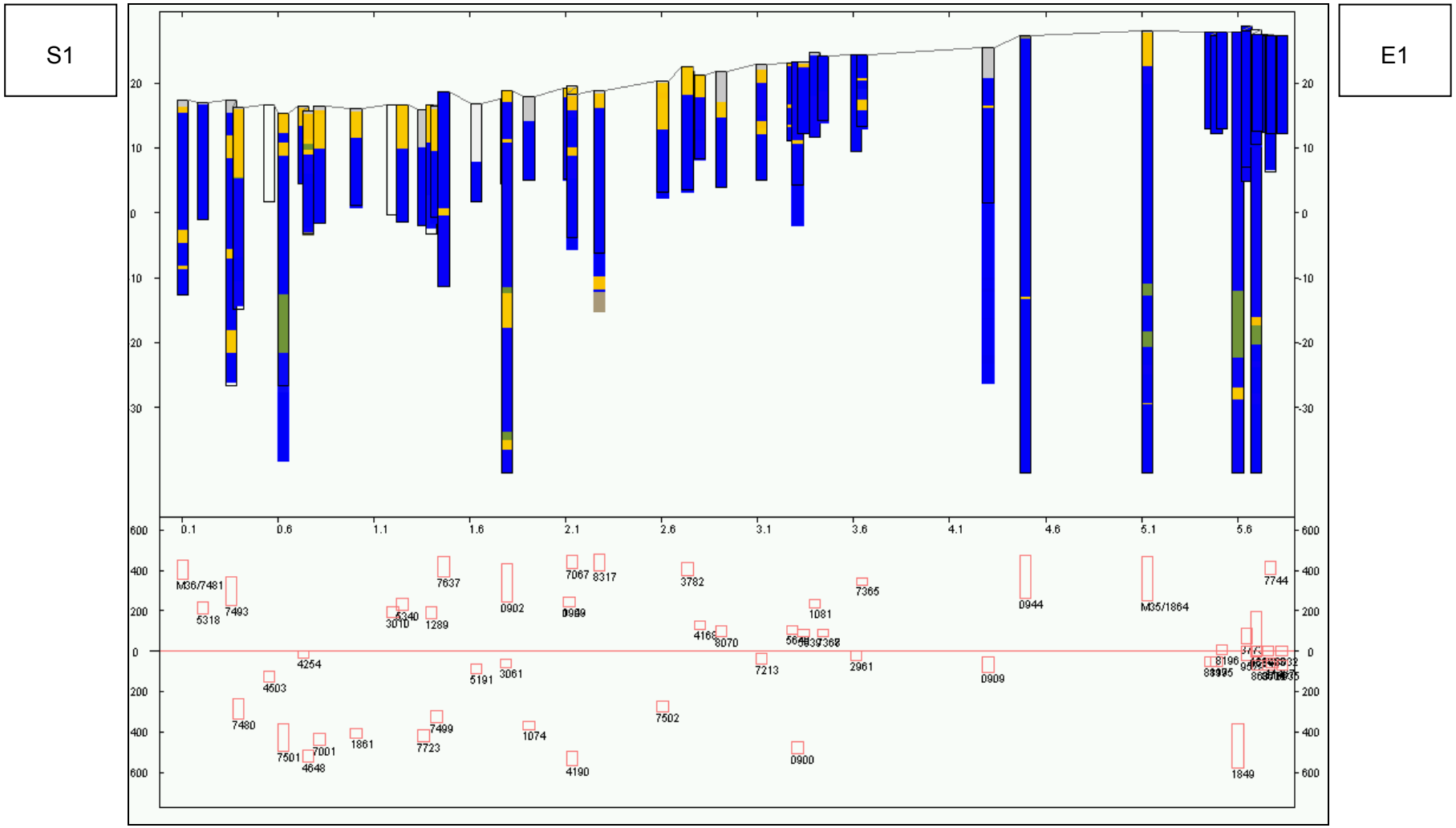


Figure A1.1. Cross section s720.

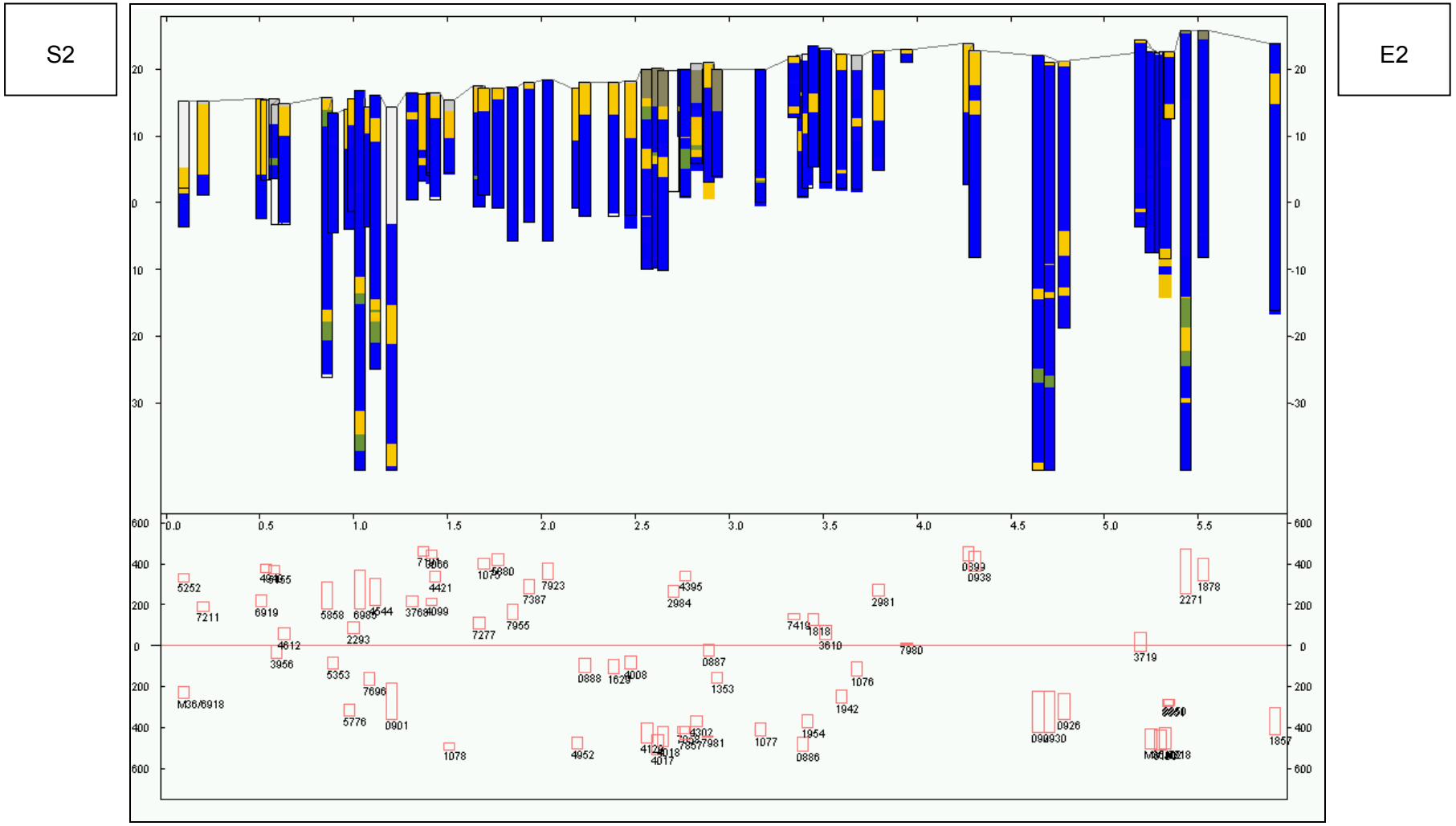


Figure A1.2. Cross section s730.

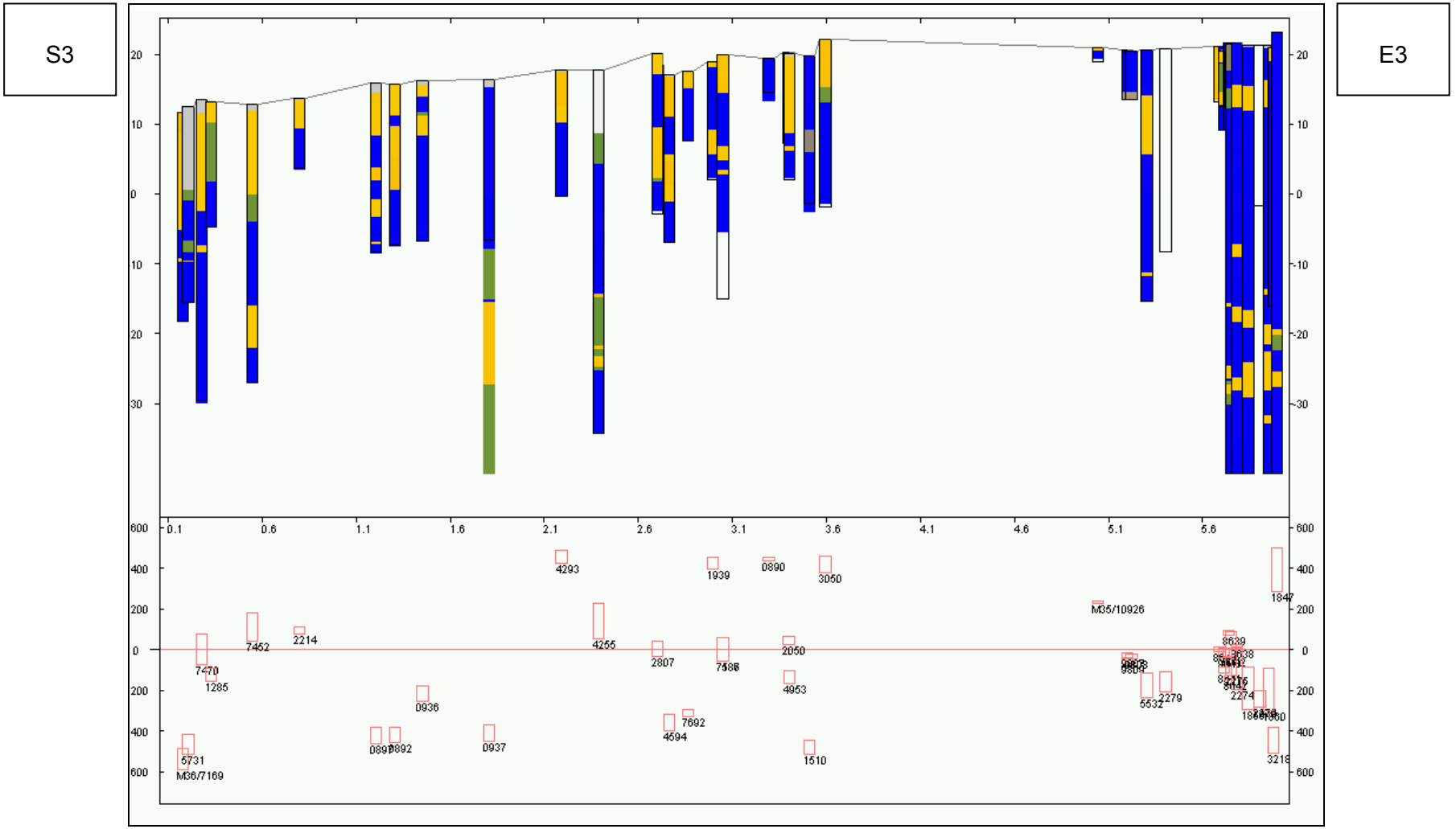


Figure A1.3. Cross section s740.

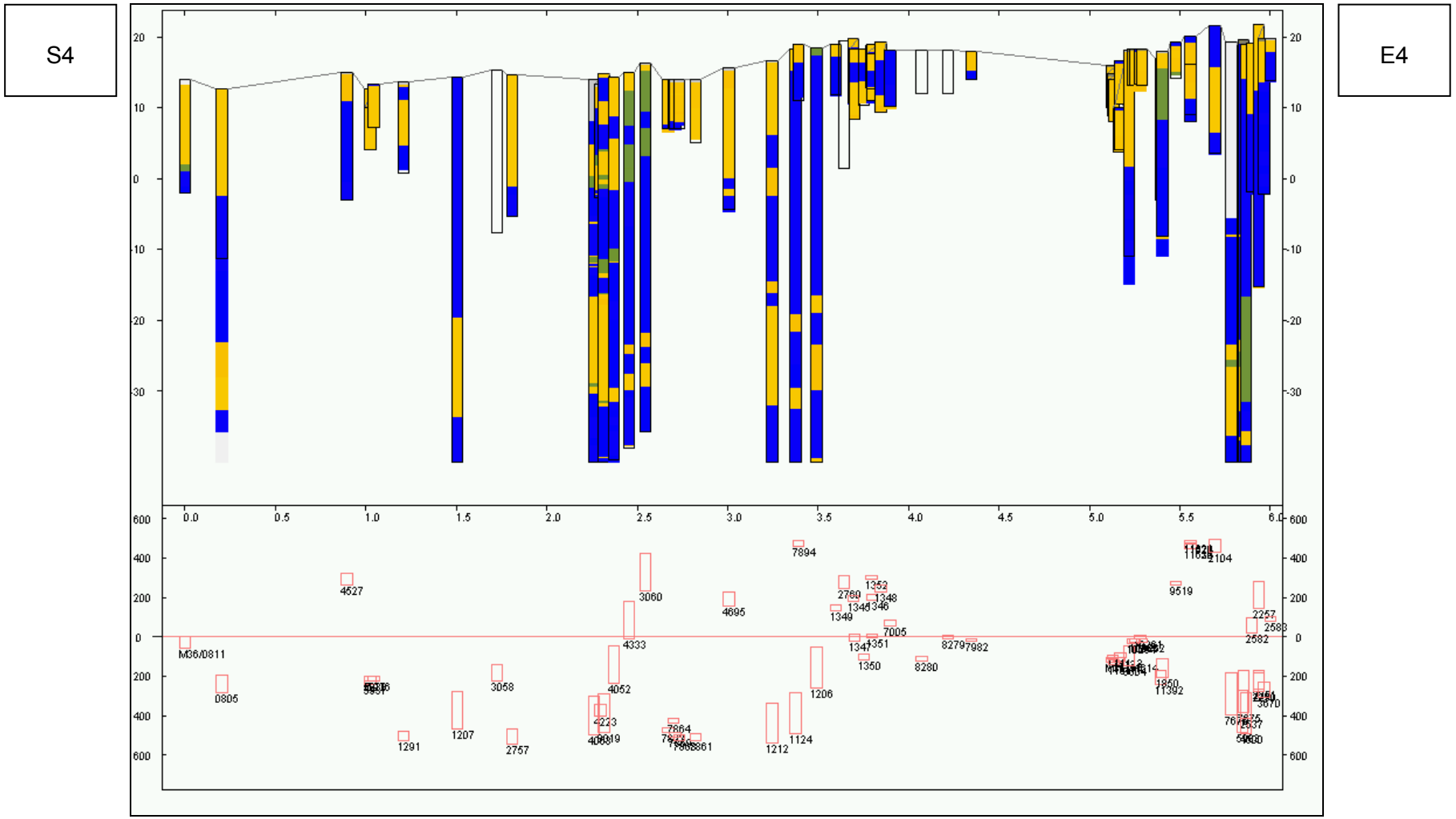


Figure A1.4. Cross section s750.

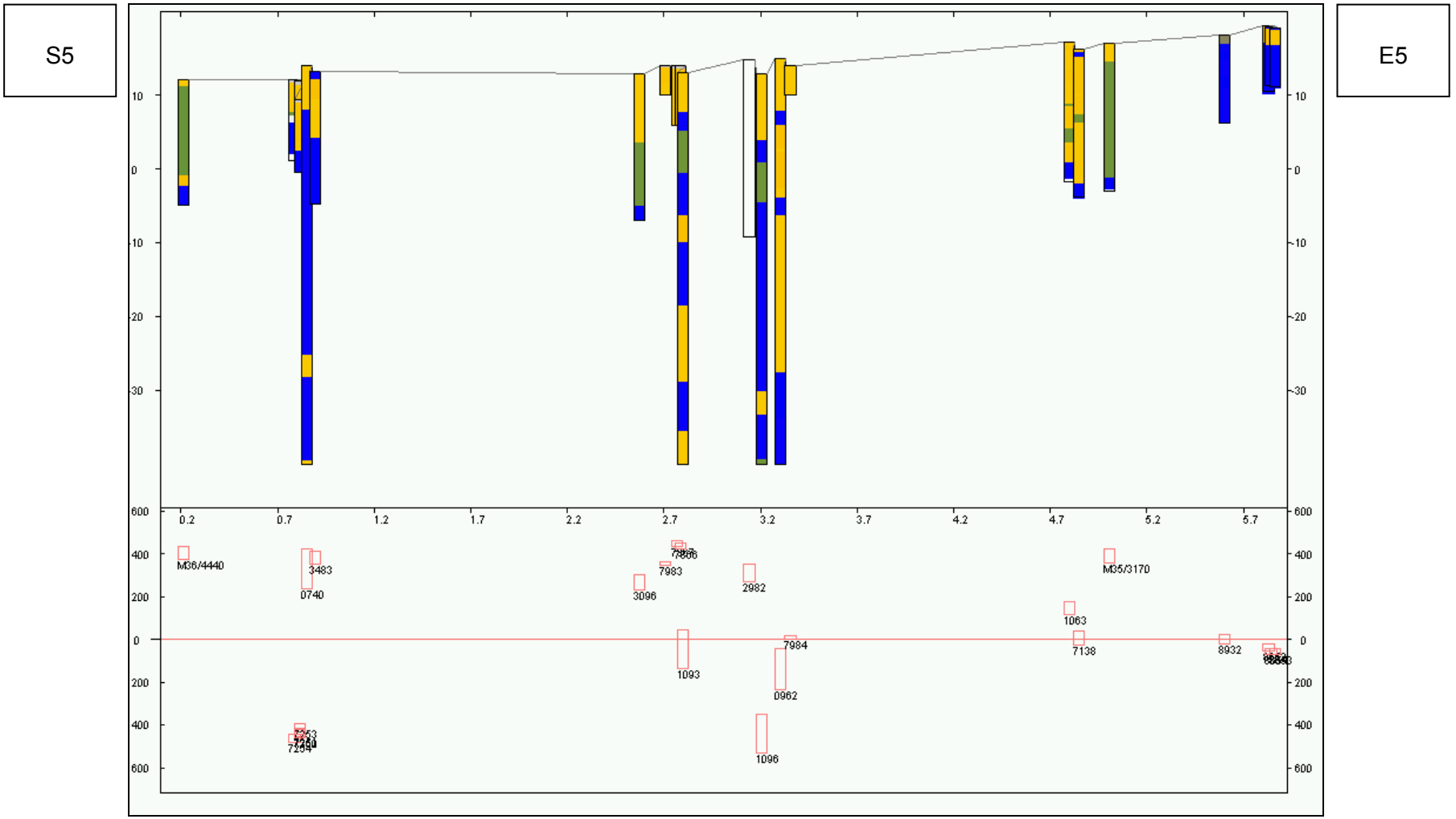


Figure A1.5. Cross section s760.

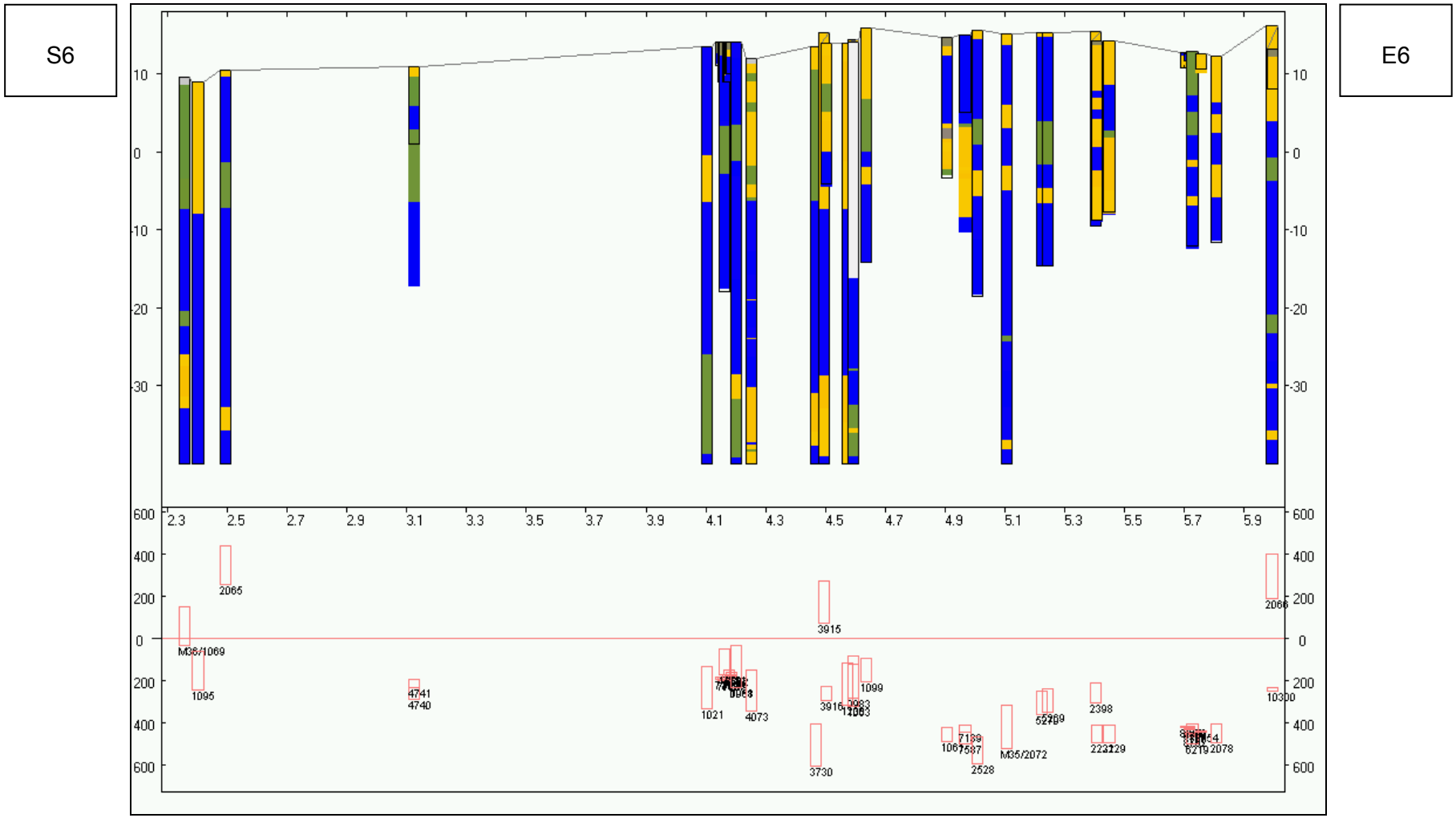


Figure A1.6. Cross section s770.

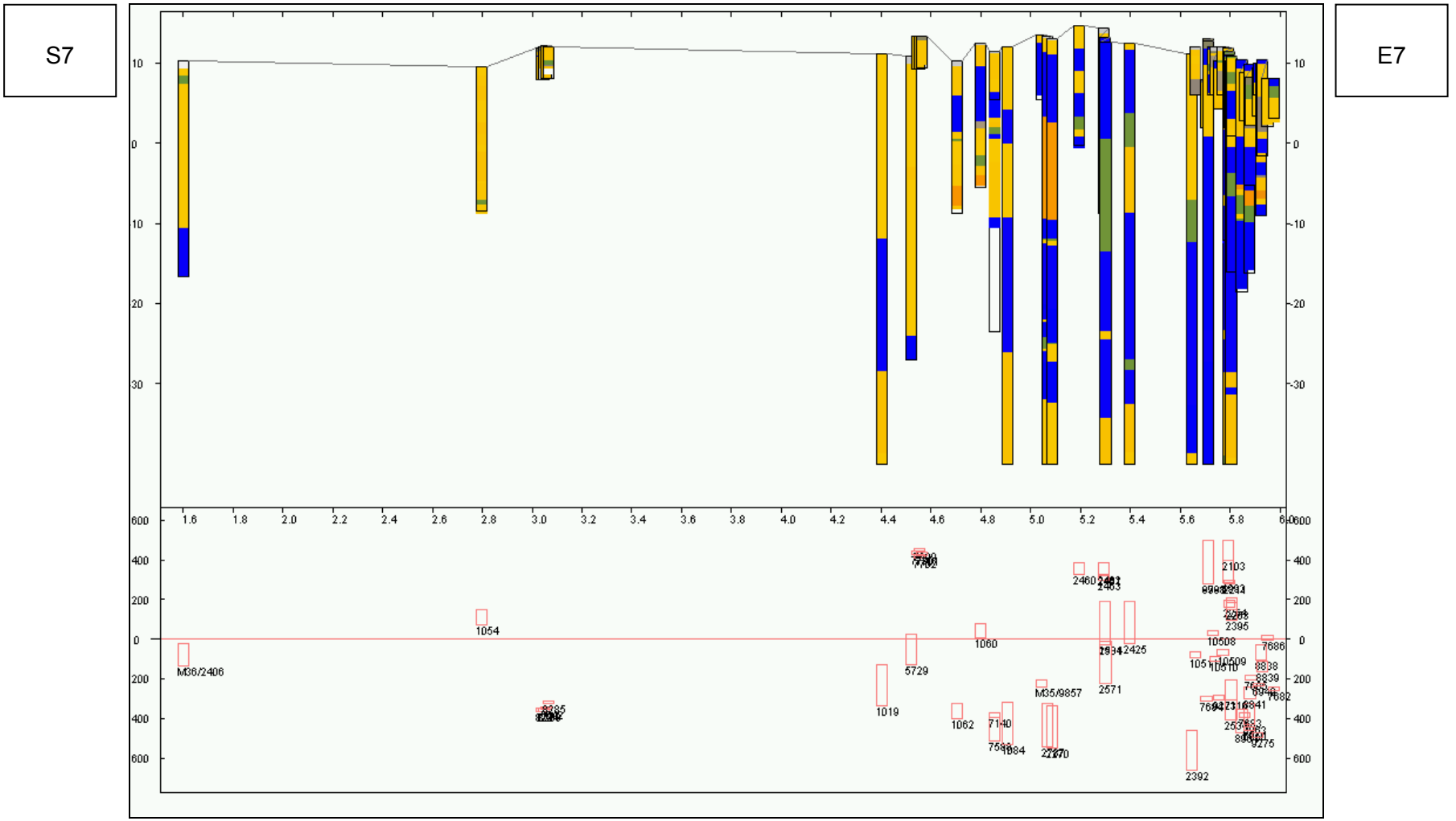


Figure A1.7. Cross section s780.

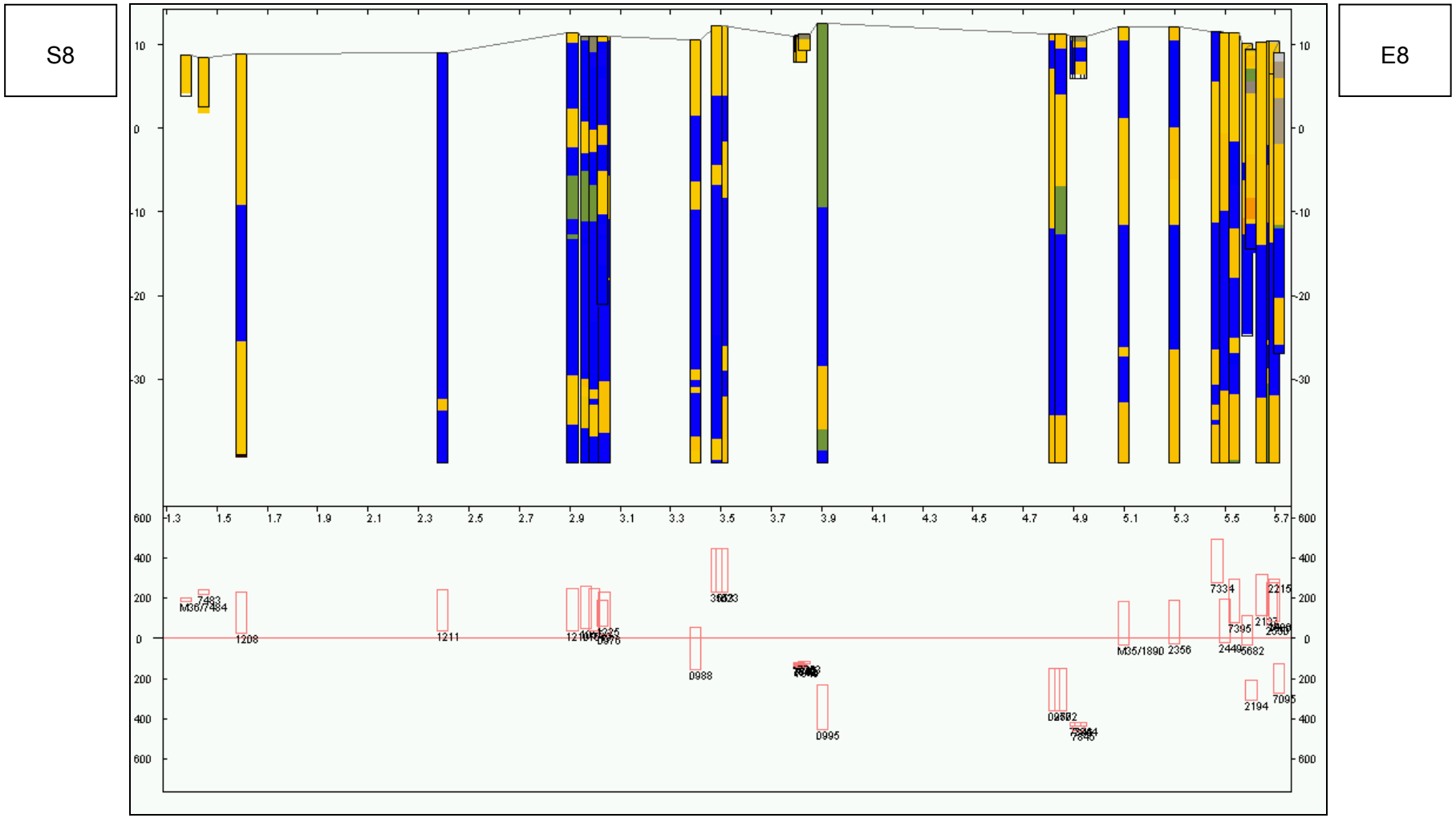


Figure A1.8. Cross section s790.

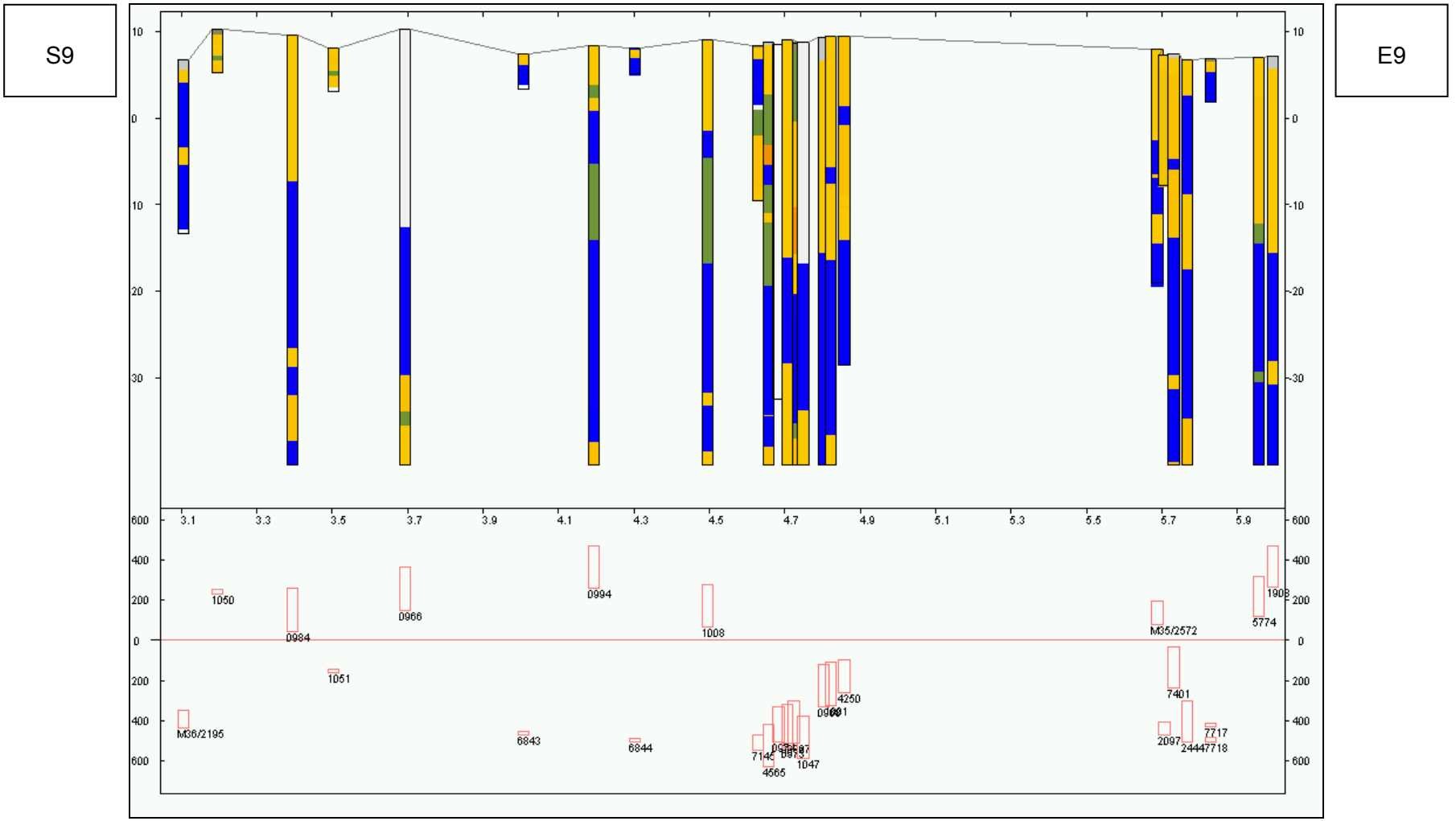


Figure A1.9. Cross section s800.

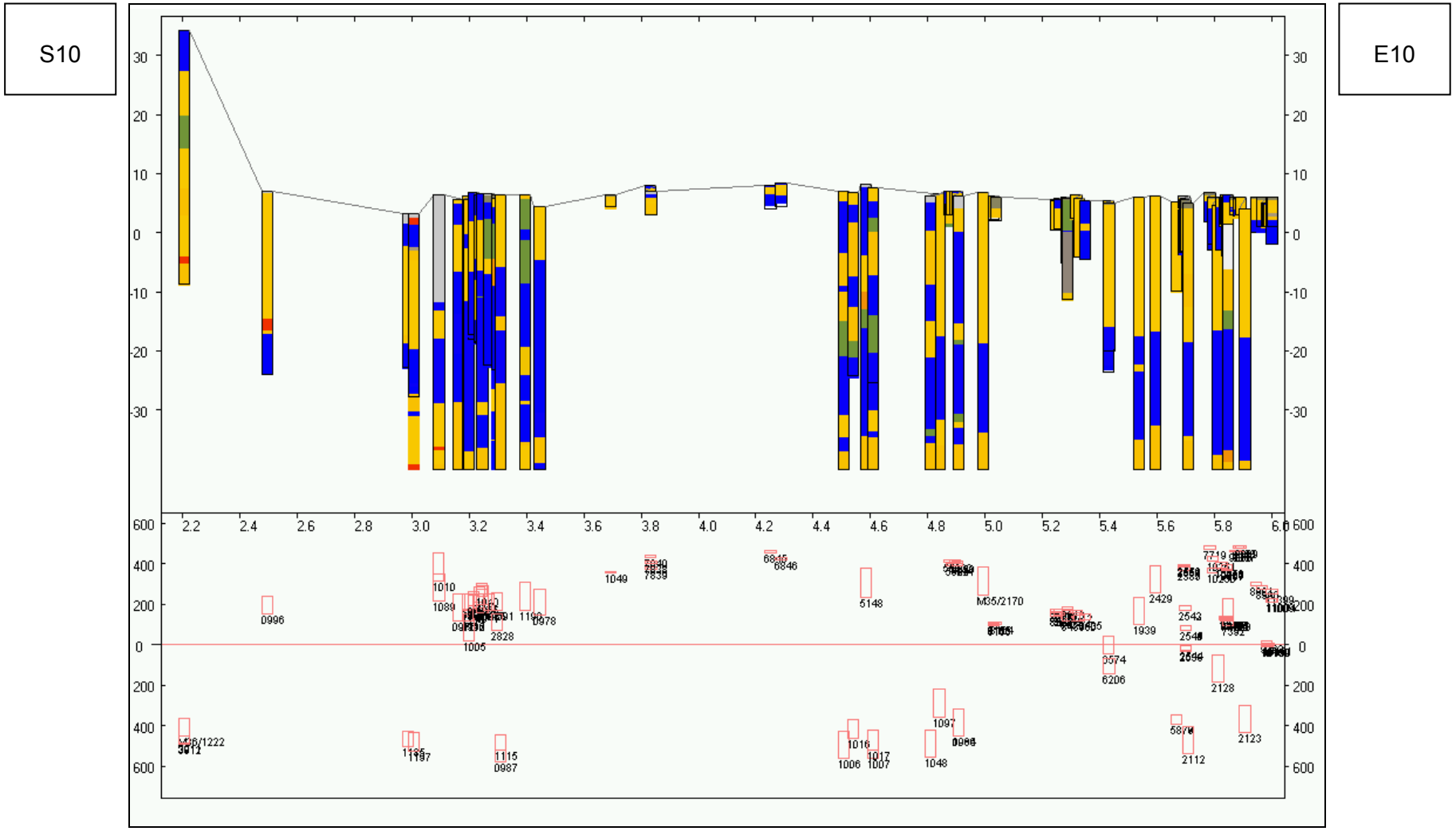


Figure A1.10. Cross section s810.

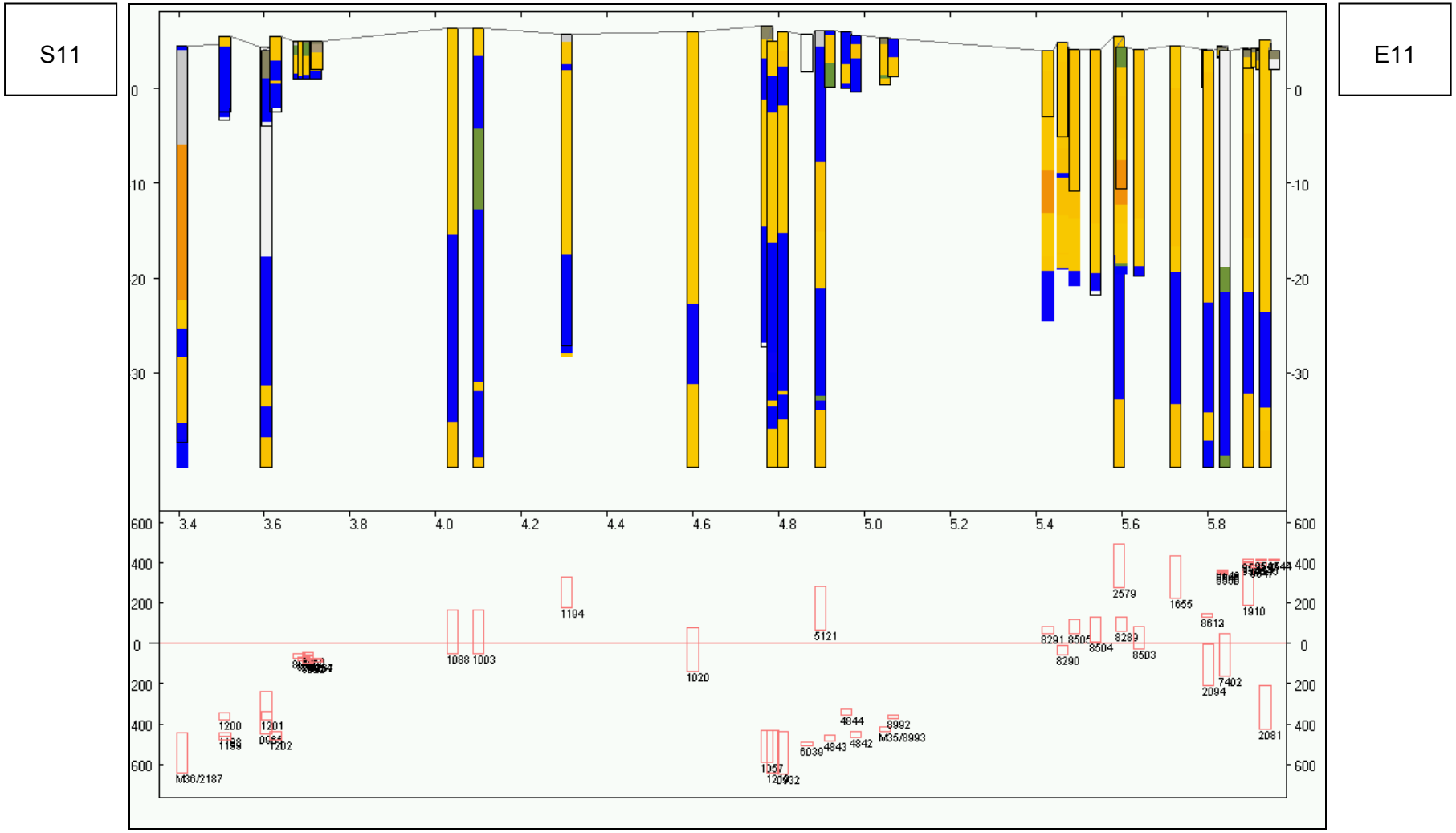


Figure A1.11. Cross section s820.

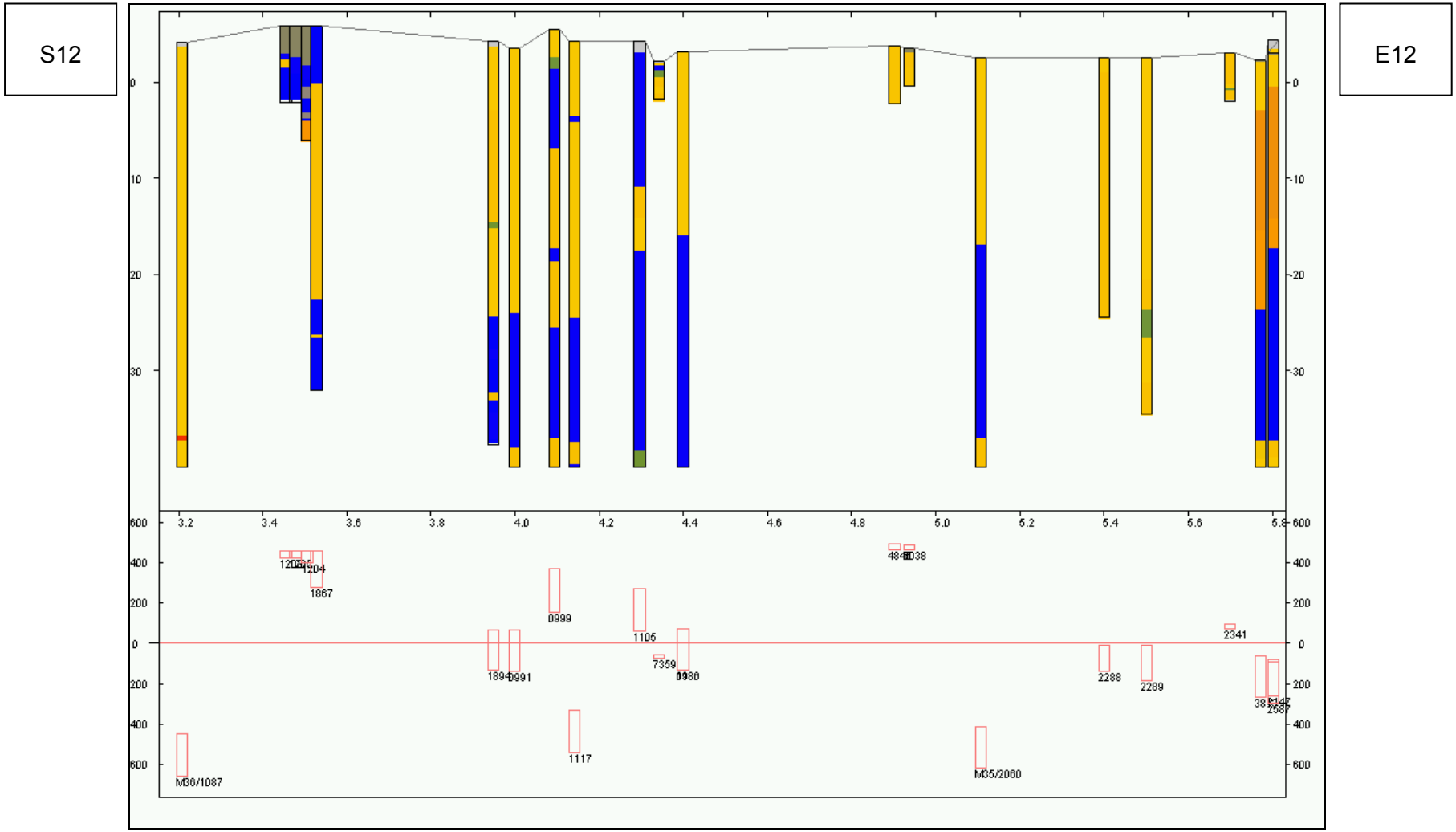


Figure A1.12. Cross section s830.

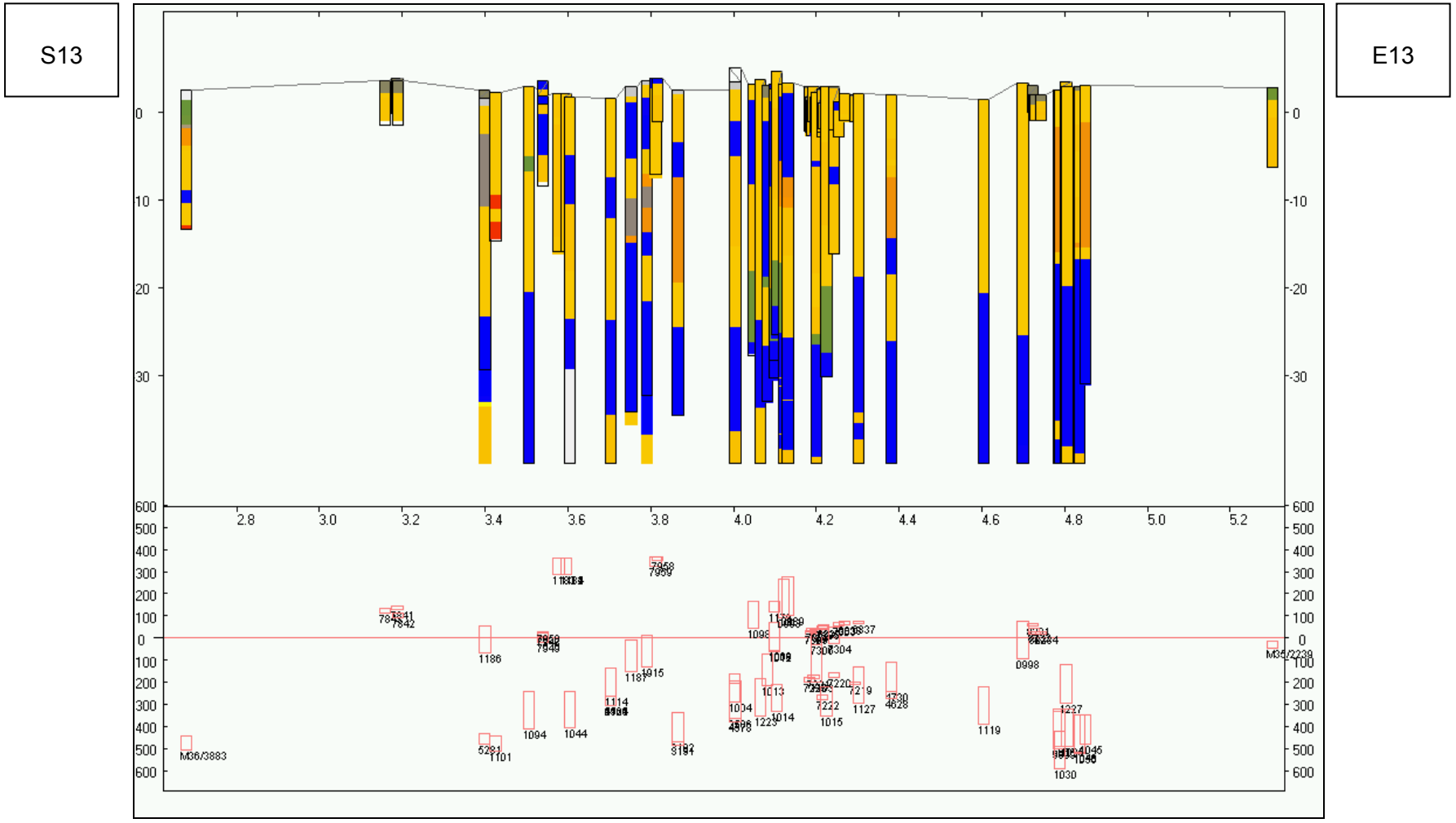


Figure A1.13. Cross section s840.

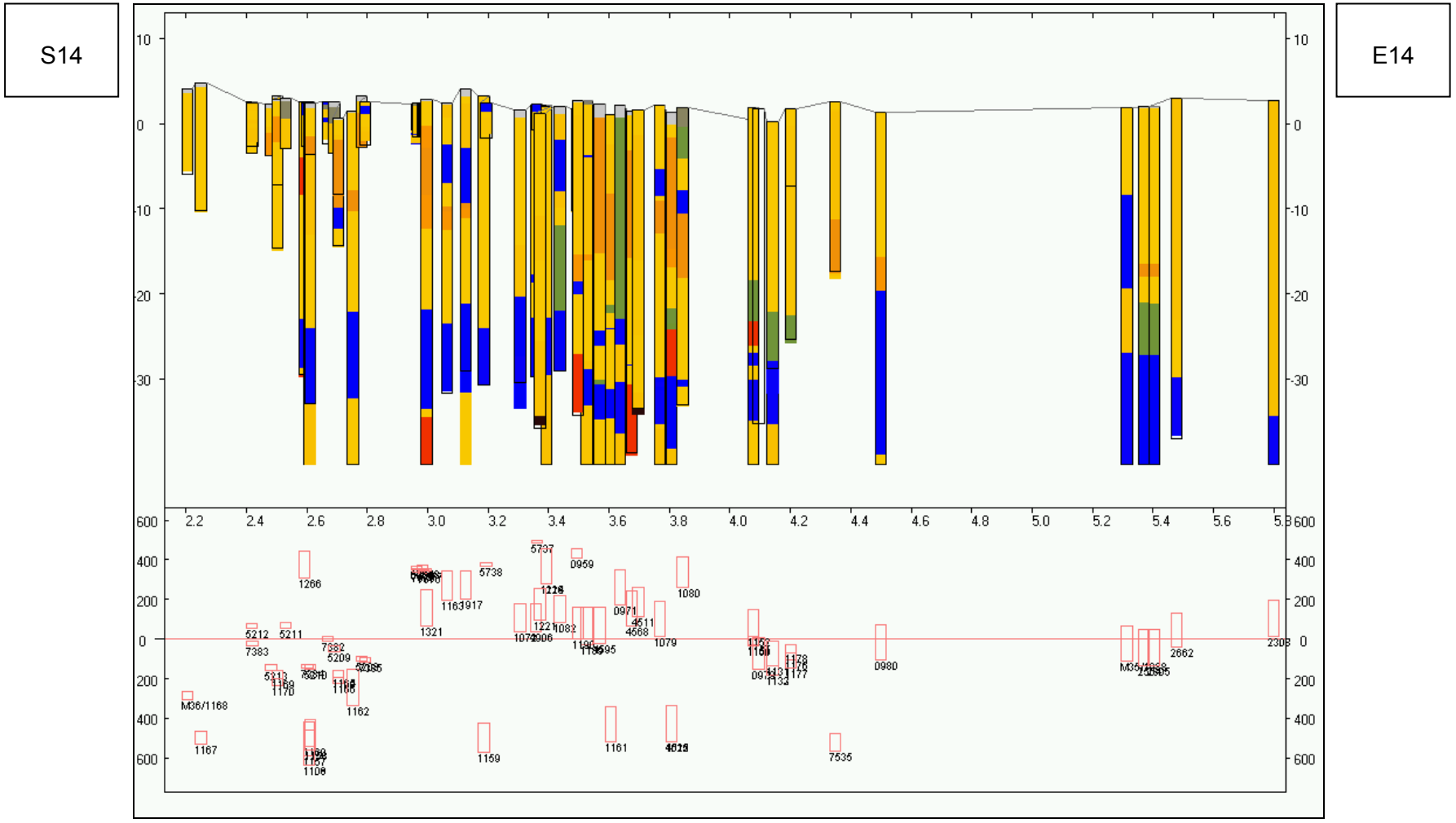


Figure A1.14. Cross section s850.

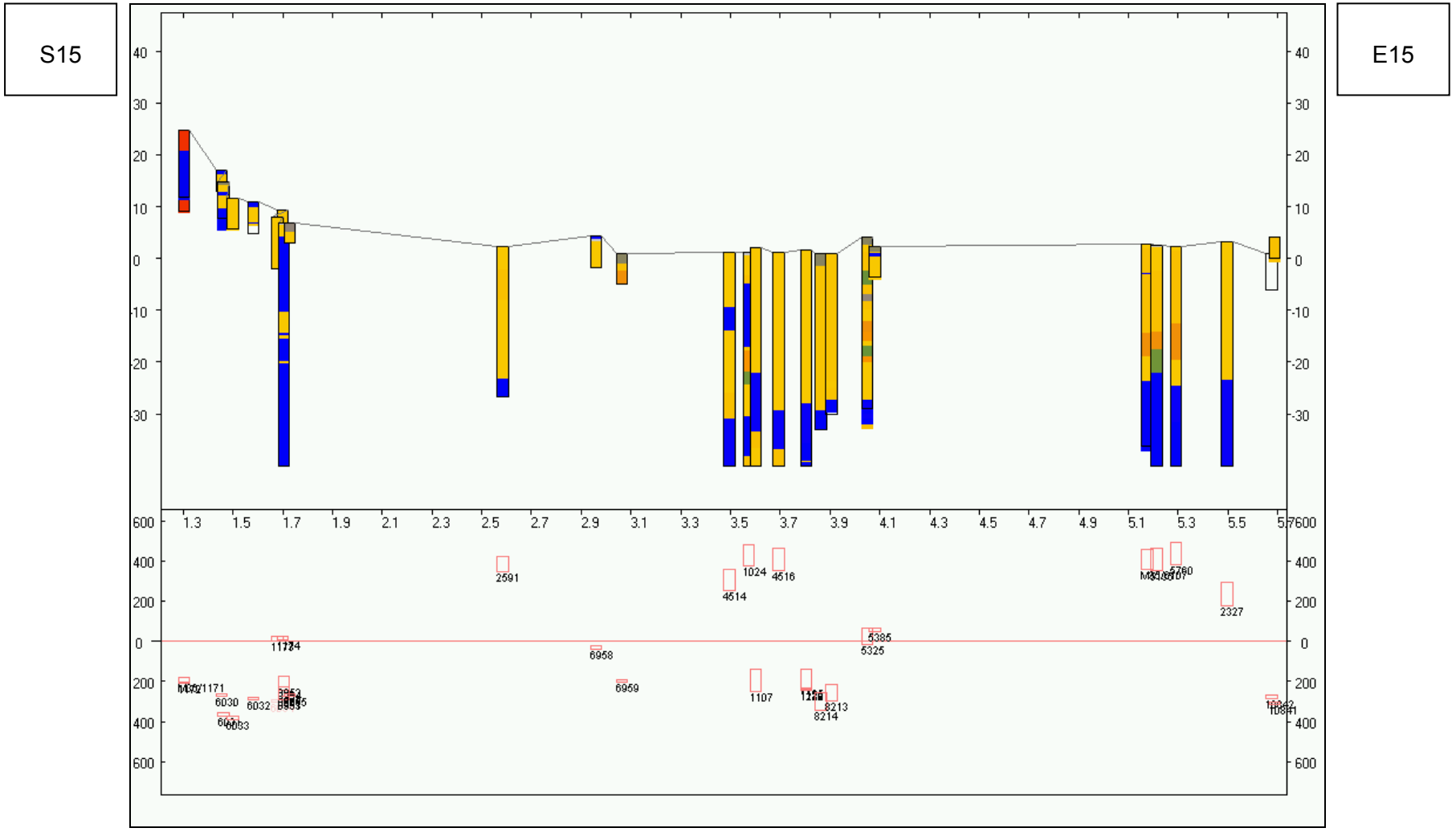


Figure A1.15. Cross section s860.

APPENDIX 2 - GEOLOGICAL LOGS IN CENTRAL-WEST CHRISTCHURCH CITY

Two conventions are used to plot the location of sections:

- S1 – E1 etc (Figure 34) being the start and end points of log selection zones for cross sections;
- cw1 etc (Figure 44) being the location of wells at the ends of each section.

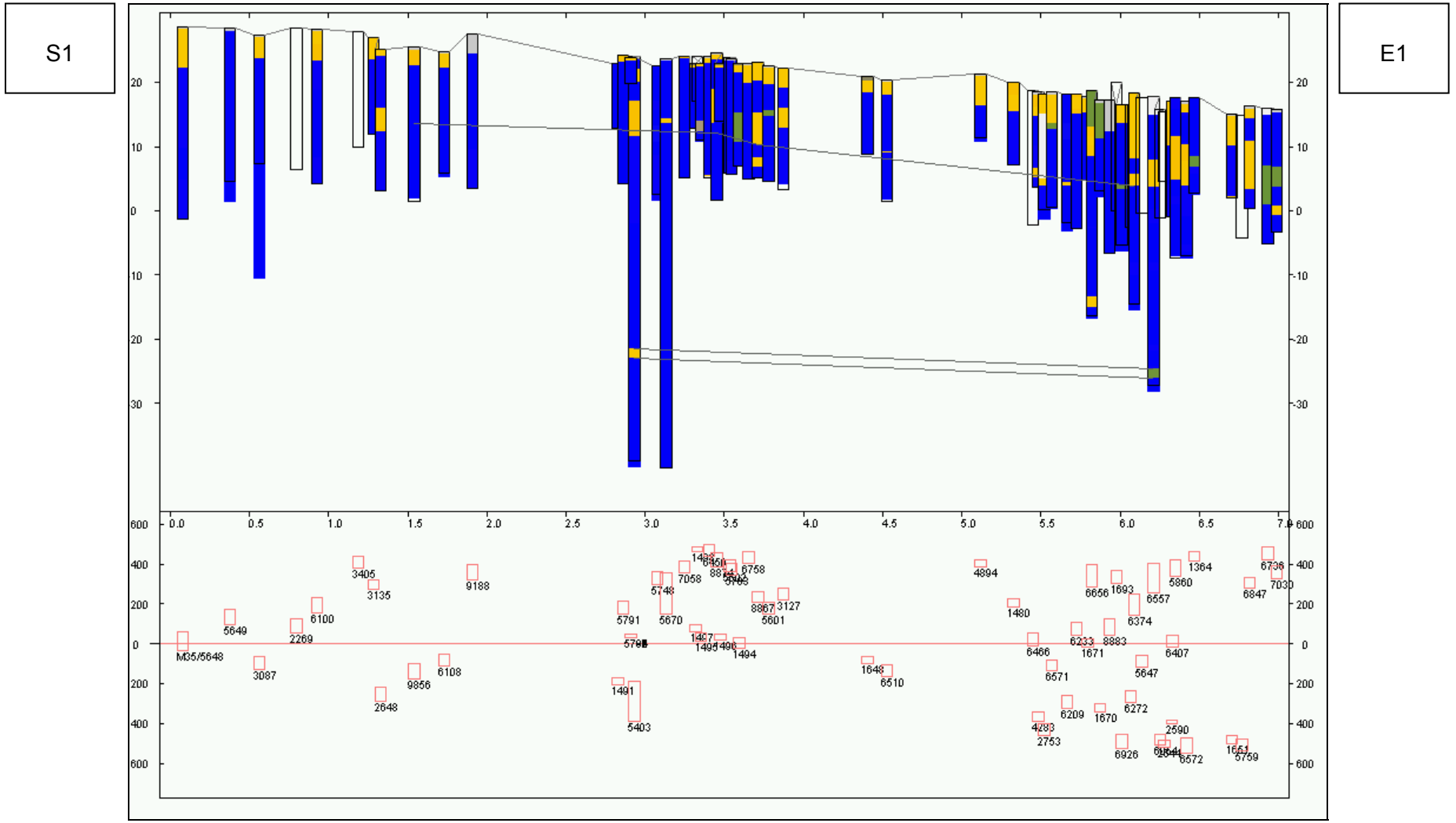


Figure A2.1. Cross section cw1.

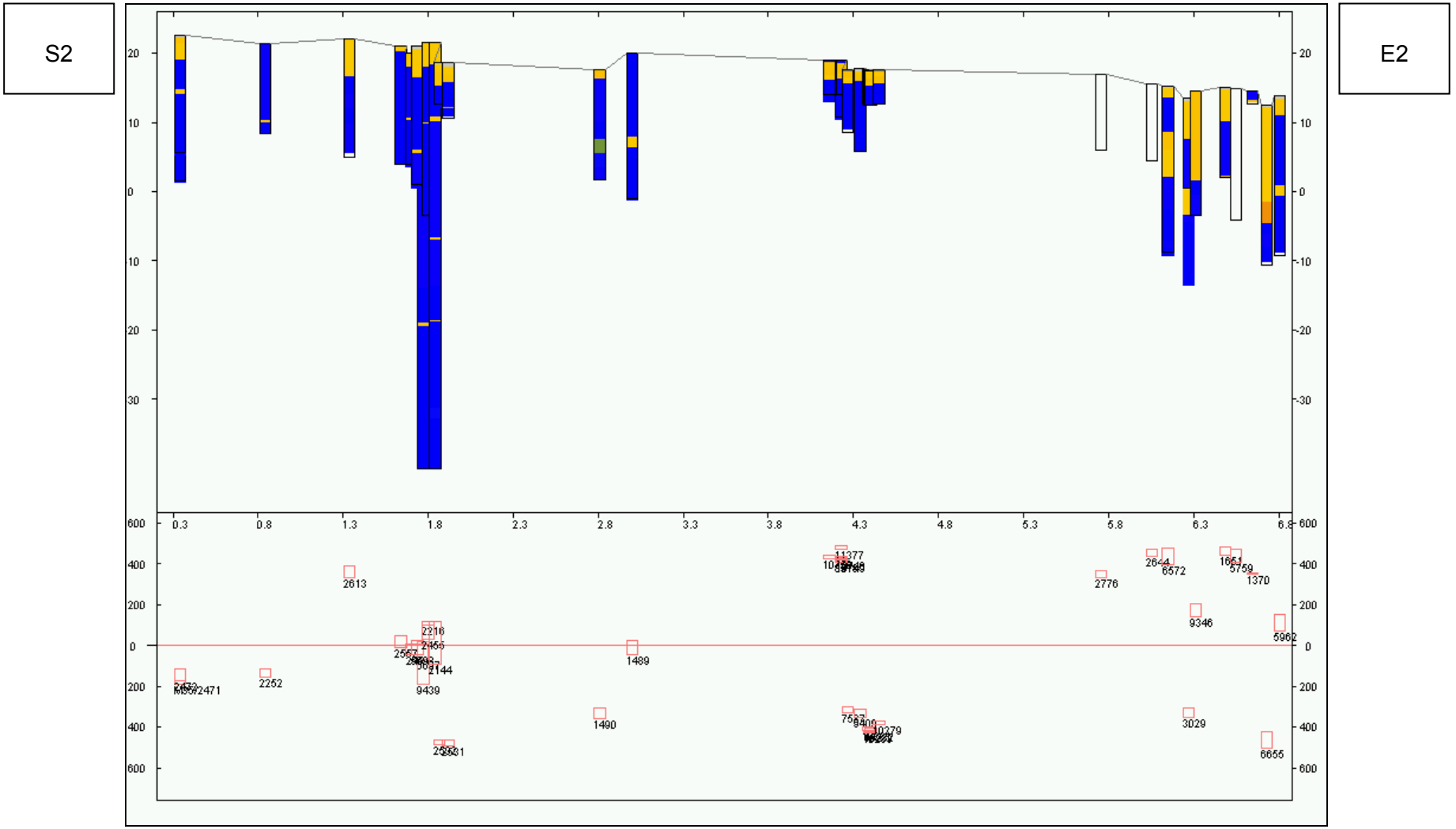


Figure A2.2. Cross section cw2.

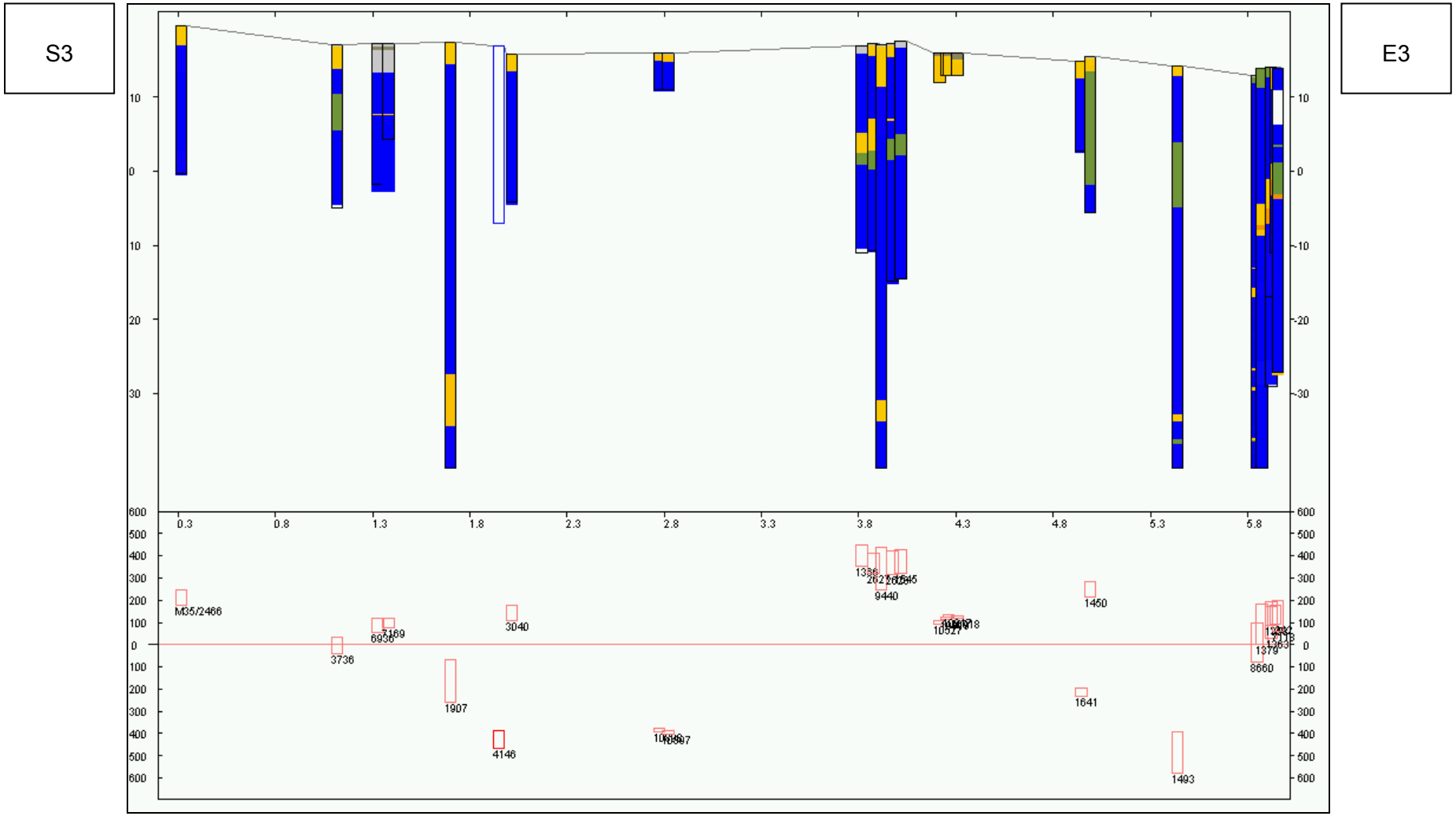


Figure A2.3. Cross section cw3.

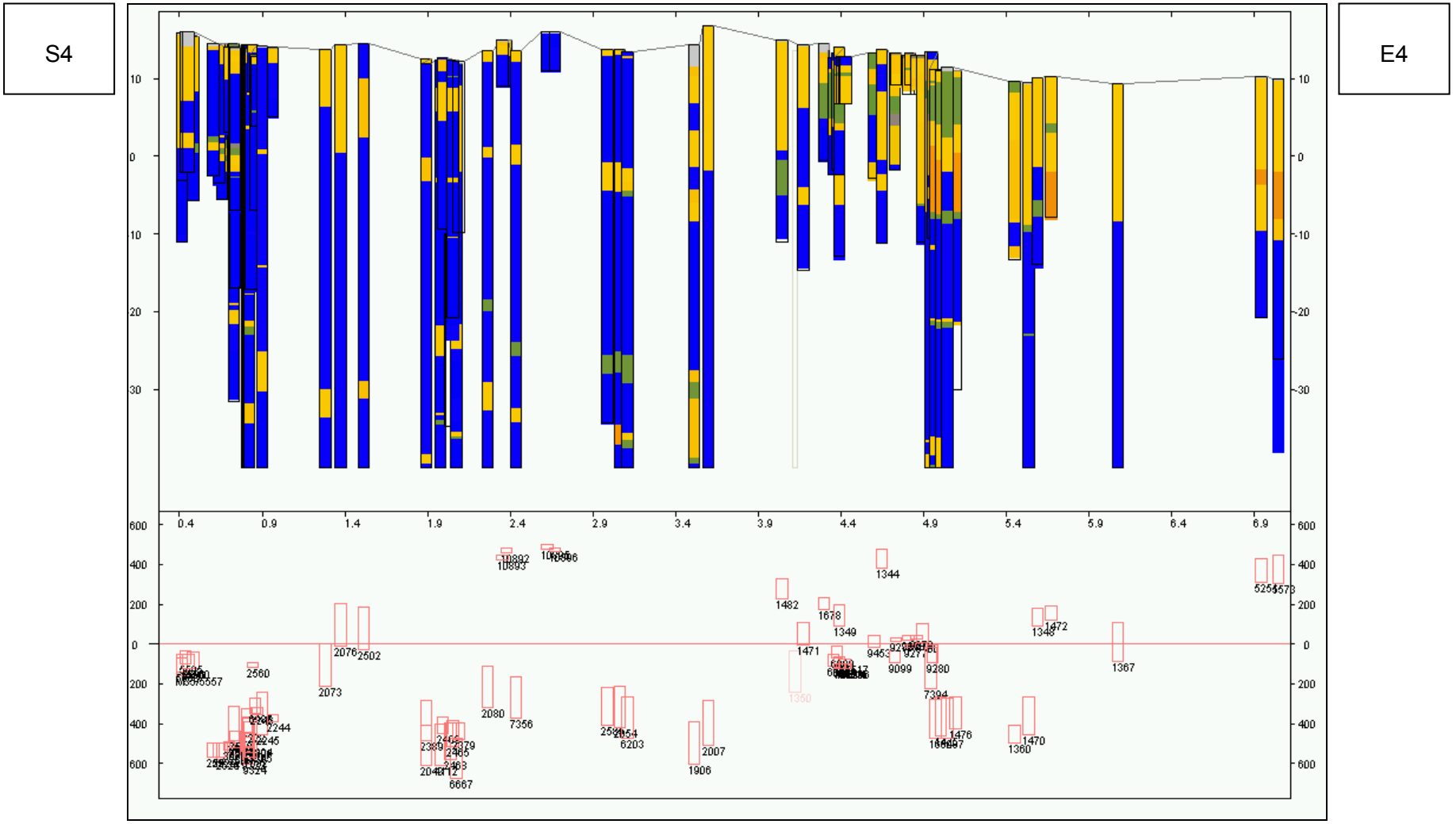


Figure A2.4. Cross section cw4.

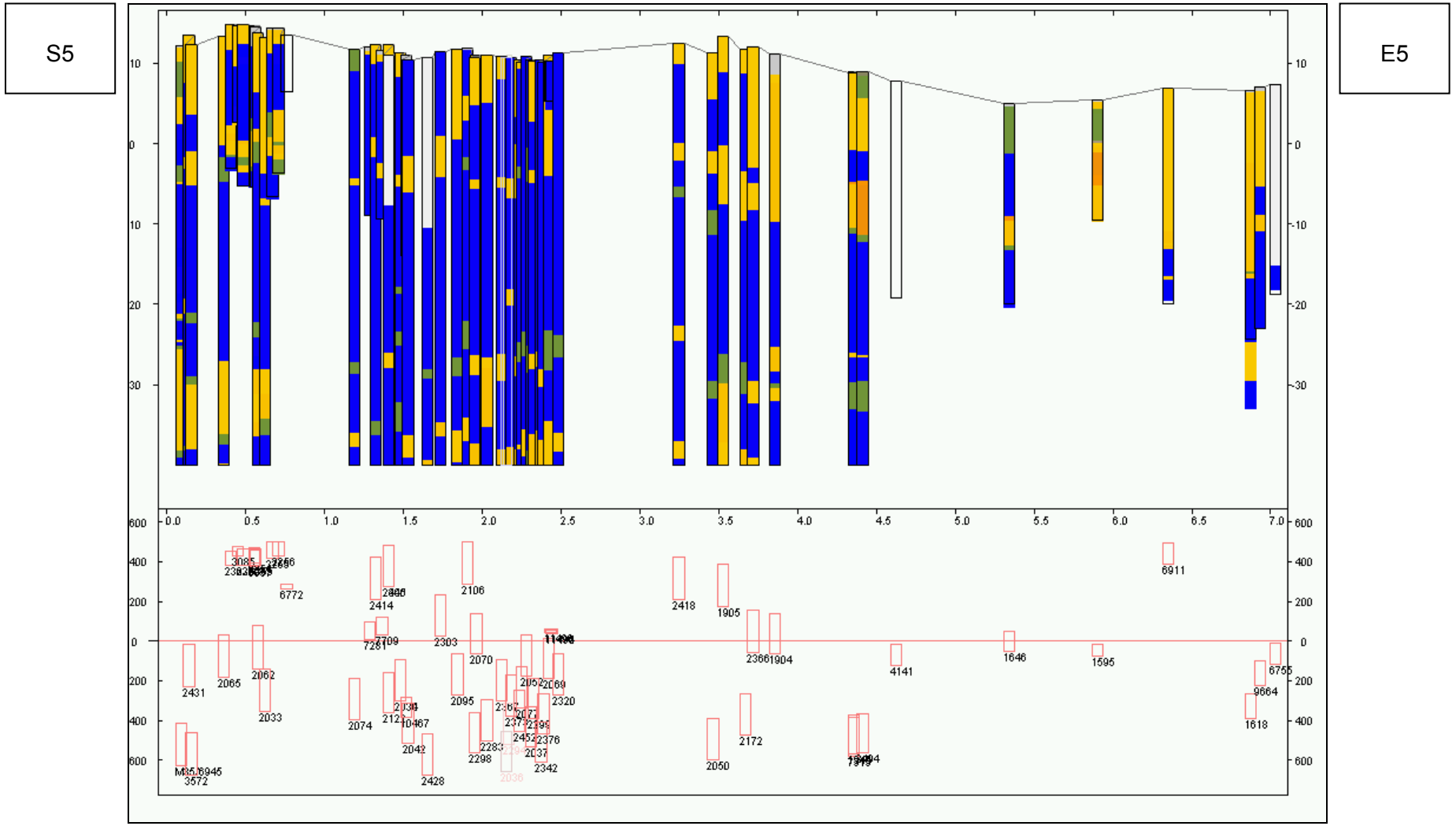


Figure A2.5. Cross section cw5.

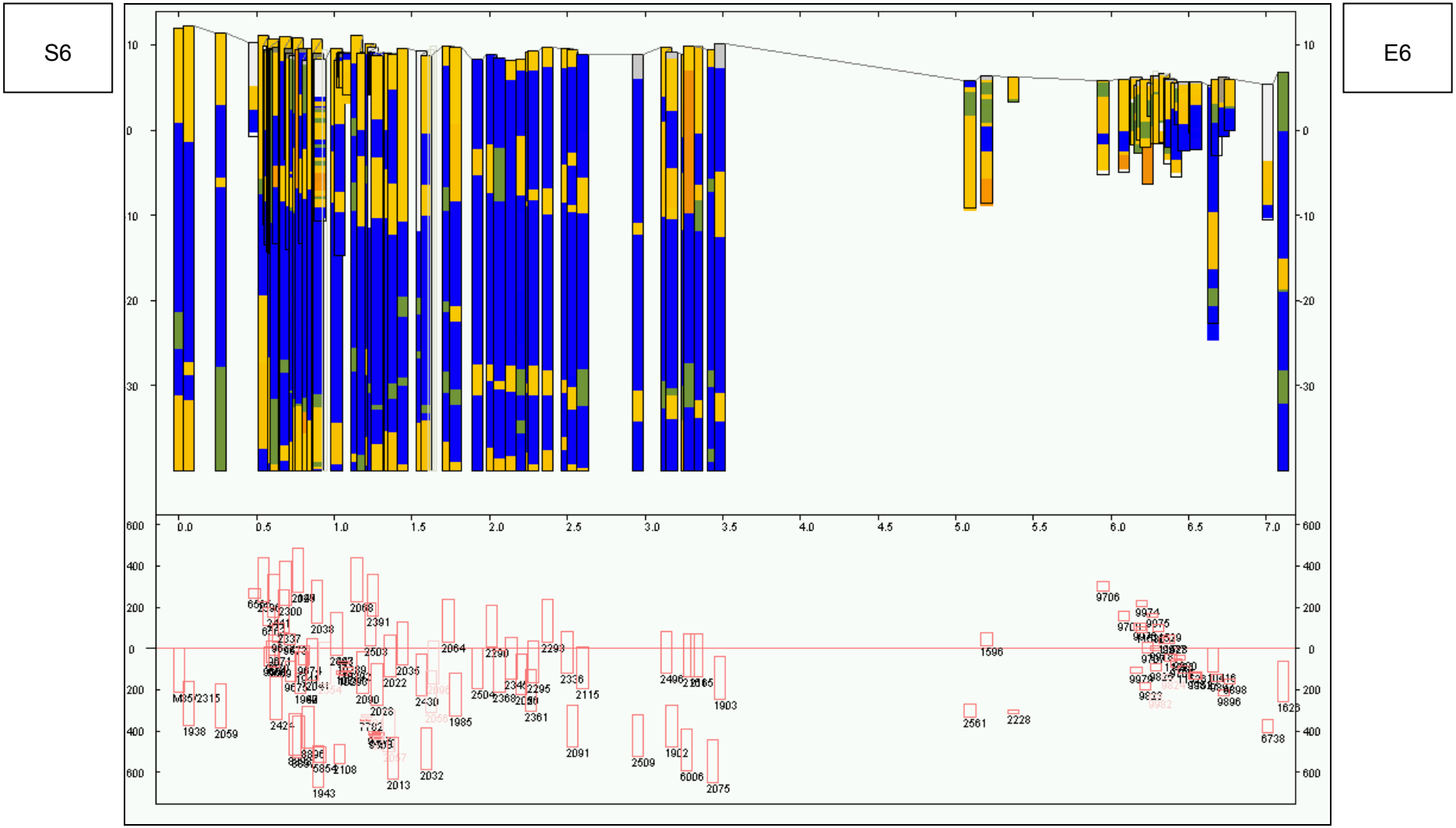


Figure A2.6. Cross section cw6.

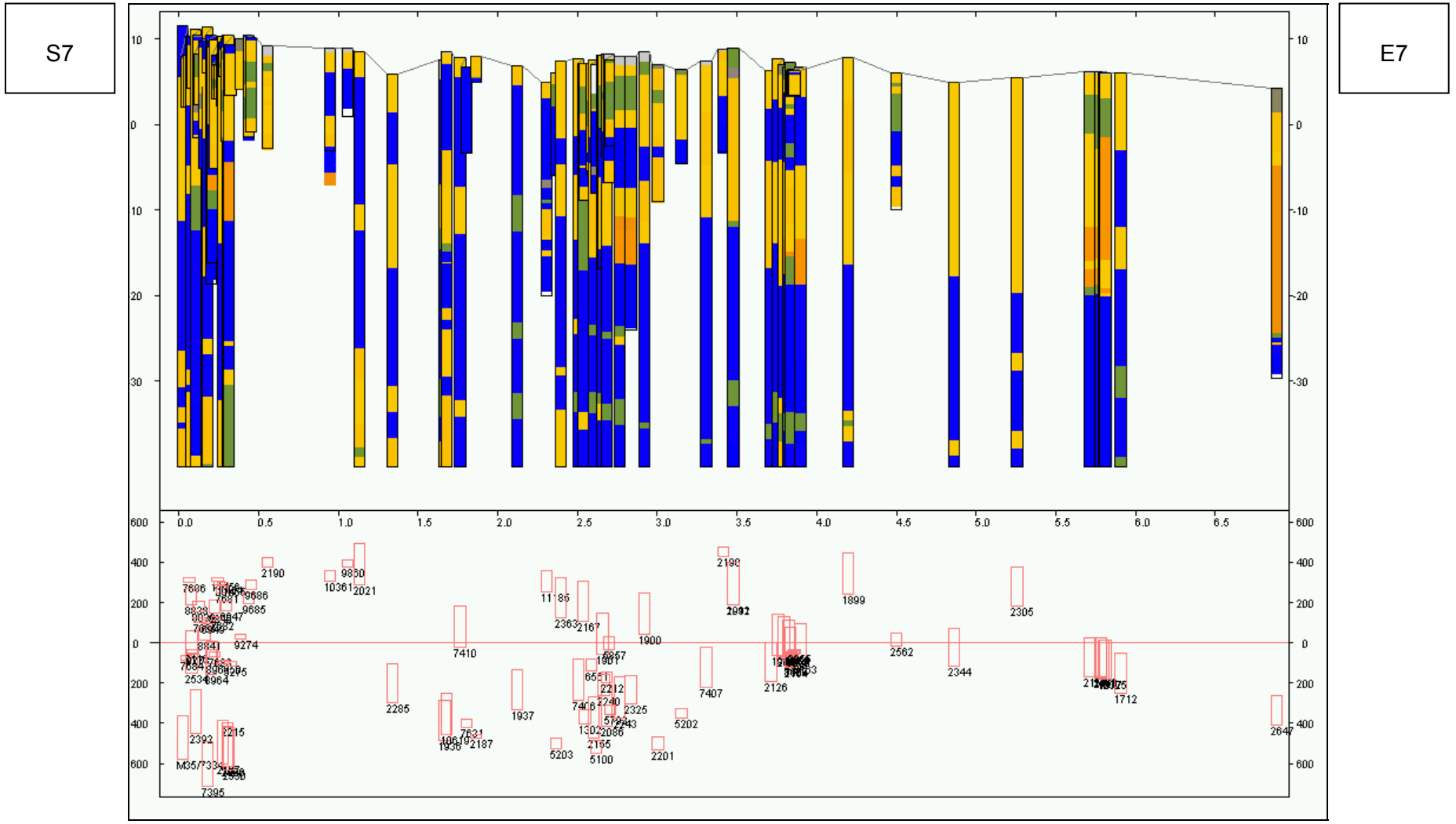


Figure A2.7. Cross section cw7.

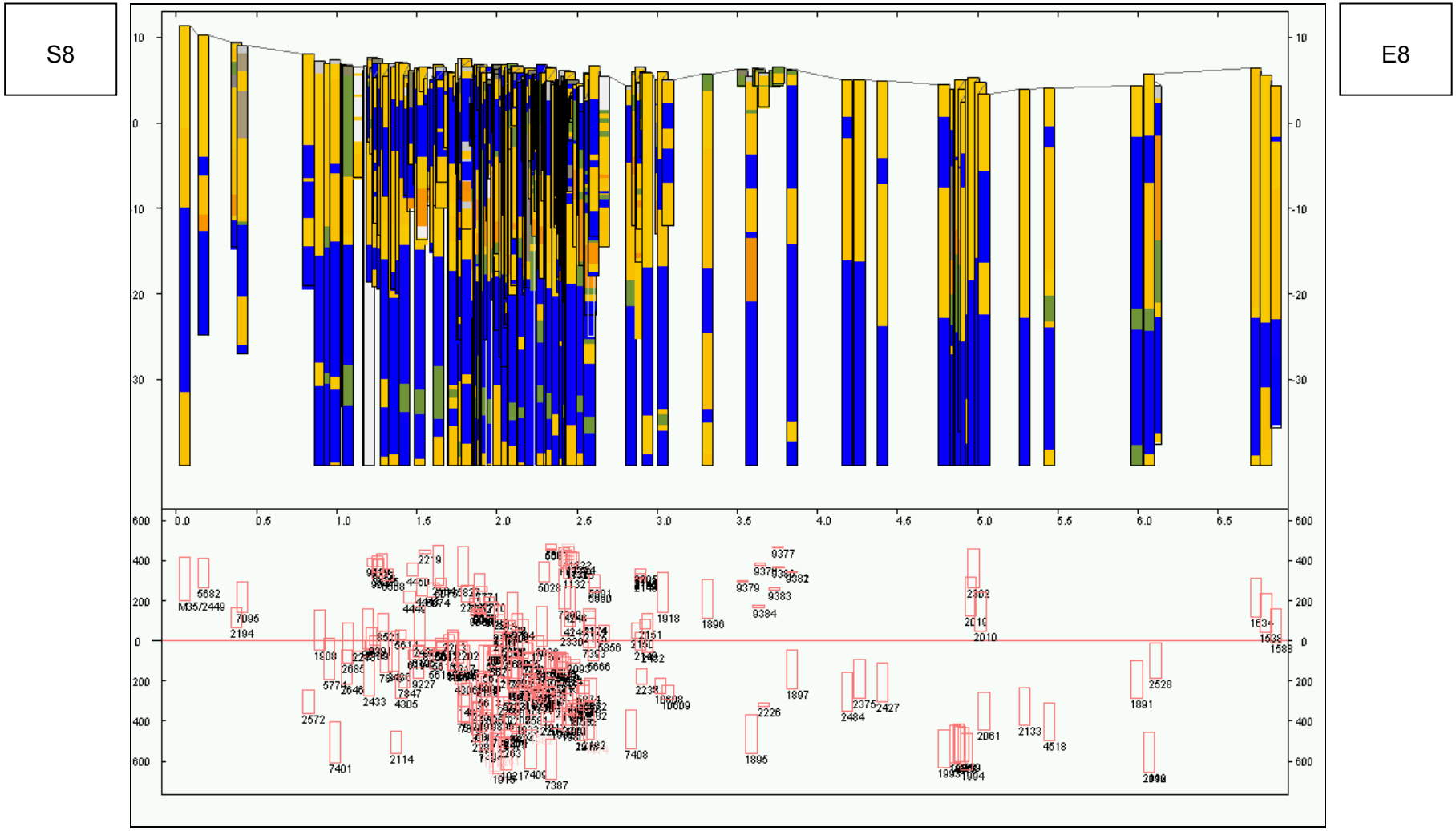


Figure A2.8. Cross section cw8.

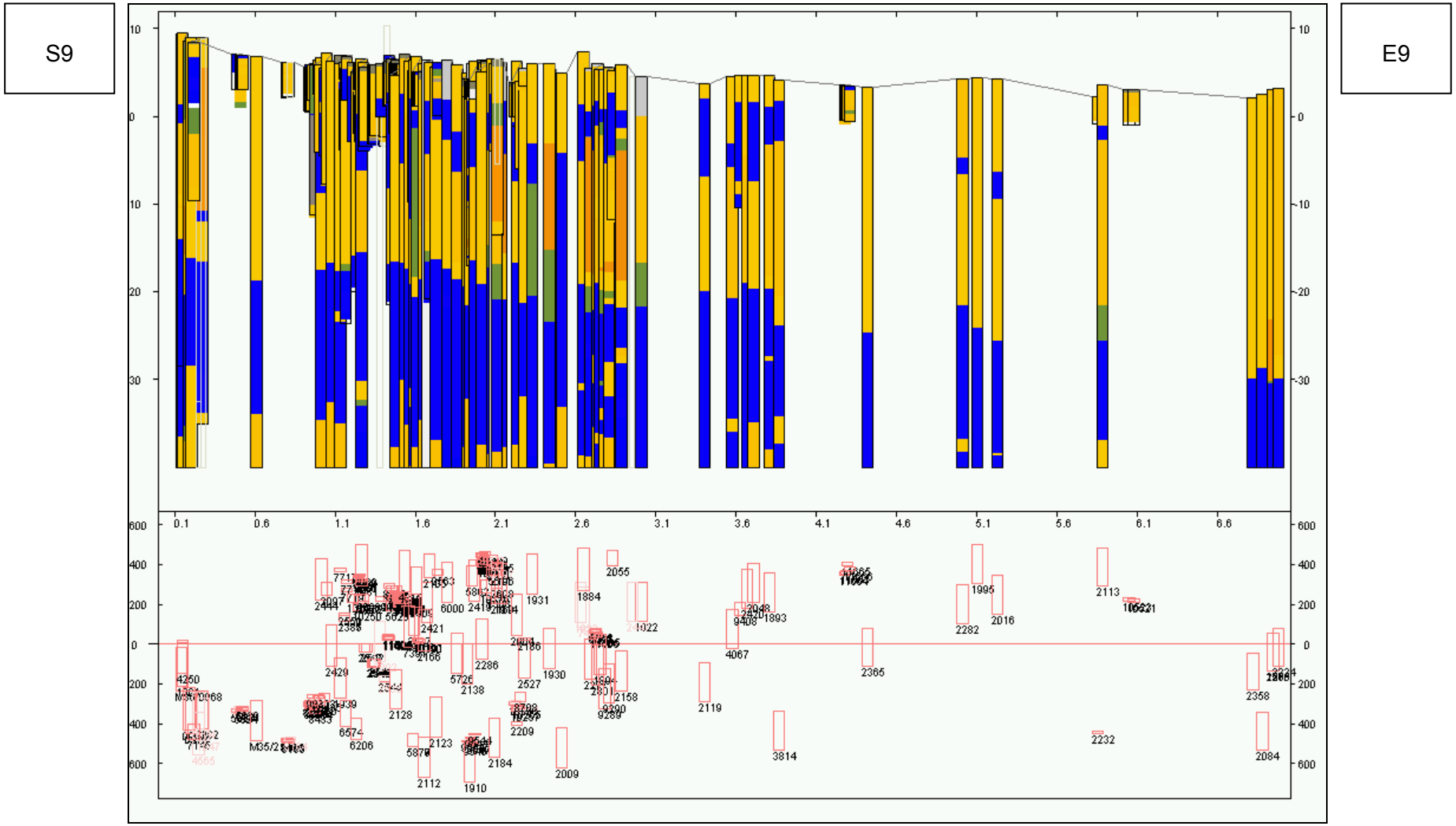


Figure A2.9. Cross section cw9.

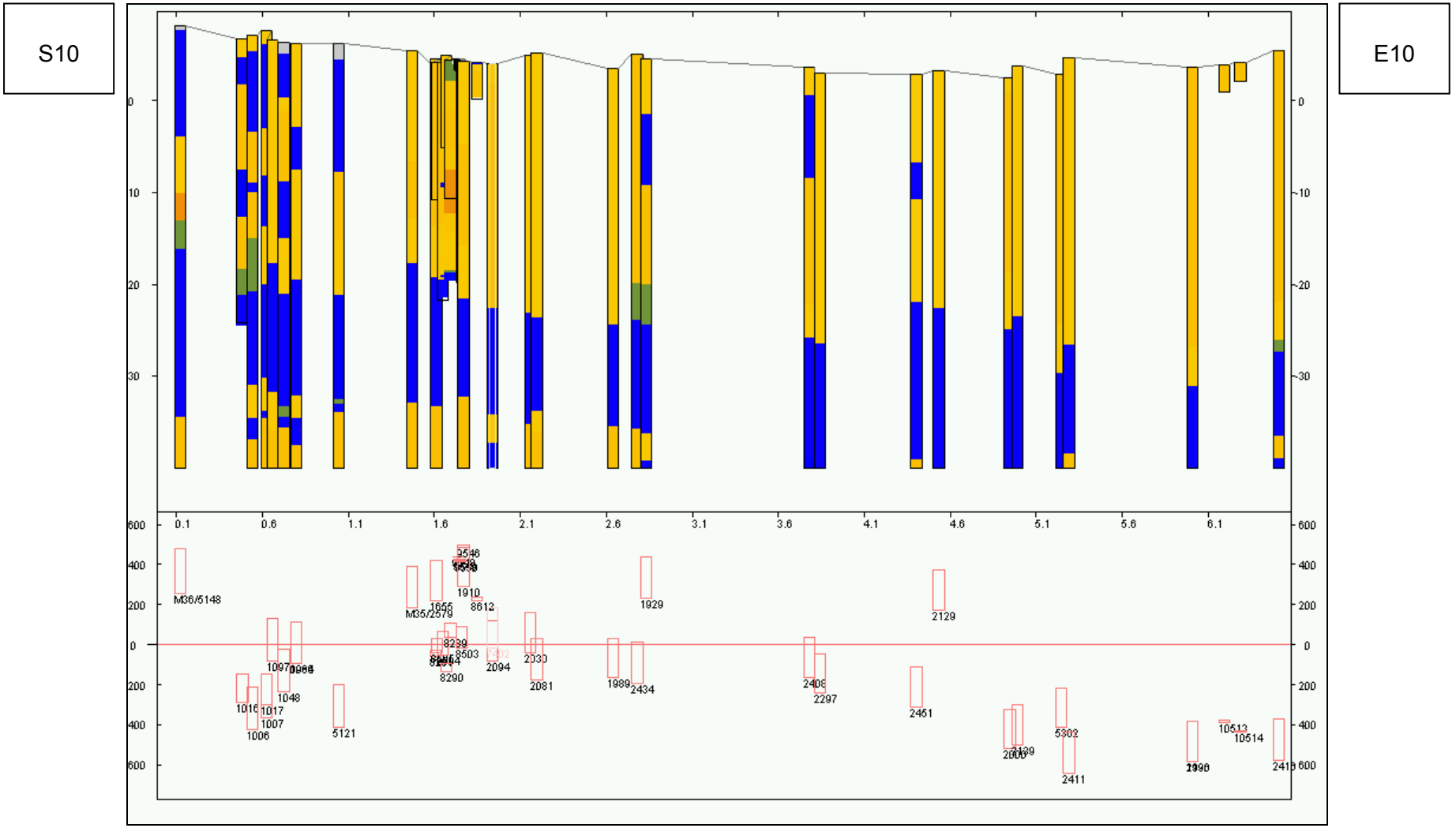


Figure A2.10. Cross section cw10.

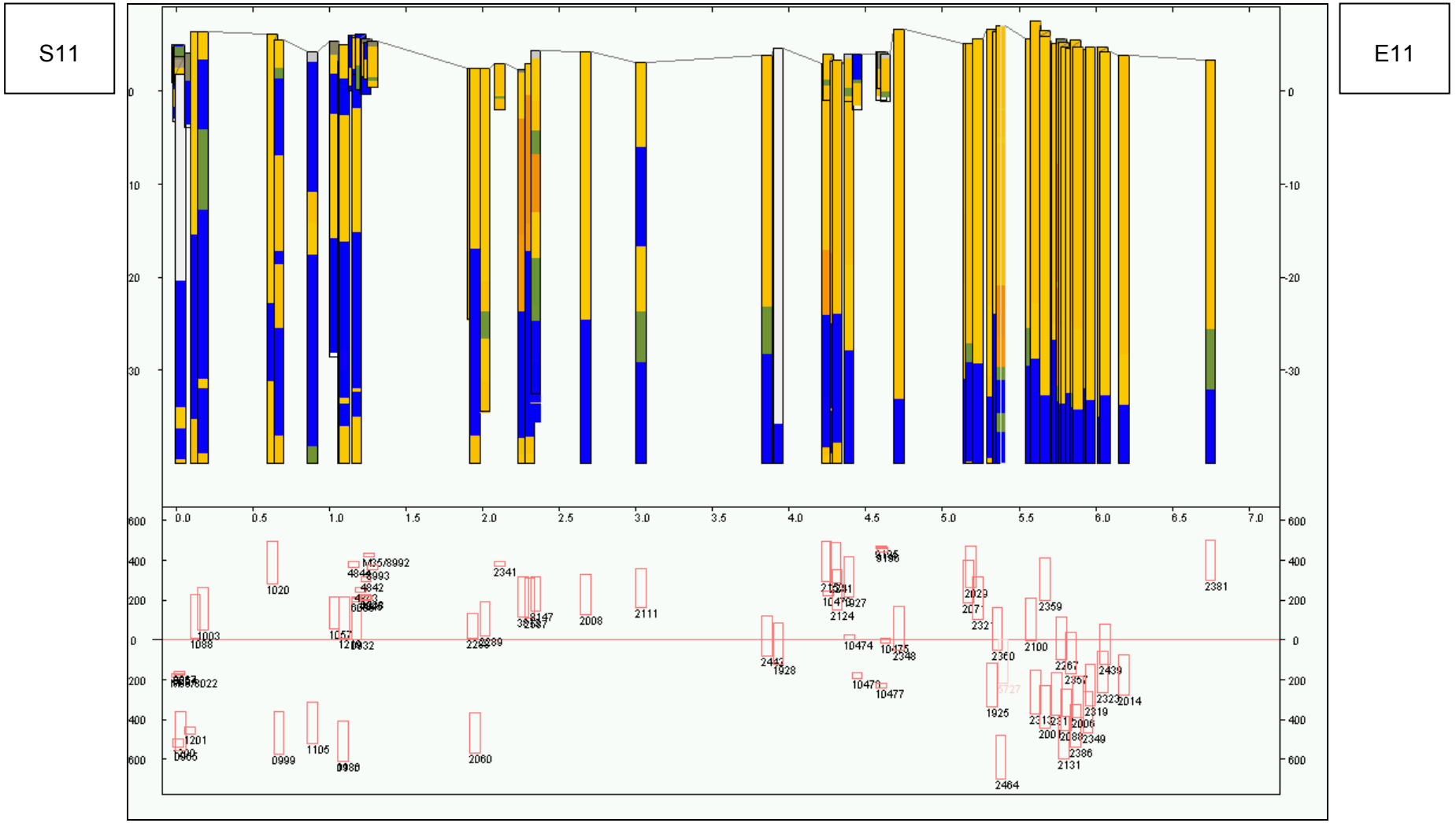


Figure A2.11. Cross section cw11.

APPENDIX 3 - GEOLOGICAL LOGS IN SOUTH-WEST CHRISTCHURCH CITY

Two conventions are used to plot the location of sections:

- S1 – E1 etc (Figure 35) being the start and end points of log selection zones for cross sections;
- sw1 etc (Figure 44) being the location of wells at the ends of each section.

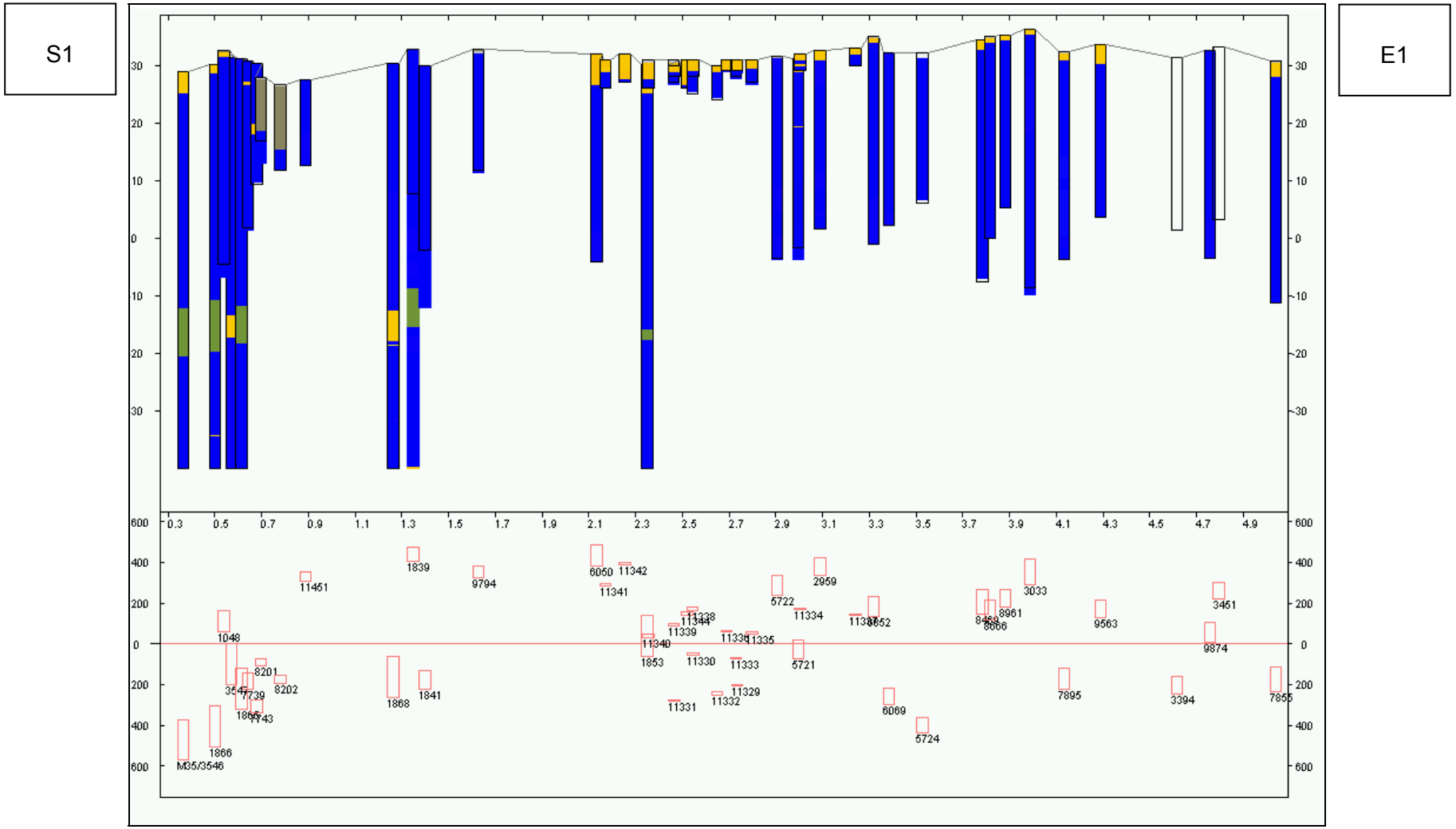


Figure A3.1. Cross section sw1.

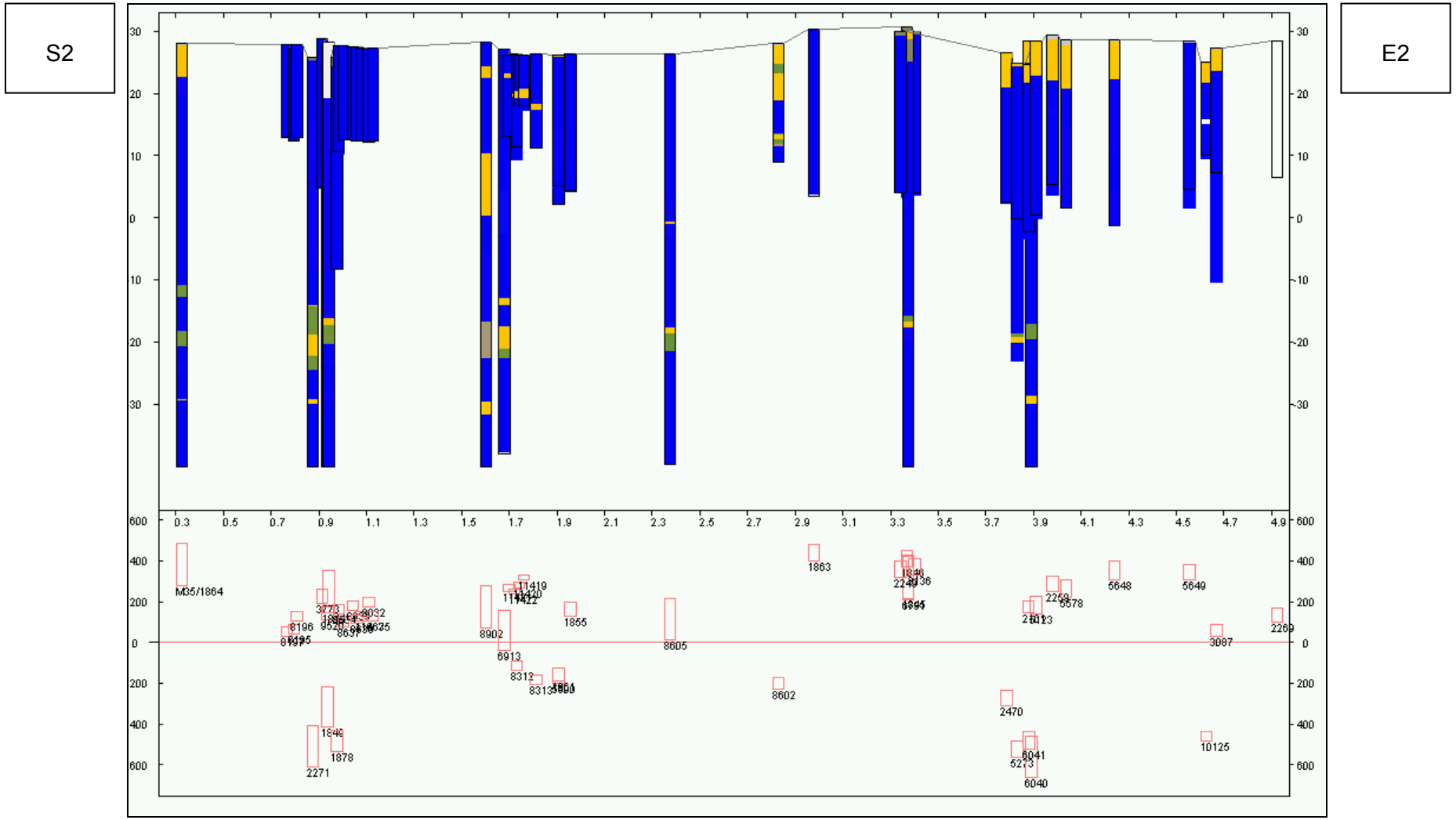


Figure A3.2. Cross section sw2.

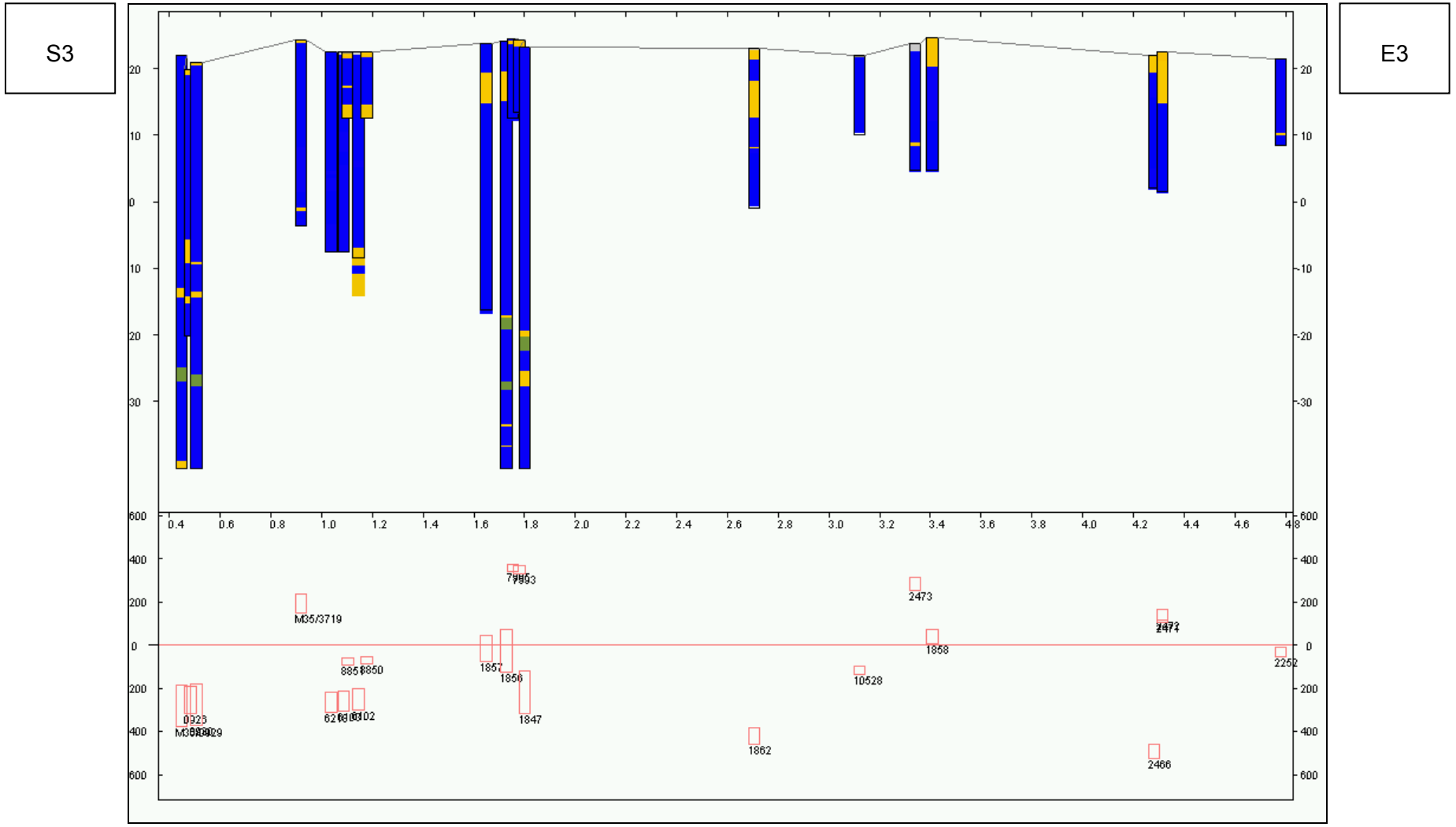


Figure A3.3. Cross section sw3.

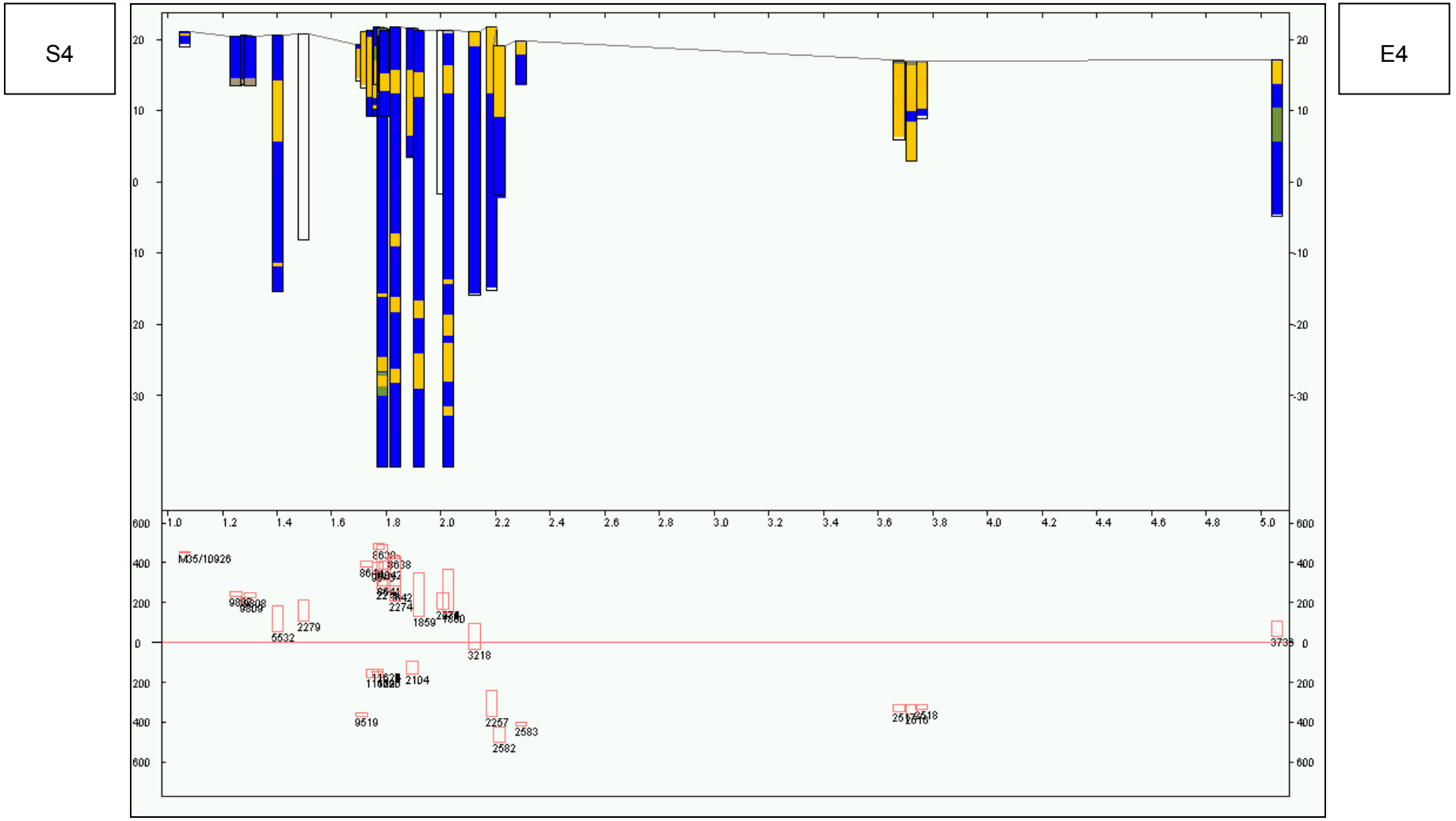


Figure A3.4. Cross section sw4.

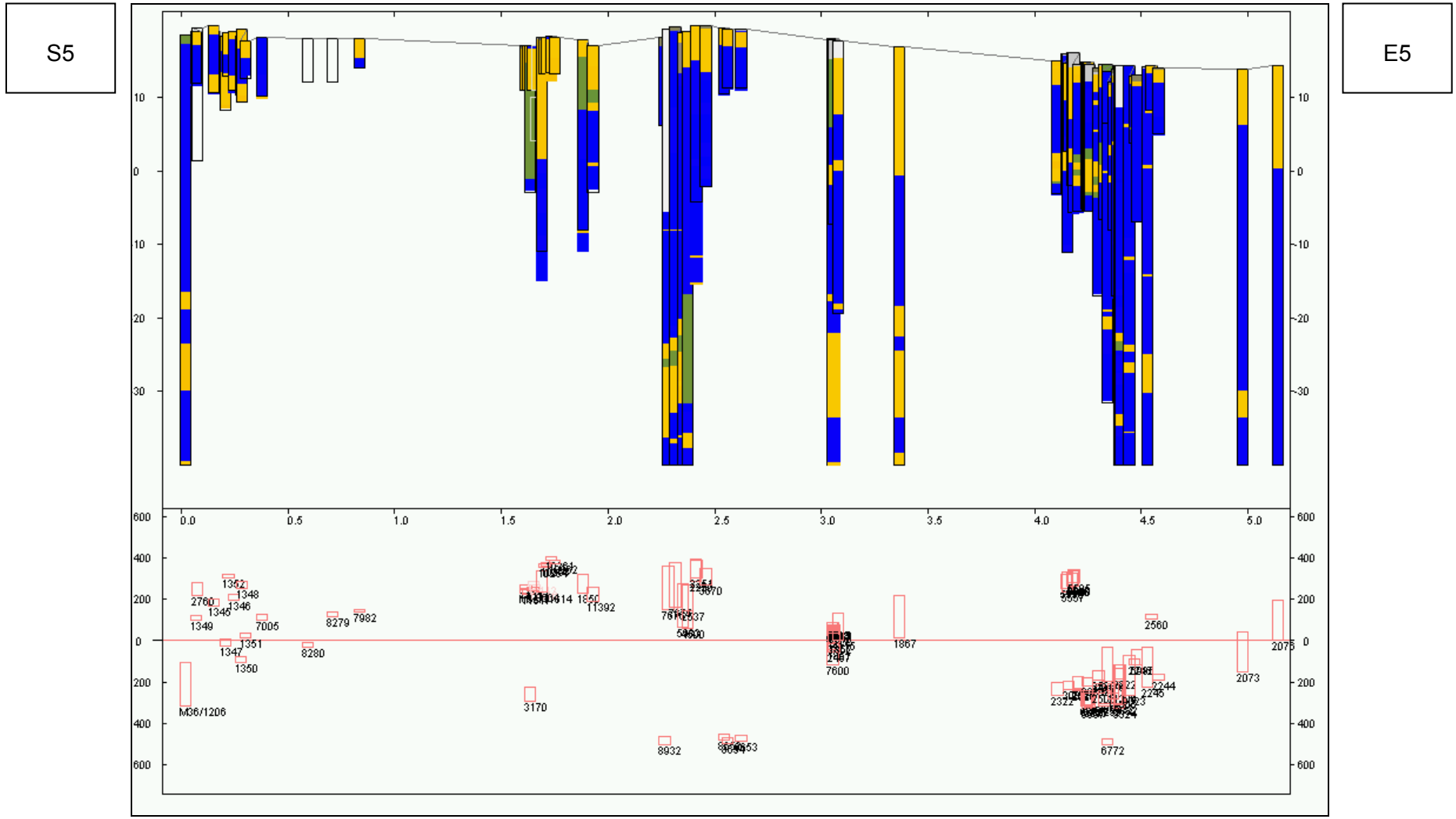


Figure A3.5. Cross section sw5.

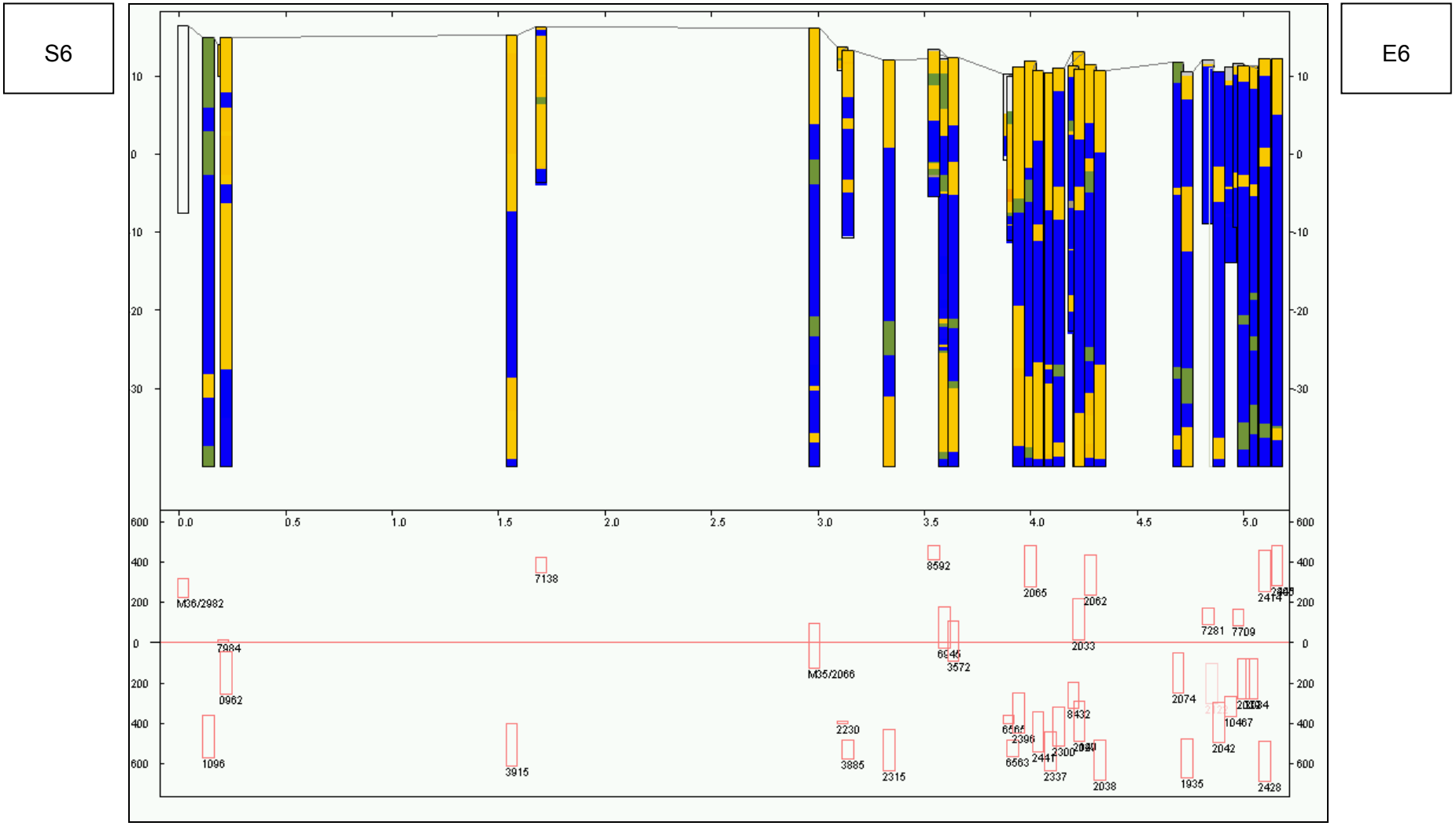


Figure A3.6. Cross section sw6.

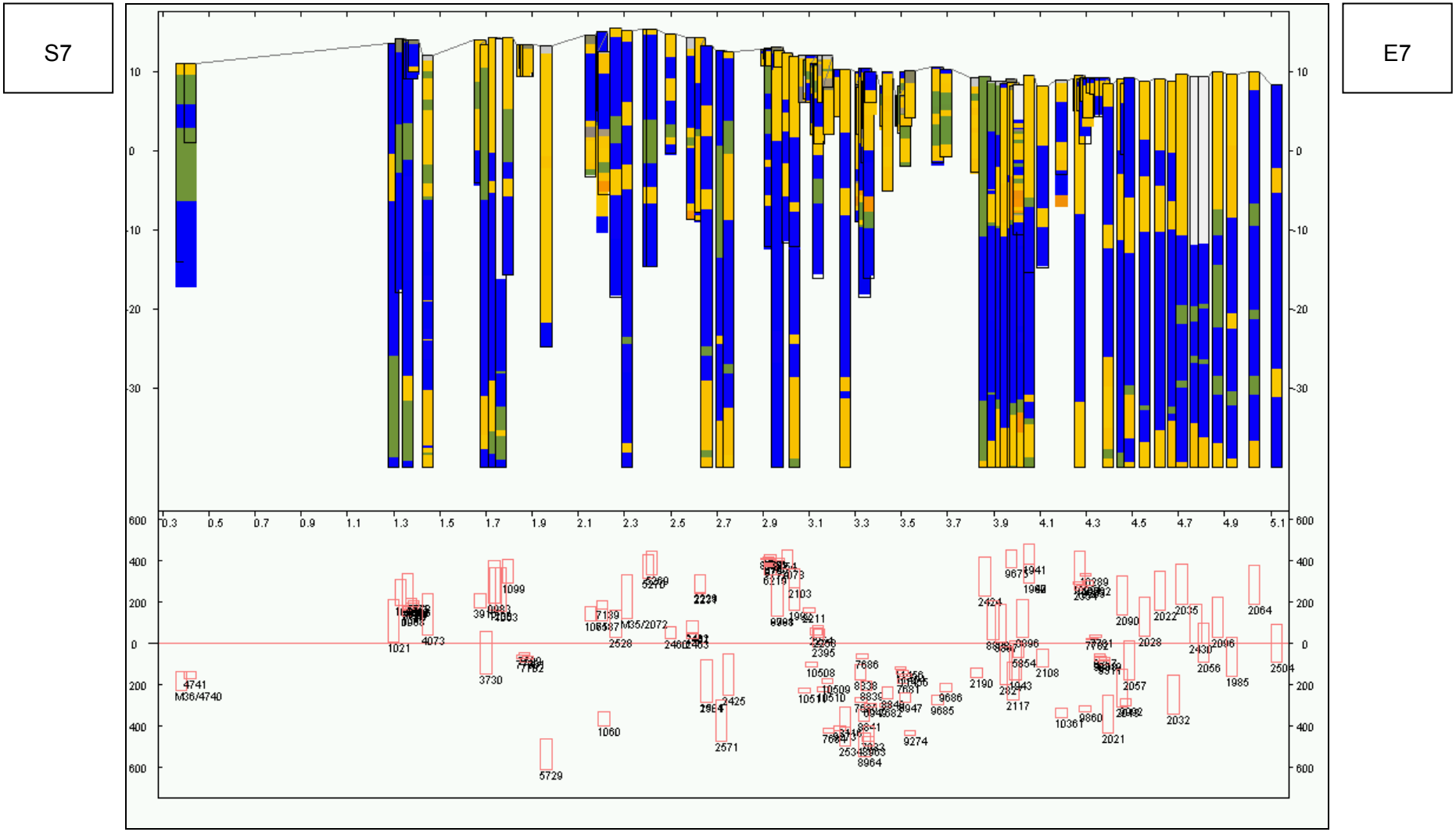


Figure A3.7. Cross section sw7.

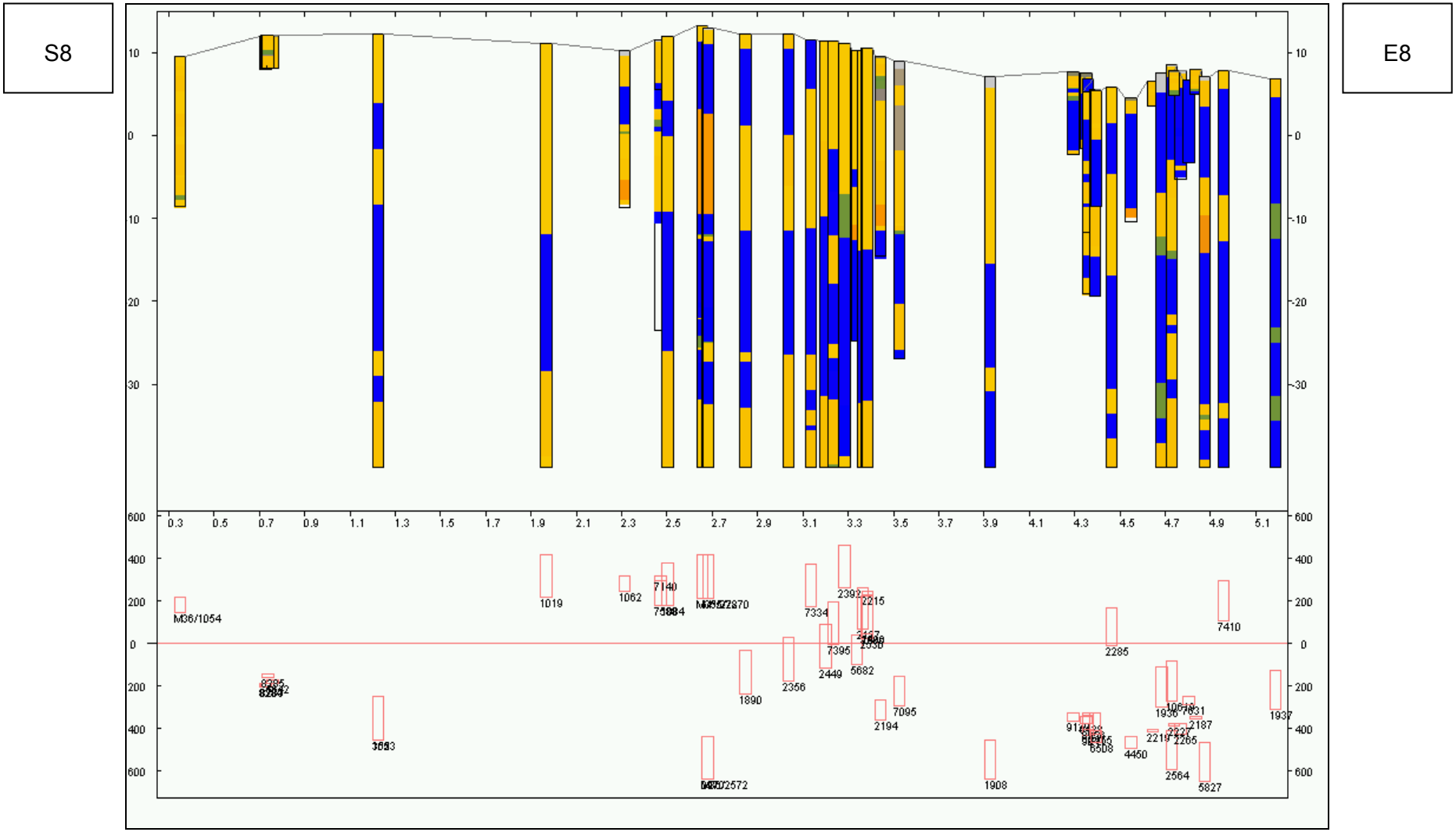


Figure A3.8. Cross section sw8.

APPENDIX 4 - GEOLOGICAL LOGS IN NORTH CHRISTCHURCH CITY

Two conventions are used to plot the location of sections:

- S1 – E1 etc (Figure 36) being the start and end points of log selection zones for cross sections;
- n1 etc (Figure 44) being the location of wells at the ends of each section.

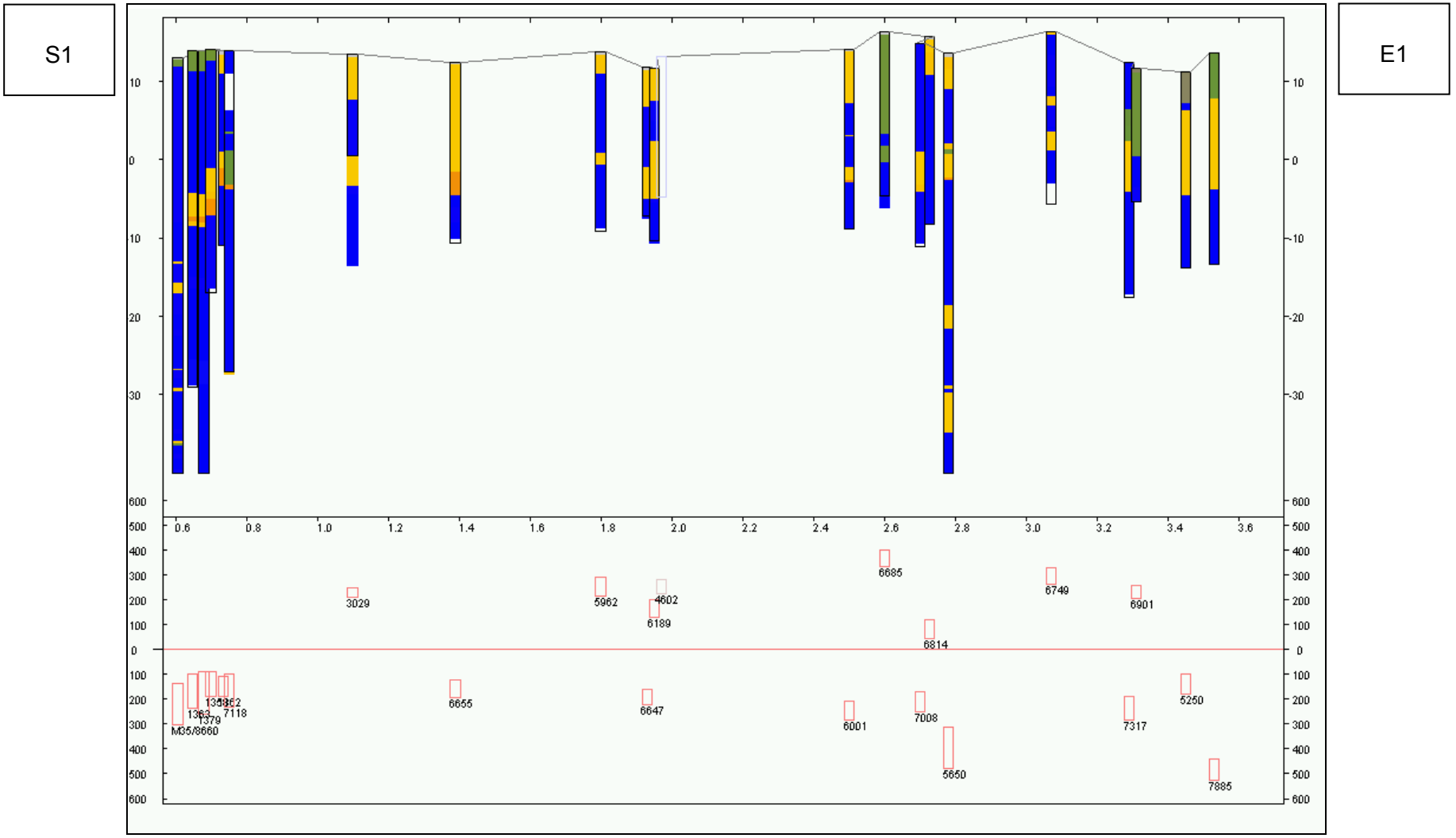


Figure A4.1. Cross section n1.

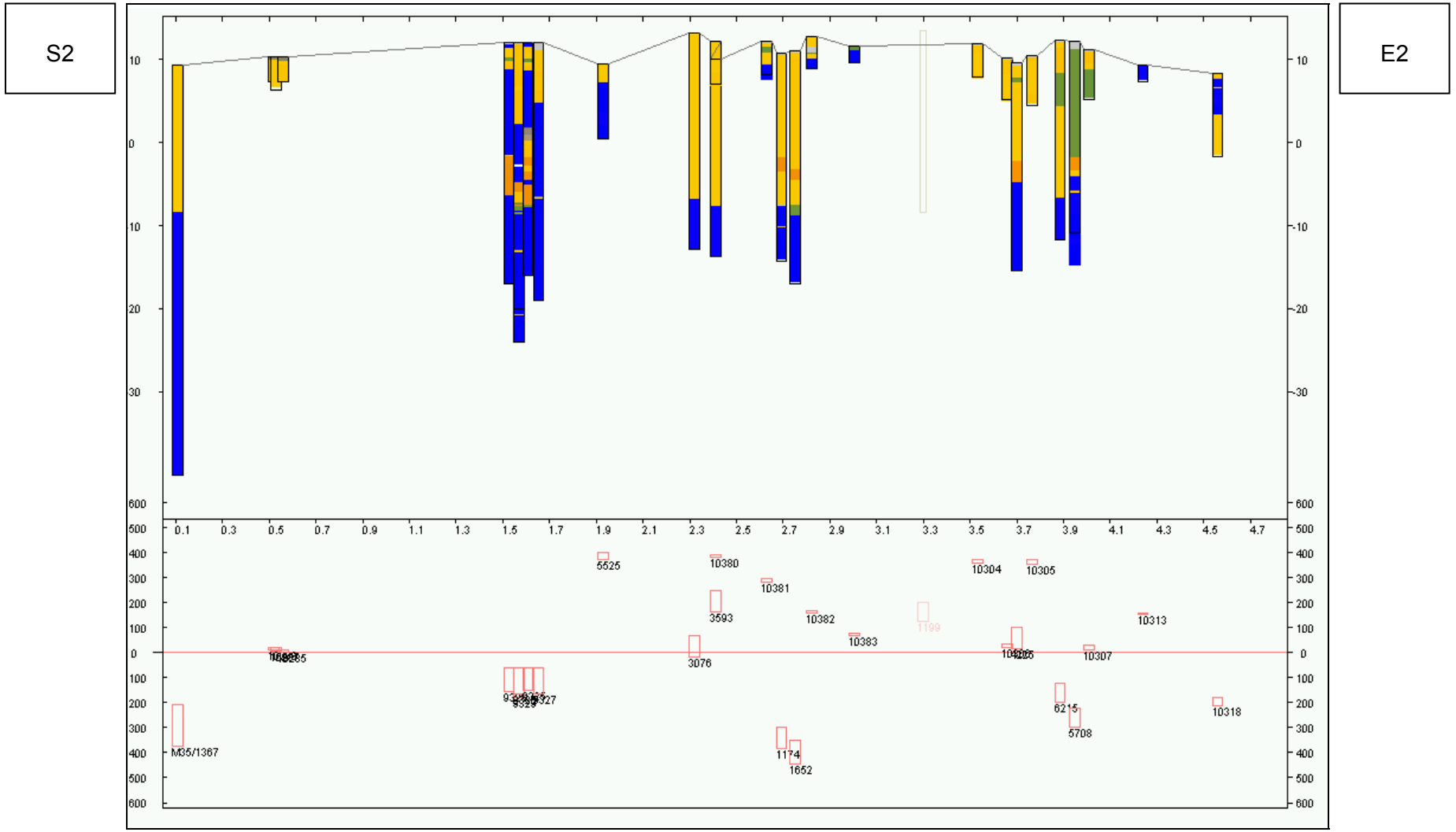


Figure A4.2. Cross section n2.

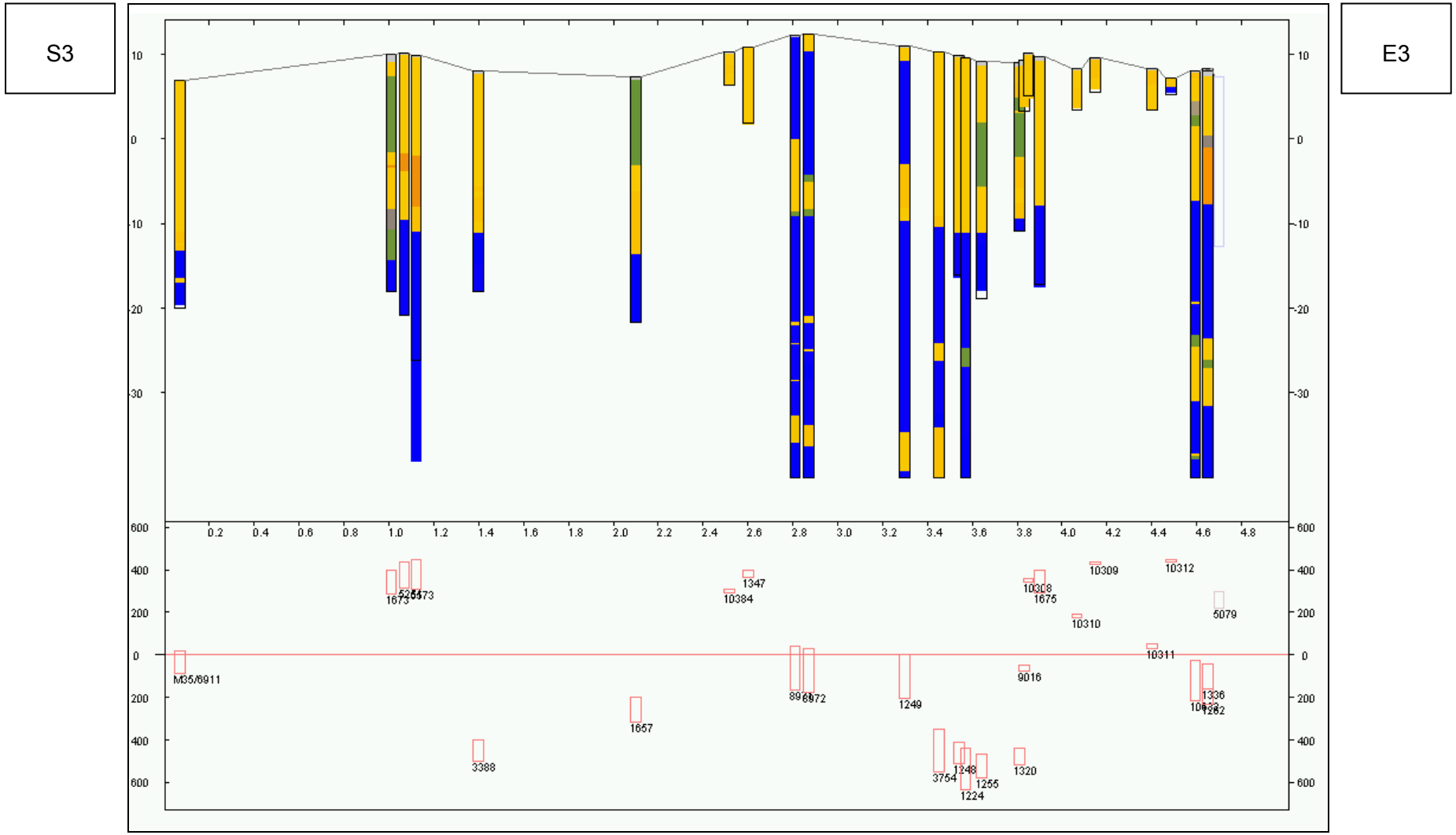


Figure A4.3. Cross section n3.

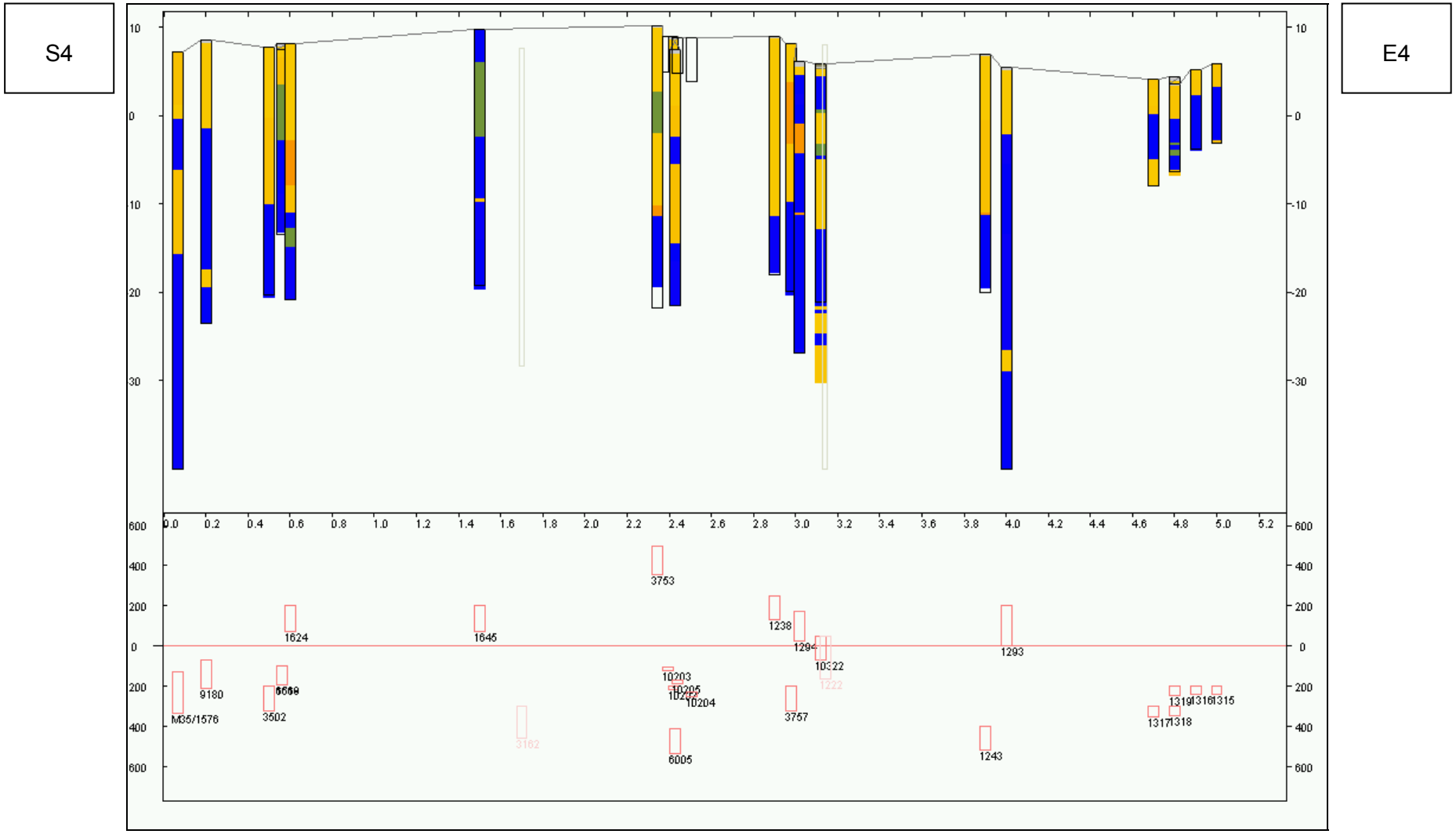


Figure A4.4. Cross section n4.

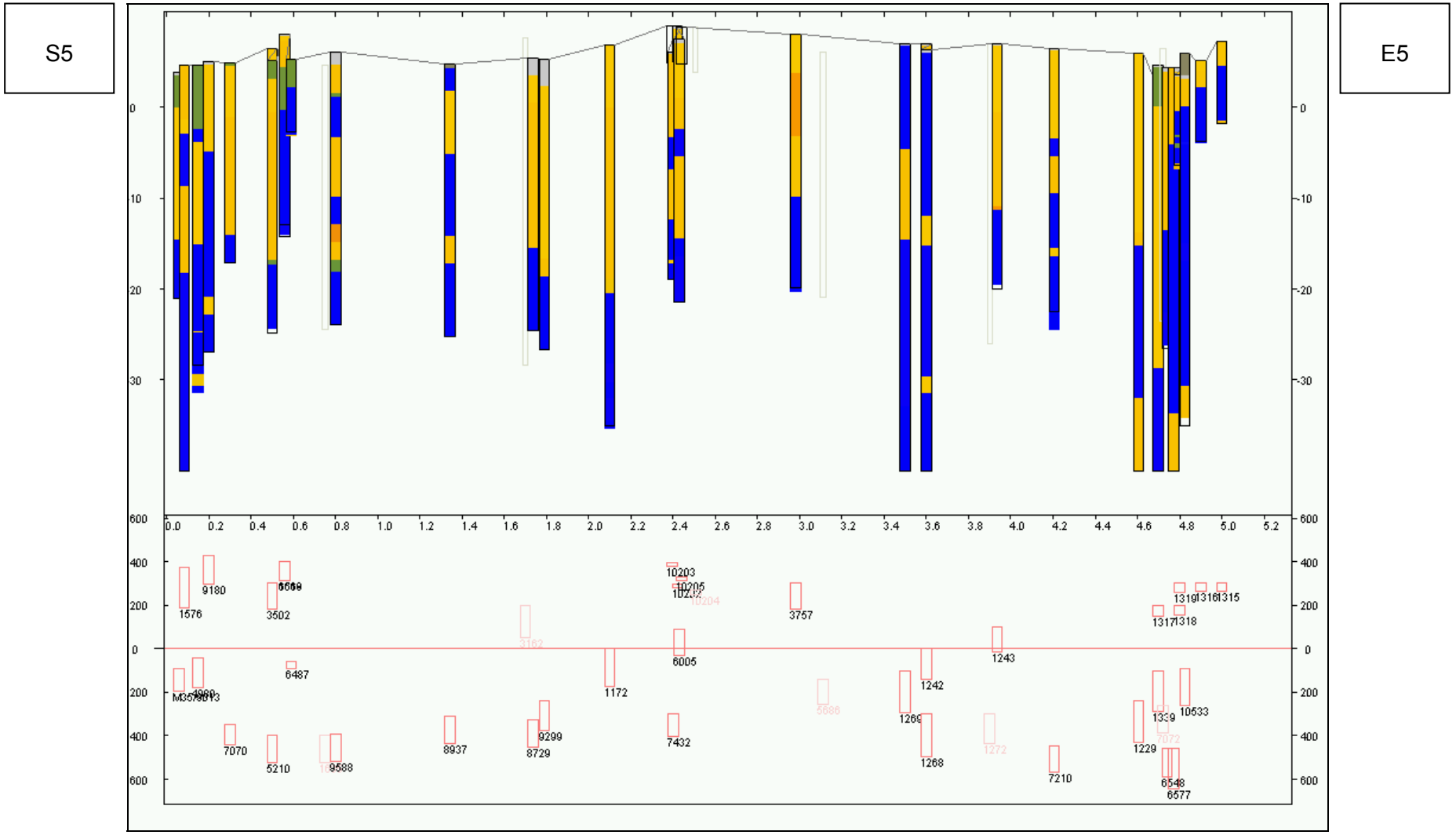


Figure A4.5. Cross section n5.

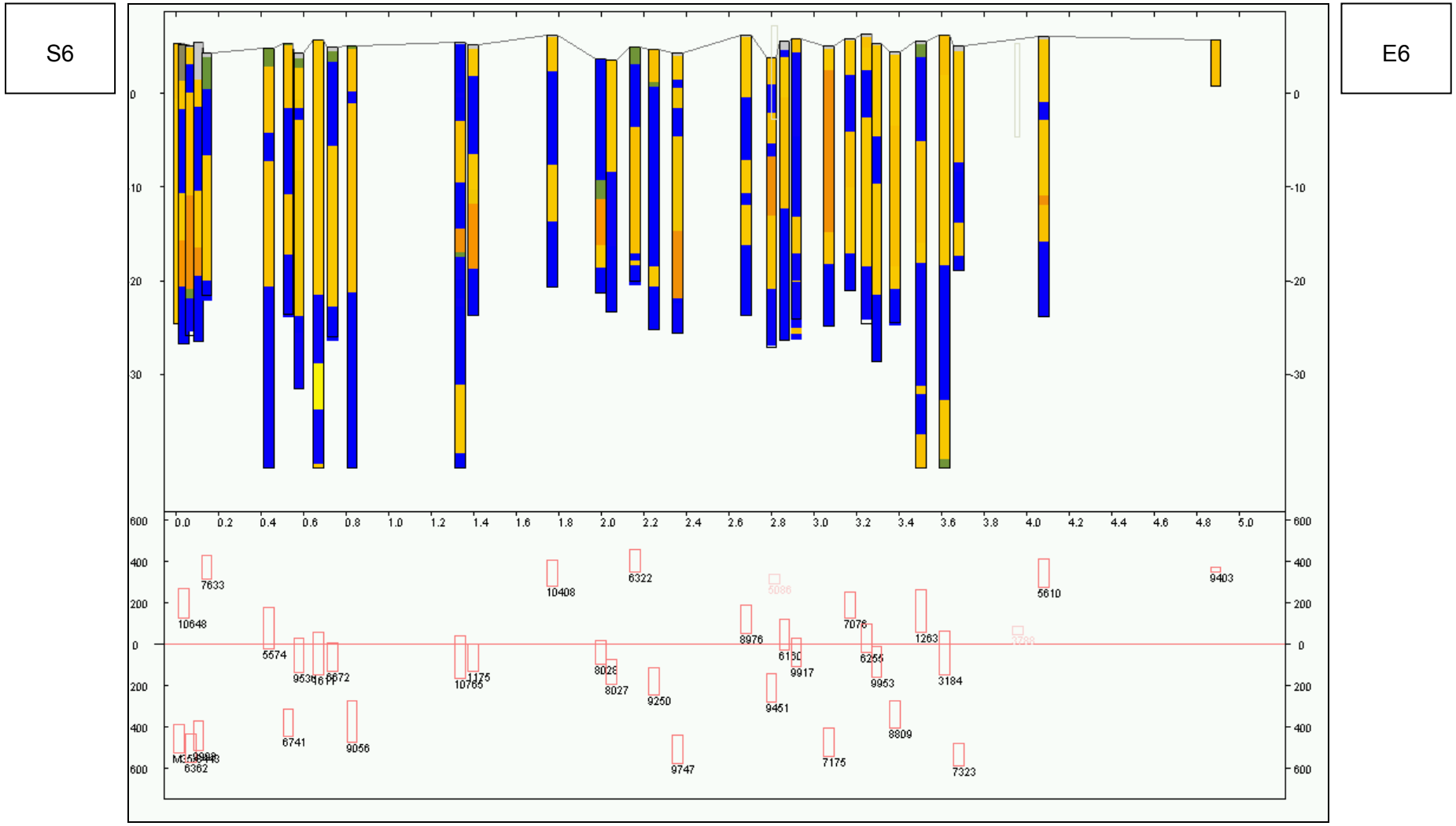


Figure A4.6. Cross section n6.

APPENDIX 5 - RADIOCARBON DATES OF SHALLOW SEDIMENTS

This appendix summarises radiocarbon ages measured in shallow sediments in the greater Christchurch City area as follows:

Table A5.1 lists radiocarbon ages measured by the Rafter Radiocarbon Laboratory in shallow sediments in the greater Christchurch City area under the following headings (Chambers pers. comm.):

- R number – Rafter laboratory tracking number for radiocarbon sample and analysis;
- F number – file number for fossil record sample held in the "Fossil Record File";
- NZ number – GNS Science file number of actual radiocarbon analysis;
- Locality;
- C14 age – original analysis C14 age measured on the sample;
- C14 age – recalculated C14 age recalculated in May 2007 to the revised international C14 half life (Chambers, pers. comm.);
- Grid reference (original) – grid reference as noted at sample collection, contains inch-to-mile coordinates and metric coordinates;
- Grid reference (NZMS260) – eastings and northings calculated from grid reference (original) by Reeves (pers. comm.).

Table A5.2 contains a sub-set of the radiocarbon age data relevant to the assessment of Springston Formation gravel lobes in Christchurch City specifically:

- samples collected south of the Waimakariri River;
- samples collected on the Canterbury Plains;
- samples with a radiocarbon age less than 10000 years old;
- samples with location information;
- samples not related to pre-historic human occupation (i.e. samples from Moa Point Cave and 47 Sumner Road relate to early Maori occupation).

Table A5.3 assesses the provenance of samples, particularly as related to gravel deposition, including:

- R number;
- geological information – whether or not geological information is noted with the sample collection records;
- gravel in profile – whether or not gravel is noted with sample collection records;
- depth to gravel – as noted in sample collection records. Depth is zero where gravel occurs at the ground surface;
- depth to radiocarbon sample – as noted in sample collection records;
- radiocarbon sample provenance and gravel occurrence – comments on the type of sample, the type of substrate, and location of sample relative to gravel sediments;
- P code. This is a code that describes the location of the radiocarbon sample, relative to gravel sediments noted in the sample collection records, as follows
  - ax above the shallowest gravel;
  - iax immediately above the shallowest gravel;
  - wx within the shallowest gravel;

- ibx immediately below the shallowest gravel;
- bx below the shallowest gravel;
- iay immediately above the 2nd- shallowest gravel;
- wy within the 2nd-shallowest gravel;
- iby immediately below the 2nd-shallowest gravel;
- ng no gravel is noted in the sample record;
- uk unknown gravel occurrence.

Table A5.4 lists radiocarbon samples or shallow sediments with both:

- radiocarbon analyses in Table A5.2;
- geological information in the sample collection record.

Original radiocarbon dates are listed in Table A5.4 as these are used (Section 3.4.1) in the analysis of Springston Formation gravel deposition.

Table A5.1. Radiocarbon ages of shallow sediments measured in greater Christchurch City area.

R number	F number	NZ number	Locality	C14 age - original analysis (years before present)	C14 age - recalculated (years before present)	Grid reference (original)	Grid reference (NZMS260 easting)	Grid reference (NZMS260 northing)	Sample provenance information
20	S84/f504	NZ 84	Christchurch Public Hospital	1550±80	1572±42	S84 995558	2479756	5741473	yes
258	S83/f511	NZ 493	Lincoln College Farm	8895±130	8872±76	S83 862418	2467827	5728456	yes
1001	S84/f540	NZ 645	Smart's Gravel Pit Hornby	3230±75	3233±106	S84 904553	2471445	5740867	yes
1391	S83/f502	NZ 576	Prebbleton	5650±125	5650±128	S83 899424	2471200	5729066	yes
1392	S83/f512	NZ 549	Elliott's Gravel Pit Yaldhurst	2310±80	2313±66	S83 881581	2469296	5743388	yes
2030	unknown	NZ 781	Kairaki 13 Site near Kaiapoi	467±51	781+/-60	no location data			
2983	S83/f513	NZ 1294	Springston Canterbury	34600±2750	34523±3410	S83 840440	2465780	5730431	
4193	S76/f522	NZ 1544	Test bore Christchurch	4390±80	4388±76	S76 942614	2474818	5746505	yes
4704	S83/f515	NZ 1930	Lincoln	39500±2700	39521±2270	S83 861432	2467713	5729734	
5069	S83/f516	NZ 3946	Templeton	5020±70	5029±54	S83 838546	2465423	5740118	yes
5175	S83/f517	NZ 3966	Springston Canterbury	40100±5700	40091±4063	no location data			
5192	S76/f524	NZ 4045	Waikuku Nth Canterbury	7490±150	7824+/-143	S76 058853	2485030	5768544	
5363	M36/f1	NZ 4260	Lincoln College	>48,300	nonsense value	M36 672297	2467200	5729700	yes
9218	M35/f5	NZ 5195	Sockburn Christchurch	50869±16053		M35 741411	2474100	5741100	yes
9219	M35/f13	NZ 5196	Clarkville Nth Canterbury	1875±65	1877±61	M35 793563	2479300	5756300	yes
9220	M36/f11	NZ 5174	Prebbleton	>36,800	nonsense value	M36 710355	2471000	5735500	
9309	M36/f23	NZ 5382	Banks Peninsula	27700±1400	27116±1151	M36 892352	2489200	5735200	yes
11178	M36/f34	NZ 7014	Chapmans 6 DSIR Farm Lincoln	6950±65	6920±80	M36 668318	2466800	5731800	yes
1000/1	S83/f503	NZ 428	Paparua Prison	2800±96	2800±103	S83 841593	2465620	5744420	yes
1000/1	S83/f503	NZ 428	Paparua Prison	2800±96	2800±103	S83 841593	2465620	5744420	yes
1000/3	S83/f505	NZ 429	West Melton	1100±76	1098±92	S83 750595	2457298	5744453	yes
1000/4	S83/f506	NZ 430	Broadfields	1725±78	1860±96	S83 842505	2465856	5736377	yes
1000/5	S83/f507	NZ 434	Yaldhurst	1015±75	1009±91	S83 886593	2469734	5744494	yes
1000/6	S76/f508	NZ 431	Harewood	930±60	926±90	S76 928631	2473511	5748037	yes
1000/7	S76/f509	NZ 432	Harewood	<200	-1427±79	S76 914608	2472269	5745911	yes
1000/8	S83/f510	NZ 433	Williamson's Farm Lincoln	2440±95	2434±100	S83 897421	2471022	5728788	yes
1052/1	S84/f76	NZ 459	47 Sumner Rd Redcliffs Chch	location of original file record unknown	777±87	S84 089529	2488396	5738977	
1052/2	S84/	NZ 460	47 Sumner Rd Redcliffs Chch	location of original file record unknown	480±84	S84 089529	2488396	5738977	
1052/4	S84/	NZ 461	47 Sumner Rd Redcliffs Chch	location of original file record unknown	1602±111	S84 089529	2488396	5738977	
1283 (duplicate 595)	S84/f539	NZ 530	University of Canterbury Ilam	6790±30	6750±62	S84 955572	2476076	5742687	yes
1393/1	S84/f550	NZ 550	BNZ Site Cathedral Square	1590±70	1592±63	S84 004560	2480575	5741671	yes
1393/2	S84/f551	NZ 551	BNZ Site Cathedral Square	1585±70	1590±63	S84 004560	2480575	5741671	yes
1393/3	S84/f552	NZ 564	Cathedral Square	7120±110	7678+/-99	S84 004560	2480575	5741671	yes
1556/1	S76/f511	NZ 709	Belfast Christchurch	4020±70	4024±78	S76 959643	2476325	5749184	yes
1556/2	S76/f512	NZ 710	Brooklands	2180+/-55	2494±54	S76 055722	2484971	5756564	yes
1559/1	S84/f557	NZ 712	Cnr Awatea & Carrs Rd Wigram	6450±55	6438±56	S84 928525	2473685	5738346	yes
1559/2	S84/f558	NZ 713	Sockburn Christchurch	6330±100	6340±104	S84 933546	2474108	5740274	yes
1559/3	S84/f560	NZ 715	Heathcote Chch	>44,100	>44,100	S84 056525	2485386	5738557	yes
1724/1	S84/f563	NZ 691	Heathcote Chch	7820±70	8326±56	S84 042528	2484101	5738808	yes
1724/2	S84/f564	NZ 690	Heathcote Chch	6270±85	not in database	S84 042528	2484101	5738808	yes
1724/3	S84/f565	NZ 689	Heathcote Chch	3410±45	3417±47	S84 042528	2484101	5738808	yes
2286/1	unknown	NZ 3466	unknown	no info in file	249±32	no location data			

R number	F number	NZ number	Locality	C14 age - original analysis (years before present)	C14 age - recalculated (years before present)	Grid reference (original)	Grid reference (NZMS260 easting)	Grid reference (NZMS260 northing)	Sample provenance information
2286/1B	unknown	NZ 3528	Lincoln	no info in file	253±32	no location data			
2286/2	unknown	NZ 3467	unknown	no info in file	187±30	no location data			
2286/3	unknown	NZ 3476	unknown	no info in file	141±32	no location data			
2286/3B	unknown	NZ 3527	Lincoln	no info in file	431±32	no location data			
2286/4	unknown	NZ 3511	unknown	no info in file	361±32	no location data			
2286/5	unknown	NZ 3512	Lincoln	no info in file	442±44	no location data			
229/2	S76/f505	NZ 117	Moore's Gravel Pit Kaiapoi	6800±90	6679±58	S76 033773	2482876	5761190	yes
229/3	S83/f501	NZ 118	Lake Ellesmere	9400+/-120	9439±72	S83 891322	2470636	5719728	yes
229/4	S84/f522	NZ 119	Cnr Madras and Chester Sts	8000+/-150	8065±84	S84 010565	2481115	5742138	yes
229/5	S84/f523	NZ 120	Clarence Rd Riccarton	6200+/-120	6096±69	S84 974563	2477828	5741896	yes
229/6	S84/F524	NZ 121	Clarence Rd Riccarton	>40,000	>40,000	S84 974563	2477828	5741896	yes
229/7	S84/f525	NZ 122	Cnr Woodham Rd and Worcester St	3810±70	3852+/-48	S84 040567	2483854	5742370	yes
2356/1	S76/f516	NZ 1084	Woodend Hotel Christchurch	1895±58	1899±64	S76 034807	2482911	5764300	
2356/2	S76/f517	NZ 1085	Waimairi: County Council well	4580±60	4583±60	S76 962611	2476652	5746264	yes
2359/1	S84/f566	NZ 1096	University of Canterbury Ilam	3750±65	3751±64	S84 958574	2476347	5742875	yes
2359/2	S84/f567	NZ 1097	University of Canterbury Ilam	3300±90	3305±104	S84 958574	2476347	5742875	yes
2359/3	S84/f568	NZ 1098	Cnr Manchester & Salisbury ChCh	2040±80	1866±74	S84 008569	2480926	5742500	yes
2359/4	S84/f569	NZ 1099	Cnr Manchester & Salisbury ChCh	4240±100	4390±113	S84 008569	2480926	5742500	yes
2359/5	S84/f571	NZ 1100	Cnr Manchester & Cashel ChCh	4200±105	4202±111	S84 007558	2480853	5741493	yes
2359/6	S84/f572	NZ 1101	Cnr Manchester & Cashel ChCh	3730±75	3737±83	S84 007558	2480853	5741493	yes
2359/7	S84/f573	NZ 1102	Christ's College Christchurch	3030±90	3033±102	S84 996563	2479839	5741932	yes
2359/8	S84/f574	NZ 1103	Christ's College Christchurch	4200±105	1662±92	S84 996563	2479839	5741932	yes
2980/1	S76/f518	NZ 1243	Kaiapoi	3470±95	3474±105	S76 027727	2482403	5756975	yes
2980/2	S76/f519	NZ 1244	Kaiapoi	7370±110	7678±140	S76 029726	2482587	5756887	yes
2980/2	S76/f519	NZ 1244	Kaiapoi	7370±110	7678±140	S76 029726	2482587	5756887	yes
2980/3	S76/f521	NZ 1245	Kaiapoi	7350±130	7655±144	S76 033771	2482879	5761007	yes
2980/3	S76/f521	NZ 1245	Kaiapoi	7350±130	7655±144	S76 033771	2482879	5761007	yes
392/1	S84/f531	NZ 305	Cnr Hills & Edgeware Rds ChCh	2040±60	2088±43	S84 018584	2481815	5743888	yes
392/2	S84/f532	NZ 306	Cambridge Terrace Christchurch	3750±80	3812±48	S84 001564	2480294	5742032	yes
392/3	S84/f533	NZ 307	Cnr Conference and Durham Sts	3160±80	2252±52	S84 002572	2480372	5742765	yes
393/1	S84/f77	NZ 437	Moa Point Cave Redcliffs	646±62	642±88	S84 088529	2488305	5738975	
393/2	S84/f76	NZ 438	Moa Point Cave Redcliffs	1170±65	1167±91	S84 088529	2488305	5738975	
4196/1	S84/f584	NZ 1585	Lincoln Rd Canterbury	4060±80	4055±74	S84 975541	2477955	5739886	yes
4196/2	S84/f585	NZ 1586	Wrights Road, Addington	3030±70	3033±69	S84 970542	2477496	5739970	yes
4705/1	S84/f586	NZ 1816	Port Hills Rd Christchurch	5830±90	6151±59	S84 057512	2485499	5737370	yes
4705/3	S84/f587	NZ 1818	Heathcote River Banks Peninsula	7050±120	7365±95	S84 054532	2485192	5739194	yes
4705/4	S84/f588	NZ 1819	Heathcote River	9180±140	9173±118	S84 054532	2485192	5739194	yes
4705/5	S84/f589	NZ 1809	Ilam Campus Christchurch	350±70	347±57	S84 958573	2476348	5742784	yes
4705/6	S84/f590	NZ 1820	Southern end Port Hills	1900±70	1874±64	S84 954347	2476355	5722117	yes
4705/7	S84/f591	NZ 1821	cnr Port Hills & Scruttons Roads	6190±100	not in database	S84 057512	2485499	5737370	yes
584/1	S84/f536	NZ 274	Palmers Rd	5520±70	5928+/-53	S84 072592	2486739	5744708	yes
584/2	S84/f537	NZ 275	Palmers Rd	7780±80	8160+/-63	S84 072592	2486739	5744708	yes
584/3	S84/f538	NZ 276	Palmers Rd	8530±110	8872+/-66	S84 072595	2486734	5744982	yes

R number	F number	NZ number	Locality	C14 age - original analysis (years before present)	C14 age - recalculated (years before present)	Grid reference (original)	Grid reference (NZMS260 easting)	Grid reference (NZMS260 northing)	Sample provenance information
5861/2	M36/f12	NZ 4850	Prebbleton	27900±750	27931±706	M36 699355	2469900	5735500	
595 (duplicate 1283)	S84/f539	NZ 308	University of Canterbury Ilam	6980±100	6971±60	S84 955572	2476076	5742687	yes
693/1	S75/f511	NZ 382	Lower Waimakariri Road	650±40	625±40	S75 821600	2463780	5745027	yes
693/2	S83/f508	NZ 383	Waimakariri Rd Templeton	3500±70	3506±48	S83 868542	2468172	5739802	yes
693/3	S83/f509	NZ 384	Boyes Farm Broadfields	6495±95	6502±94	S83 842505	2465856	5736377	yes
90/4	S84/f507	NZ 312	Woolston Park	735±55	753+/-40	S84 037543	2483620	5740171	yes
90/5	S84/f516	NZ 99	Blighs Rd	>45,000	nonsense value	S84 972594	2477594	5744726	yes
90/6	S84/f517	NZ 310	Spreydon School Christchurch	2990±110	2980±70	S84 964535	2476959	5739320	yes
90/6	S84/f517	NZ 310	Lincoln Rd	2990±110	2980±70	S84 964535	2476959	5739320	yes
91/2	S84/f521	NZ 86	Bowenvale Rd Christchurch	940±70	959±41	S84 009515	2481106	5737566	yes
91/4	S84/f519	NZ 277	Railway excavation	5270±80	5244±56	S84 101549	2489460	5740825	yes
91/5	S84/f518	NZ 311	Sparks Rd Bridge Christchurch	2460±70	2430±44	S84 982521	2478628	5738070	yes
91/6	S84/f520	NZ 309	Jeffreys Rd Fendalton	4660±90	4662±51	S84 970585	2477426	5743900	yes
9553/1	M35/f15	NZ 5586	Law Courts	894±49	894±47	M35 804422	2480400	5742200	yes
9553/2	M35/f16	NZ 5587	Law Courts	1900±50	1900±48	M35 804422	2480400	5742200	yes
9767/1	M35/f7523	NZ 6505	Kaiapoi	9980±140	9974±115	M35 826569	2482600	5756900	yes
9767/2	M35/f9578	NZ 6478	Moorhouse Av	1875±60	1877±56	M35 815407	2481500	5740700	yes
9767/3	m35/f9581	NZ 6515	Central Police Station	4204±72		M35 803416	2480300	5741600	yes
9767/4	M36/f7580	NZ 6516	Dyers Rd Woolston	3690±90	3706±69	M36 852398	2485200	5739800	yes
9767/5	M36/f7582	NZ 6504	Barrington St	4480±80	4483±69	M36 784398	2478400	5739800	yes
S1334/1	S84/f503	NZ 75	Manderville Road Riccarton	3570±70	3567±49	S84 979558	2478293	5741447	yes
T2823/1	S84/f505b	NZ 25	Cnr Blighs Rd and Waiariki Rd	>40,000	not in database	S84 972594	2477594	5744726	yes
T2823/2	S84/f508	NZ 26	Cashmere Hospital	2420+/-100	not in database	S84 989514	2479279	5737441	yes
T2823/3	S84/f506	NZ 27	St Asaph St	3720+/-100	not in database	S84 995555	2479760	5741199	yes

Notes:

- Brown and Weeber (1992) consider R2359/4 as a duplicate of M35/2149 (10 m deep sample). However the listed ages are different in Table A5.1 and Table A6.1. The age of R2359/4 is listed here;
- C14 sample NZ 713A, R1559/2, age 6330 yr is the analysis in M35/5572 (Appendix 6). Well M35/5572 has no well log (Weeber pers. comm.). However R1559/2 has provenance information on the field collection sheet.

Table A5.2 Radiocarbon ages of shallow sediments in the Christchurch City area.

R number	F number	NZ number	Locality	C14 age - original analysis (years before present)	C14 age - recalculated (years before present)	Grid reference (original)	Grid reference (NZMS260 easting)	Grid reference (NZMS260 northing)	Sample provenance information
20	S84/f504	NZ 84	Christchurch Public Hospital	1550±80	1572±42	S84 995558	2479756	5741473	yes
258	S83/f511	NZ 493	Lincoln College Farm	8895±130	8872±76	S83 862418	2467827	5728456	yes
1001	S84/f540	NZ 645	Smart's Gravel Pit Hornby	3230±75	3233±106	S84 904553	2471445	5740867	yes
1283	S84/f539	NZ 530	University of Canterbury Ilam	6790±30	6750±62	S84 955572	2476076	5742687	yes
1391	S83/f502	NZ 576	Prebbleton	5650±125	5650±128	S83 899424	2471200	5729066	yes
1392	S83/f512	NZ 549	Elliott's Gravel Pit Yaldhurst	2310±80	2313±66	S83 881581	2469296	5743388	yes
4193	S76/f522	NZ 1544	Test bore Christchurch	4390±80	4388±76	S76 942614	2474818	5746505	yes
5069	S83/f516	NZ 3946	Templeton	5020±70	5029±54	S83 838546	2465423	5740118	yes
11178	M36/f34	NZ 7014	Chapmans 6 DSIR Farm Lincoln	6950±65	6920±80	M36 668318	2466800	5731800	yes
1000/1	S83/f503	NZ 428	Paparua Prison	2800±96	2800±103	S83 841593	2465620	5744420	yes
1000/1	S83/f503	NZ 428	Paparua Prison	2800±96	2800±103	S83 841593	2465620	5744420	yes
1000/3	S83/f505	NZ 429	West Melton	1100±76	1098±92	S83 750595	2457298	5744453	yes
1000/4	S83/f506	NZ 430	Broadfields	1725±78	1860±96	S83 842505	2465856	5736377	yes
1000/5	S83/f507	NZ 434	Yaldhurst	1015±75	1009±91	S83 886593	2469734	5744494	yes
1000/6	S76/f508	NZ 431	Harewood	930±60	926±90	S76 928631	2473511	5748037	yes
1000/7	S76/f509	NZ 432	Harewood	<200	-1427±79	S76 914608	2472269	5745911	yes
1000/8	S83/f510	NZ 433	Williamson's Farm Lincoln	2440±95	2434±100	S83 897421	2471022	5728788	yes
1393/1	S84/f550	NZ 550	BNZ Site Cathedral Square	1590±70	1592±63	S84 004560	2480575	5741671	yes
1393/2	S84/f551	NZ 551	BNZ Site Cathedral Square	1585±70	1590±63	S84 004560	2480575	5741671	yes
1393/3	S84/f552	NZ 564	Cathedral Square	7120±110	7678+/-99	S84 004560	2480575	5741671	yes
1556/1	S76/f511	NZ 709	Belfast Christchurch	4020±70	4024±78	S76 959643	2476325	5749184	yes
1556/2	S76/f512	NZ 710	Brooklands	2180+/-55	2494±54	S76 055722	2484971	5756564	yes
1559/1	S84/f557	NZ 712	Cnr Awatea & Carrs Rd Wigram	6450±55	6438±56	S84 928525	2473685	5738346	yes
1559/2	S84/f558	NZ 713	Sockburn Christchurch	6330±100	6340±104	S84 933546	2474108	5740274	yes
1724/1	S84/f563	NZ 691	Heathcote Chch	7820±70	8326±56	S84 042528	2484101	5738808	yes
1724/2	S84/f564	NZ 690	Heathcote Chch	6270±85	not in database	S84 042528	2484101	5738808	yes
1724/3	S84/f565	NZ 689	Heathcote Chch	3410±45	3417±47	S84 042528	2484101	5738808	yes
229/3	S83/f501	NZ 118	Lake Ellesmere	9400+/-120	9439±72	S83 891322	2470636	5719728	yes
229/4	S84/f522	NZ 119	Cnr Madras and Chester Sts	8000+/-150	8065±84	S84 010565	2481115	5742138	yes
229/5	S84/f523	NZ 120	Clarence Rd Riccarton	6200+/-120	6096±69	S84 974563	2477828	5741896	yes
229/7	S84/f525	NZ 122	Cnr Woodham Rd and Worcester St	3810±70	3852+/-48	S84 040567	2483854	5742370	yes
2356/2	S76/f517	NZ 1085	Waimairi: County Council well	4580±60	4583±60	S76 962611	2476652	5746264	yes
2359/1	S84/f566	NZ 1096	University of Canterbury Ilam	3750±65	3751±64	S84 958574	2476347	5742875	yes
2359/2	S84/f567	NZ 1097	University of Canterbury Ilam	3300±90	3305±104	S84 958574	2476347	5742875	yes
2359/3	S84/f568	NZ 1098	Cnr Manchester & Salisbury ChCh	2040±80	1866±74	S84 008569	2480926	5742500	yes
2359/4	S84/f569	NZ 1099	Cnr Manchester & Salisbury ChCh	4240±100	4390±113	S84 008569	2480926	5742500	yes
2359/5	S84/f571	NZ 1100	Cnr Manchester & Cashel ChCh	4200±105	4202±111	S84 007558	2480853	5741493	yes
2359/6	S84/f572	NZ 1101	Cnr Manchester & Cashel ChCh	3730±75	3737±83	S84 007558	2480853	5741493	yes
2359/7	S84/f573	NZ 1102	Christ's College Christchurch	3030±90	3033±102	S84 996563	2479839	5741932	yes
2359/8	S84/f574	NZ 1103	Christ's College Christchurch	4200±105	1662±92	S84 996563	2479839	5741932	yes
392/1	S84/f531	NZ 305	Cnr Hills & Edgeware Rds ChCh	2040±60	2088±43	S84 018584	2481815	5743888	yes
392/2	S84/f532	NZ 306	Cambridge Terrace Christchurch	3750±80	3812±48	S84 001564	2480294	5742032	yes

R number	F number	NZ number	Locality	C14 age - original analysis (years before present)	C14 age - recalculated (years before present)	Grid reference (original)	Grid reference (NZMS260 easting)	Grid reference (NZMS260 northing)	Sample provenance information
392/3	S84/f533	NZ 307	Cnr Conference and Durham Sts	3160±80	2252±52	S84 002572	2480372	5742765	yes
4196/1	S84/f584	NZ 1585	Lincoln Rd Canterbury	4060±80	4055±74	S84 975541	2477955	5739886	yes
4196/2	S84/f585	NZ 1586	Wrights Road, Addington	3030±70	3033±69	S84 970542	2477496	5739970	yes
4705/1	S84/f586	NZ 1816	Port Hills Rd Christchurch	5830±90	6151±59	S84 057512	2485499	5737370	yes
4705/3	S84/f587	NZ 1818	Heathcote River Banks Peninsula	7050±120	7365±95	S84 054532	2485192	5739194	yes
4705/4	S84/f588	NZ 1819	Heathcote River	9180±140	9173±118	S84 054532	2485192	5739194	yes
4705/5	S84/f589	NZ 1809	Ilam Campus Christchurch	350±70	347±57	S84 958573	2476348	5742784	yes
4705/6	S84/f590	NZ 1820	Southern end Port Hills	1900±70	1874±64	S84 954347	2476355	5722117	yes
4705/7	S84/f591	NZ 1821	cnr Port Hills & Scruttons Roads	6190±100	not in database	S84 057512	2485499	5737370	yes
584/1	S84/f536	NZ 274	Palmers Rd	5520±70	5928+/-53	S84 072592	2486739	5744708	yes
584/2	S84/f537	NZ 275	Palmers Rd	7780±80	8160+/-63	S84 072592	2486739	5744708	yes
584/3	S84/f538	NZ 276	Palmers Rd	8530±110	8872+/-66	S84 072595	2486734	5744982	yes
693/1	S75/f511	NZ 382	Lower Waimakariri Road	650±40	625±40	S75 821600	2463780	5745027	yes
693/2	S83/f508	NZ 383	Waimakariri Rd Templeton	3500±70	3506±48	S83 868542	2468172	5739802	yes
693/3	S83/f509	NZ 384	Boyes Farm Broadfields	6495±95	6502±94	S83 842505	2465856	5736377	yes
90/4	S84/f507	NZ 312	Woolston Park	735±55	753+/-40	S84 037543	2483620	5740171	yes
90/6	S84/f517	NZ 310	Spreydon School Christchurch	2990±110	2980±70	S84 964535	2476959	5739320	yes
90/6	S84/f517	NZ 310	Lincoln Rd	2990±110	2980±70	S84 964535	2476959	5739320	yes
91/2	S84/f521	NZ 86	Bowenvale Rd Christchurch	940±70	959±41	S84 009515	2481106	5737566	yes
91/4	S84/f519	NZ 277	Railway excavation	5270±80	5244±56	S84 101549	2489460	5740825	yes
91/5	S84/f518	NZ 311	Sparks Rd Bridge Christchurch	2460±70	2430±44	S84 982521	2478628	5738070	yes
91/6	S84/f520	NZ 309	Jeffreys Rd Fendalton	4660±90	4662±51	S84 970585	2477426	5743900	yes
9553/1	M35/f15	NZ 5586	Law Courts	894±49	894±47	M35 804422	2480400	5742200	yes
9553/2	M35/f16	NZ 5587	Law Courts	1900±50	1900±48	M35 804422	2480400	5742200	yes
9767/2	M35/f9578	NZ 6478	Moorhouse Av	1875±60	1877±56	M35 815407	2481500	5740700	yes
9767/3	m35/f9581	NZ 6515	Central Police Station	4204±72		M35 803416	2480300	5741600	yes
9767/4	M36/f7580	NZ 6516	Dyers Rd Woolston	3690±90	3706±69	M36 852398	2485200	5739800	yes
9767/5	M36/f7582	NZ 6504	Barrington St	4480±80	4483±69	M36 784398	2478400	5739800	yes
S1334/1	S84/f503	NZ 75	Manderville Road Riccarton	3570±70	3567±49	S84 979558	2478293	5741447	yes
T2823/2	S84/f508	NZ 26	Cashmere Hospital	2420+/-100	not in database	S84 989514	2479279	5737441	yes
T2823/3	S84/f506	NZ 27	St Asaph St	3720+/-100	not in database	S84 995555	2479760	5741199	yes

Table A5.3. Provenance of radiocarbon samples and location of gravel sediments.

R Number	Geological information	Gravel in profile	Depth to gravel (m)	Depth to RC sample (m)	RC sample provenance and gravel occurrence	P Code
20	√	√	6	3.3 - 4.5	wood samples at 3.3m - 4.5m in silty sand over gravel	ax
258	x	-	-	0.8 - 1.1	wood sample depth 0.8m - 1.1m	-
258	x	-	-	1	buried wood in clay substrate approximately 1m below ground level	-
1001	√	√	0?	9	wood, matai buried in 9m of gravel	wx
1391	√	√	1.4	0.6	charcoal 0.6m below ground level	iax
1392	√	√	0?	6	charcoal - matai below 6m of gravel	wx
4193	x	-	-	9 - 10.5	sample 9m - 10.5m deep possibly from base of Springton or Christchurch Formation	-
5069	√	√	1.2	0.56	charcoal (Totara) 0.56m deep	iax
5363	√	√	2 gravel layers: 4.6 - 25.6, 31.4 - 36.0 (eoh)	25.6	Sample 25.6m deep in pug and wood	ibx
9218	√	√	2 gravel layers: 0 - 10, 10 - 40	40 - 43	sample at base of second gravel layer 40m - 43m	iby
9219	√	√	8.5	7.6 - 8.5 or 6.4	wood sample at 7.6m - 8.5m or 6.4m	ax
9309	√	x	-	10	Moa bone femur 10m deep in loess on Port Hills close to base of loess	ng
11178	√	x	-	0.67	Sample 0.67m deep in soils. NB record notes soils 'within post glacial Springston alluvium'	wx
693/3	√	?	0	0.6 - 0.8	charcoal 0.6m - 0.8m below surface and 0.6m of gravel	ibx
1000/1	√	√	0	4.5	wood from log lying horizontally 4.5m below surface	wx
1000/3	x	-	-	0.2	charcoal sample depth 0.2m	-
1000/4	x	-	-	0.3 - 0.45	charcoal sample depth 0.3m - 0.45m	-
1000/5	√	x	-	0.45	charcoal from base of Selwyn soil and sediment	ax
1000/6	√	√	0	3	wood buried in 3m of gravel	wx
1000/7	√	√	0	3	wood, washed in, lying horizontal 3m below surface in gravels	wx
1000/8	√	√ alluvium	0.2	0.6	wood from base of alluvium	ibx
1052/1	x	x	-	1	Log charcoal at base of oven	-
1052/2	x	x	-	0.5	Moa bone - pelvis fragment	-
1052/4	x	x	-	0.2	Moa bone - femur	-
1283 (duplicate 595)	x	-	-	13.8	peat sample from 13.8m	-
1393/1	√	√	at most 3.7	3.65	wood within coarse sand, gravel overlying, silt under	bx
1393/2	√	√	5.7	5.7	wood at top of gravel	iay
1393/3	x	-	-	20.4 - 21	sample depth 20.4m - 21m Christchurch Formation	-
1556/1	√	√	2 gravel layers: 0 - 9.2, 10.7 - 15	9.2 - 10.7	peat from base of shallow gravel 9.2m - 10.7m	ibx
1556/2	x	-	-	5.1 - 6	shell 5.1m - 6m	-
1559/1	√	√	2 gravel layers: 2.1 - 11.1, 14.2 - 21.0 (eoh)	13.5 - 14.1	wood, 13.5m - 14.1m	bx
1559/2	√	√	2 layers: 0 - 7.2, 12 to deeper	7.5	wood sample from 7.5m	ibx
1559/3	x	-	-	90.9 -93.3	sample from 90.9m -93.3m	-
1724/1	√	x	-	16.8 to 17.7	Shell sample 16.8m to 17.7m deep in blue-grey clay (Christchurch Formation)	ng
1724/2	√	x	-	12.6 to 13.8	Sample 12.6m to 13.8m deep in blue-grey sand (Christchurch Formation)	ng
1724/3	√	x	-	9.6 to 10.2	wood and charcoal sample 9.6m to 10.2m deep in fine blue-grey sand (Christchurch Formation)	ng
229/2	x	-	0	9	sample depth 9m in gravel pit	wx
229/3	x	-	-	22.5	sample depth 22.5m	-
229/4	x	-	-	21.9	sample depth 21.9m	-
229/5	x	-	-	12.9	sample depth 12.9m	-
229/6	x	-	-	41.1	sample depth 41.1m	-
229/7	x	-	-	4.2	sample depth 4.2m	-
2356/2	√	√	2 gravel layers: 1.2 - 11.7, 15.9 - 27	14.4 - 14.7	sample depth 14.4m - 14.7m Christchurch Formation	bx
2359/1	√	√	1.3m to 3.6m	3.3	silty clays at 3.3m - presumably above gravels	iax
2359/2	√	√	1.3 to 3.6	1.3	wood? Sample at 1.3m depth	iax

R Number	Geological information	Gravel in profile	Depth to gravel (m)	Depth to RC sample (m)	RC sample provenance and gravel occurrence	P Code
2359/3	√	√	2 gravel layers: 3.9 - 6.8, 8.0 - 9.9	6.8 - 8.0	sample depth 6.8m - 8.0m below shallow gravel	ibx
2359/4	√	√	2 gravel layers: 3.9 - 6.8, 8.0 - 9.9	9 - 9.9	sample depth 9m - 9.9m at base of deeper gravel	iby
2359/5	x	-	-	7.5 - 9	wood and peat 7.5m - 9m deep	-
2359/6	x	-	-	10.5	wood 10.5m deep	-
2359/7	√	√	4.5	4.5	wood sample 4.5m deep on top of gravel	iax
2359/8	√	√	4.5	9.6	sample at 9.6m at base of gravel	ibx
2980/1	x	-	-	15	wood 15m deep, 0.9m above Christchurch Formation	-
2980/2	x	-	-	6.6	shell, 6.6m deep, Christchurch Formation	-
2980/3	x	-	-	13.5 - 15	shell, 13.5m - 15m deep	-
392/1	x	-	-	1.3	peat 0.3m thick at a depth of 1.3m	-
392/2	x	-	-	10	peat from swamp forest 10m deep	-
392/3	x	-	-	3	peat at 3m at base of 'overburden'	-
4196/1	√	√	2.7 (estimate)	9.6 - 9.9	wood 9.6m - 9.9m 'under' 6.9m of gravel	bx
4196/2	√	√	2.7 (estimate)	8.1 - 9.6	wood 8.1m - 9.6m deep	bx
4705/1	√	x	-	2.15	shell sample depth 2.15m	ng
4705/3	x	-	-	17.4 to 18.0	shell sample (?) depth 17.4 to 18.0 m, Christchurch Formation	-
4705/4	x	-	-	24.0 to 26.1	peat sample (?) depth 24.0 to 26.1m, near base of Christchurch Formation	-
4705/5	√	√	gravel noted, but no estimate of depth	1.5	podocarp sample 1.5m deep	ax
4705/6	x	-	-	2.94	moa bone depth 2.94m, in peat, near Motukarara	-
4705/7	x	-	-	3	shell sample (?) depth 3.0 m, Christchurch Formation	-
584/1	√	√	?	elevation - 15.3m (note elevation, not depth)	sample elevation - 15.3m Christchurch Formation	uk
584/2	x	-	-	elevation - 22.2 (note elevation, not depth)	sample elevation - 22.2m Christchurch Formation	-
584/3	x	-	-	elevation - 27.3 - 27.6 (note elevation, not depth)	sample elevation - 27.3m - 27.6m Christchurch Formation	-
693/1	√	x	-	0.8	charcoal 0.8m below surface (base of Selwyn soil)	ax
693/2	√	√	0.4	0.4 - 0.6	charcoal from base of alluvium depth 0.4m - 0.6m	ibx
90/4	x	-	-	2.7	wood 2.7m deep	-
90/4	x	-	-	2.7	sample depth 2.7m wood	-
90/5	x	-	-	45	sample depth 45m	-
90/6	x	-	-	10.5	wood 10.5m deep	-
90/6	x	-	-	10.5	sample depth 10.5m wood	-
91/2	√	x	-	2.4	wood from fine sand and silt over mud, 2.4m below road level	ng
91/4	x	-	-	5.1	blue silt in drill hole 5.1m depth	-
91/5	√	√	1.5	1.5?	sample from gravel underlying blue-grey clay. Sample 1.5m below ground level?	wx
91/6	x	-	-	5.4	peat, 5.4m depth	-
9553/1	√	√	5.5	3.5	3.5m deep, 2m above gravel	ax
9553/2	√	√	5.5	5.5	sample at 5.5m on top of gravel	iax
9767/1	√	√	3 gravel layers: 6.7 - 9.1, 10.7 - 11.3, 12.5-15.5 (eoh)	11.3	sample at 11.3m at base of second gravel layer	iby
9767/2	√	√	1	3.2	sample at 3.2m depth in gravel	wx
9767/3	√	√	2 gravel layers: 2.9 - 12.7 deep, 23.2 - 30.5(eoh)	13.1 to 14.0	sample at 13.1m to 14.0m at base of first gravel layer	ibx
9767/4	√	x	-	3.4	3.4m deep in clay-silt	ng
9767/5	√	√	4.4 to 9.1	13.1	wood, 13.1m deep	bx
S1334/1	x	-	-	4	sample from peat 4m deep in silts	-
T2823/1	√	√	2 gravels: 0.9 to 14.4, 2 - 18 to 62.7	57	peat sample depth 57m 40,000 years plus - identifying Riccarton or older gravel	wy
T2823/2	√	√	?	3.3	sample 3.3m in sandy gravel	wx
T2823/3	√	x	-	2.4	timber sample 2.4m in silty sand	-

Table A5.4. Radiocarbon samples of shallow sediments used in the analysis of gravel deposition chronology.

R number	F number	NZ number	Locality	C14 age - original analysis (years before present)	Grid reference (NZMS260 easting)	Grid reference (NZMS260 northing)	Depth to RC sample (m)	C14 age - original analysis (years before present) without error	P code
20	S84/f504	NZ 84	Christchurch Public Hospital	1550±80	2479756	5741473	3.3 - 4.5	1550	ax
1001	S84/f540	NZ 645	Smart's Gravel Pit Hornby	3230±75	2471445	5740867	9	3230	wx
1391	S83/f502	NZ 576	Prebbleton	5650±125	2471200	5729066	0.6	5650	iax
1392	S83/f512	NZ 549	Elliott's Gravel Pit Yaldhurst	2310±80	2469296	5743388	6	2310	wx
5069	S83/f516	NZ 3946	Templeton	5020±70	2465423	5740118	0.56	5020	iax
11178	M36/f34	NZ 7014	Chapmans 6 DSIR Farm Lincoln	6950±65	2466800	5731800	0.67	6950	wx
1000/1	S83/f503	NZ 428	Paparua Prison	2800±96	2465620	5744420	4.5	2800	wx
1000/5	S83/f507	NZ 434	Yaldhurst	1015±75	2469734	5744494	0.45	1015	ax
1000/6	S76/f508	NZ 431	Harewood	930±60	2473511	5748037	3	930	wx
1000/7	S76/f509	NZ 432	Harewood	<200	2472269	5745911	3	<200	wx
1000/8	S83/f510	NZ 433	Williamson's Farm Lincoln	2440±95	2471022	5728788	0.6	2440	ibx
1393/1	S84/f550	NZ 550	BNZ Site Cathedral Square	1590±70	2480575	5741671	3.65	1590	bx
1393/2	S84/f551	NZ 551	BNZ Site Cathedral Square	1585±70	2480575	5741671	5.7	1585	iay
1556/1	S76/f511	NZ 709	Belfast Christchurch	4020±70	2476325	5749184	9.2 - 10.7	4020	ibx
1559/1	S84/f557	NZ 712	Cnr Awatea & Carrs Rd Wigram	6450±55	2473685	5738346	13.5 - 14.1	6450	bx
1559/2	S84/f558	NZ 713	Sockburn Christchurch	6330±100	2474108	5740274	7.5	6330	ibx
1724/1	S84/f563	NZ 691	Heathcote Chch	7820±70	2484101	5738808	16.8 to 17.7	7820	ng
1724/2	S84/f564	NZ 690	Heathcote Chch	6270±85	2484101	5738808	12.6 to 13.8	6270	ng
1724/3	S84/f565	NZ 689	Heathcote Chch	3410±45	2484101	5738808	9.6 to 10.2	3410	ng
2356/2	S76/f517	NZ 1085	Waimairi: County Council well	4580±60	2476652	5746264	14.4 - 14.7	4580	bx
2359/1	S84/f566	NZ 1096	University of Canterbury Ilam	3750±65	2476347	5742875	3.3	3750	iax
2359/2	S84/f567	NZ 1097	University of Canterbury Ilam	3300±90	2476347	5742875	1.3	3300	iax
2359/3	S84/f568	NZ 1098	Cnr Manchester & Salisbury ChCh	2040±80	2480926	5742500	6.8 - 8.0	2040	ibx
2359/4	S84/f569	NZ 1099	Cnr Manchester & Salisbury ChCh	4240±100	2480926	5742500	9 - 9.9	4240	iby
2359/7	S84/f573	NZ 1102	Christ's College Christchurch	3030±90	2479839	5741932	4.5	3030	iax
2359/8	S84/f574	NZ 1103	Christ's College Christchurch	4200±105	2479839	5741932	9.6	4200	ibx
4196/1	S84/f584	NZ 1585	Lincoln Rd Canterbury	4060±80	2477955	5739886	9.6 - 9.9	4060	bx
4196/2	S84/f585	NZ 1586	Wrights Road, Addington	3030±70	2477496	5739970	8.1 - 9.6	3030	bx
4705/1	S84/f586	NZ 1816	Port Hills Rd Christchurch	5830±90	2485499	5737370	2.15	5830	ng
4705/5	S84/f589	NZ 1809	Ilam Campus Christchurch	350±70	2476348	5742784	1.5	350	ax
584/1	S84/f536	NZ 274	Palmers Rd	5520±70	2486739	5744708	elevation - 15.3m (note elevation, not depth)	5520	uk
693/1	S75/f511	NZ 382	Lower Waimakariri Road	650±40	2463780	5745027	0.8	650	ax
693/2	S83/f508	NZ 383	Waimakariri Rd Templeton	3500±70	2468172	5739802	0.4 - 0.6	3500	ibx
693/3	S83/f509	NZ 384	Boyes Farm Broadfields	6495±95	2465856	5736377	0.6 - 0.8	6495	ibx
91/2	S84/f521	NZ 86	Bowenvale Rd Christchurch	940±70	2481106	5737566	2.4	940	ng
91/5	S84/f518	NZ 311	Sparks Rd Bridge Christchurch	2460±70	2478628	5738070	1.5?	2460	wx
9553/1	M35/f15	NZ 5586	Law Courts	894±49	2480400	5742200	3.5	894	ax
9553/2	M35/f16	NZ 5587	Law Courts	1900±50	2480400	5742200	5.5	1900	iax
9767/3	m35/f9581	NZ 6515	Central Police Station	4204±72	2480300	5741600	13.1 to 14.0	4204	ibx
9767/2	M35/f9578	NZ 6478	Moorhouse Av	1875±60	2481500	5740700	3.2	1875	wx
9767/4	M36/f7580	NZ 6516	Dyers Rd Woolston	3690±90	2485200	5739800	3.4	3690	ng
9767/5	M36/f7582	NZ 6504	Barrington St	4480±80	2478400	5739800	13.1	4480	bx
T2823/2	S84/f508	NZ 26	Cashmere Hospital	2420+/-100	2479279	5737441	3.3	2420	wx

APPENDIX 6 - GEOLOGICAL LOGS OF WELLS AND RADIOCARBON AGES OF SEDIMENTS

Radiocarbon dates of samples taken from wells are summarised in Table A6.1.

Geological logs held by ECan is reproduced in this appendix with the radiocarbon sample data (and error) held by ECan indicated at the sample depth.

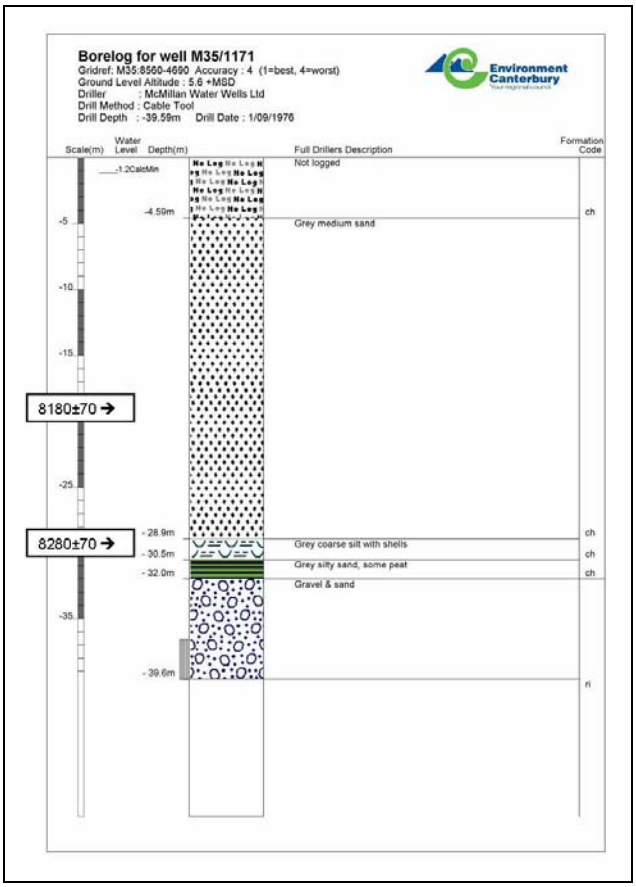
Partial geological logs are presented for some wells where the well log sheet contains lithologies that are deeper than radiocarbon samples.

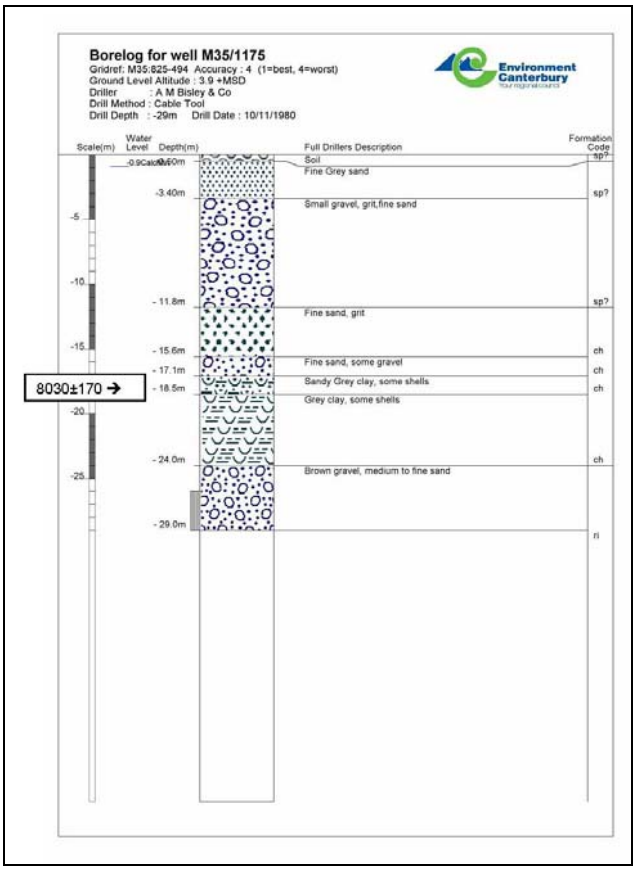
Table A6.1. Radiocarbon dates of samples taken from wells.

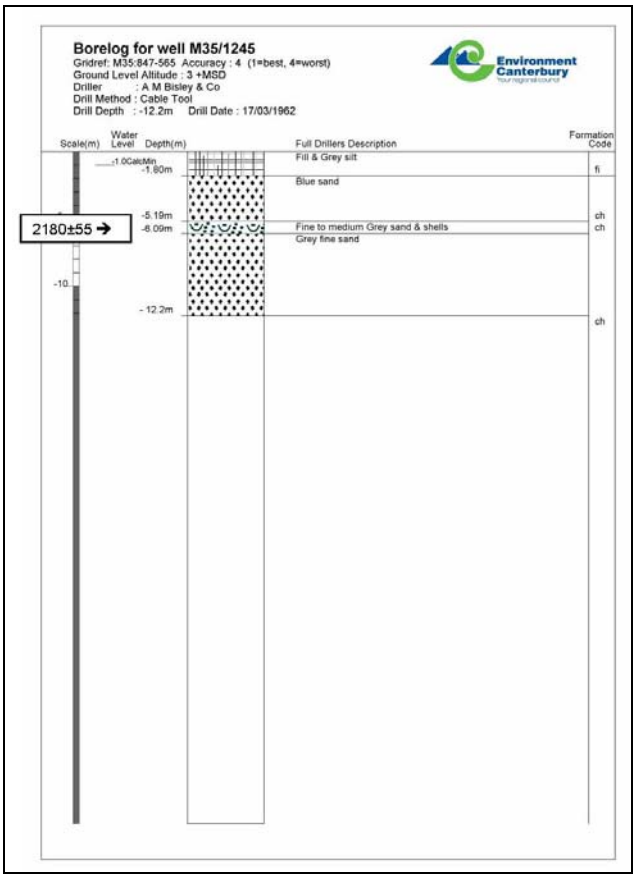
Analysis	Well_No	Depth	Test_material	Report	C14 age (years)	C14 error	Lithology classification	Easting Coordinate (m)	Northing Coordinate (m)
C14	M35/1171	30	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F1	8280	70	CFF	2485600	5746900
C14	M35/1171	19	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F2	8180	70	NBS	2485600	5746900
C14	M35/1175	18	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F7	8030	170	CFF	2482500	5749400
C14	M35/1245	6	SHELL		2180	55	NBS	2484700	5756500
C14	M35/1246	6	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F7512	2180	55	NBS	2485100	5756500
C14	M35/1358	20	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F6	6600	140	CFF	2478090	5747700
C14	M35/1364	10	PEAT	BROWN & WEEBER 1992, (LO1C-7352), M35/F7511	4020	70	SFF	2476380	5749140
C14	M35/1366	15	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F7517	4580	60	SFF	2476639	5746251
C14	M35/1495	10	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F7522	4390	80	SFF	2474750	5746450
C14	M35/1871	24	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F9537	7780	80	CF undif	2486700	5744700
C14	M35/1871	17	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F9536	5520	70	CF undif	2486700	5744700
C14	M35/1871	28	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F9538	8530	110	CF undif	2486700	5744700
C14	M35/1943	4	PEAT	BROWN & WEEBER 1992, (LO1C-7352), M35/F9503	3570	70	SFF	2478228	5741601
C14	M35/1974	22	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F9522	8000	150	CFF	2481100	5742000
C14	M35/1975	28	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F8	8410	170	CFF	2484400	5745160
C14	M35/1987	13	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F9523	6200	120	CFF	2477800	5741800
C14	M35/1987	42	PEAT	BROWN & WEEBER 1992, (LO1C-7352), M35/F9524	43000	0	Bromley	2477800	5741800
C14	M35/2054	46	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F9516	45000	0	Bromley	2477580	5744560
C14	M35/2054	58	PEAT	BROWN & WEEBER 1992, (LO1C-7352), M35/F9505	40000	0	Linwood	2477580	5744560
C14	M35/2145	14	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F9581	4180	90	SFF	2480300	5741600
C14	M35/2149	7	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F9568	2040	80	SFF	2480950	5742510
C14	M35/2149	10	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F9569	4240	100	SFF	2480950	5742510
C14	M35/2182	10	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F9532	3750	80	SFF	2480340	5741870
C14	M35/2201	3	PEAT	BROWN & WEEBER 1992, (LO1C-7352), M35/F9533	3160	80	SFF	2480500	5742800
C14	M35/2208	4	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F9550	1590	70	SFG	2480700	5741700
C14	M35/2208	6	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F9551	1585	70	SFF	2480700	5741700
C14	M35/2208	21	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F9552	7120	110	CFF	2480700	5741700
C14	M35/2243	19	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F9575	5450	100	CFF	2480120	5742790
C14	M35/2261	9	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F9572	3730	75	SFF	2480843	5741500
C14	M35/2261	10.6	WOOD/PEAT	BROWN & WEEBER 1992, (LO1C-7352), M35/F9571	4200	105	SFF	2480843	5741500
C14	M35/2265	5	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F9573	3030	90	SFG	2479800	5741800
C14	M35/2273	42	WOOD/PEAT	IN6C-332-1/1 (BROWN & WILSON 1988), M35/F5	35300	0	Bromley	2474100	5741140
C14	M35/2448	14	PEAT	BROWN & WEEBER 1992, (LO1C-7352), IN6C-332-1/8, M35/F9539	6980	100	no log	2476100	5742700
C14	M35/2448	14	PEAT	BROWN & WEEBER 1992, (LO1C-7352), M35/F9539	6790	30	SFF	2476100	5742700
C14	M35/2465	6	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F9520	4660	90	SFF	2477060	5743630
C14	M35/2790	34	PEAT	BROWN & WEEBER 1992, (LO1C-7352), M35/F10	9850	140	CFF?SFF?	2486184	5742922
C14	M35/3132	25	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F3	7940	90	NBS	2484800	5741100
C14	M35/3132	33	PEAT	BROWN & WEEBER 1992, (LO1C-7352), M35/F4	9520	130	CFF?SFF?	2484800	5741100
C14	M35/5135	22	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F18	8970	120	CFF	2485625	5740275
C14	M35/5135	17	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F17	6720	100	NBS	2485625	5740275
C14	M35/5572	8	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F9558	6330	100	SFF	2474200	5740300
C14	M35/6038	38	SHELL	U98/26, IN6C-332-1/10, M35/F56	8800	75	CFF?SFF?	2486933	5743994
C14	M35/6038	30	SHELL	U98/26, IN6C-332-1/10, M35/F54	8200	90	CFF	2486933	5743994
C14	M35/6038	37	PEAT	U98/26, IN6C-332-1/10, M35/F55	9550	84	CFF?SFF?	2486933	5743994
C14	M35/6102[1]	14	WOOD	Smith (1992)	6660	60	SFF?	2473490	5740300
C14	M35/7218	40	PEAT	IN6C-332-1/26, M35/F99	9550	70	CFF?SFF?	2487934	5743932
C14	M35/7720	12.8	WOOD	IN6C-332-1/26	1120	40	OSB	2470400	5748800
C14	M36/0886	14	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M36/F7557	6450	55	SFF	2473503	5738385
C14	M36/0981	11	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M36/F7517	2990	10	SFF	2477100	5739200
C14	M36/1024	16	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M36/F7587	7050	120	NBS	2485580	5738580
C14	M36/1024	24	PEAT	BROWN & WEEBER 1992, (LO1C-7352), M36/F7588	9180	140	CFF?SFF?	2485580	5738580
C14	M36/1024	16	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M36/F7586?	7670	110	NBS	2485580	5738580
C14	M36/1060	10	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M36/F7584	4060	80	SFF	2478000	5739800
C14	M36/1062	13	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M36/F7582	4480	80	SFF	2478400	5739700
C14	M36/1063	9	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M36/7585	3030	70	SFF	2475900	5739800
C14	M36/1161	93	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M36/F7560	44100	0	Heathcote	2485400	5738600
C14	M36/1161	12	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M36/F13	7470	120	NBS	2485400	5738600
C14	M36/1186	10	WOOD/CHARCOAL	BROWN & WEEBER 1992, (LO1C-7352), M36/F7565	3400	45	NBS	2484000	5738400
C14	M36/1187	18	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M35/F7563	7820	70	CFF	2484070	5738780
C14	M36/1187	11	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M35/F7564	6270	85	NBS	2484070	5738780
C14	M36/1321	5	SHELL	BROWN & WEEBER 1992, (LO1C-7352), M36/F31	2980	80	CFF	2484800	5738000
C14	M36/1894	19	WOOD	BROWN & WEEBER 1992, (LO1C-7352), M36/F9	8460	120	CFF?SFF?	2483000	5738950
C14	M36/4017[2]	13	WOOD	Smith (1992)	8820	70	SFF	2473480	5737610
C14	M36/4595	32.4	PEATY SILT	IN6C-332-1/26, M36/F62	50000		Riccarton	2484900	5738600
C14	M36/4740	18	WOOD	IN6C-332-1/26	8760	60	SFF	2477245	5738120

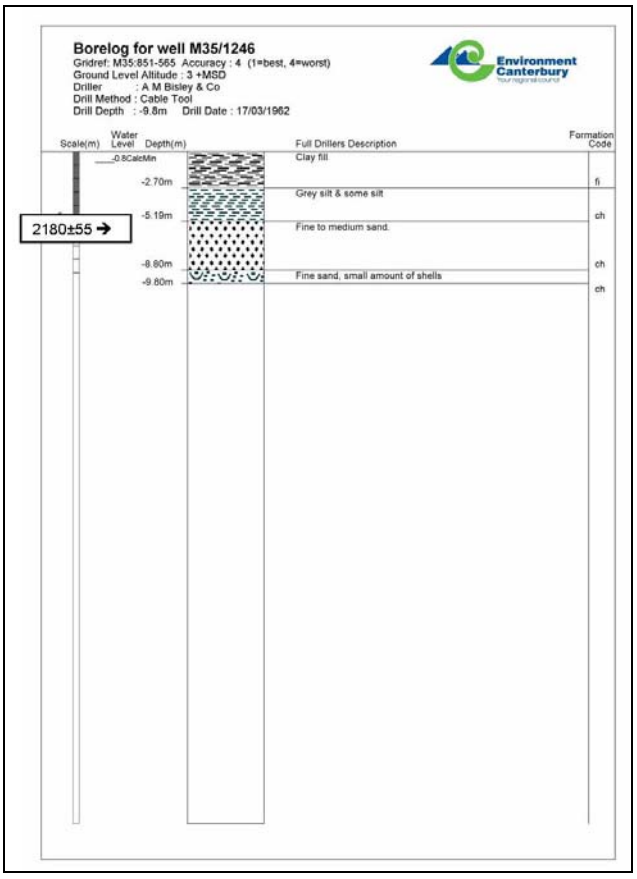
[1] Analysis of this sample was completed by Waikato University (Smith pers. comm.), sample WI-2.

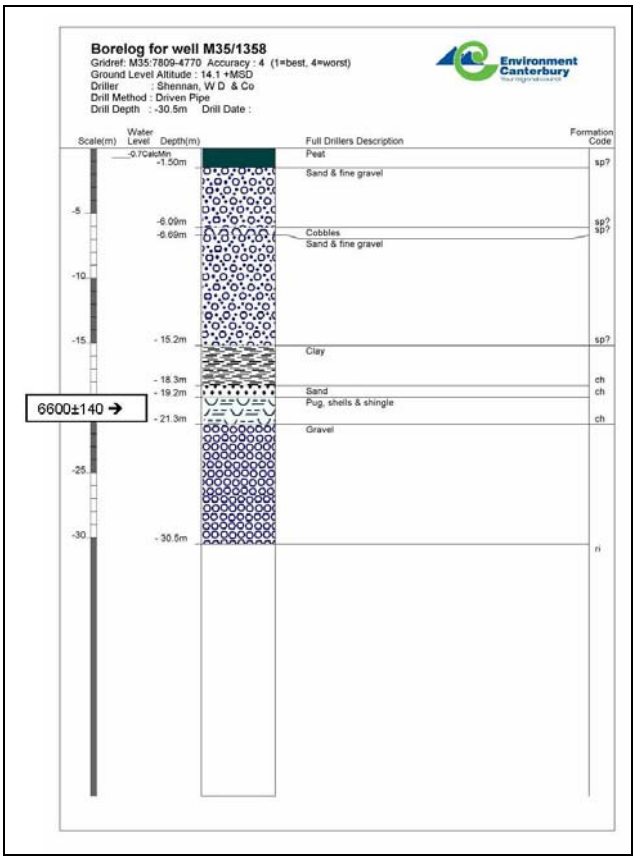
[2] Analysis of this sample was completed by Waikato University, sample CI-3). Smith (1992) assigns this analysis to two different wells: well M36/4017 (Smith, 1992 pg 50) and well M36/4120 (Smith, 1992, in her caption for her Figure 4.12)

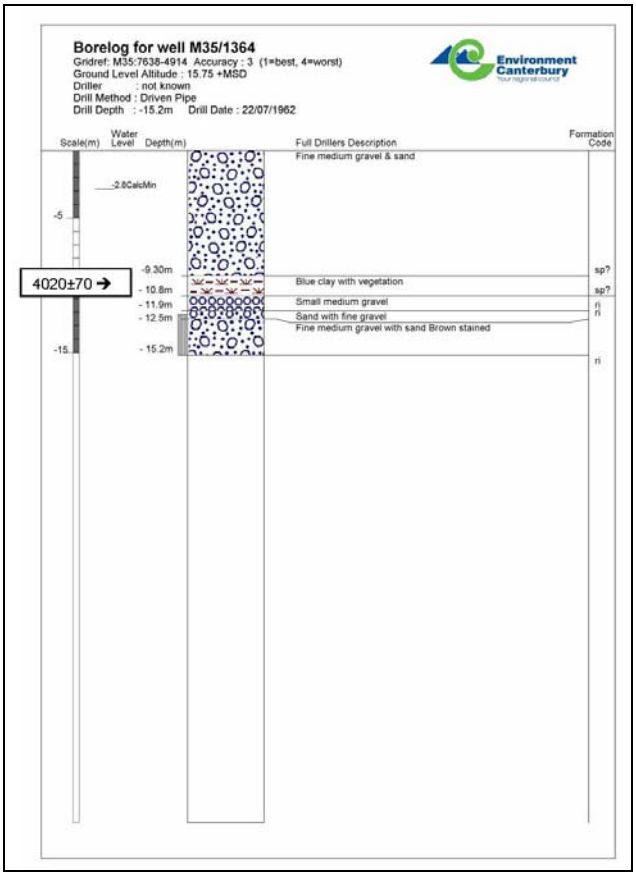

Borelog for well M35/1171
Gridref: M35:8560-4690 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 5.6 +MSD
Driller : McMillan Water Wells Ltd
Drill Method : Cable Tool
Drill Depth : -39.59m Drill Date : 1/09/1976
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
No Log
-4.59m
Not logged
Grey medium sand
ch
8180±70
-28.9m
-30.5m
-32.0m
-39.6m
8280±70
Grey coarse silt with shells
Grey silty sand, some peat
Gravel & sand
ri

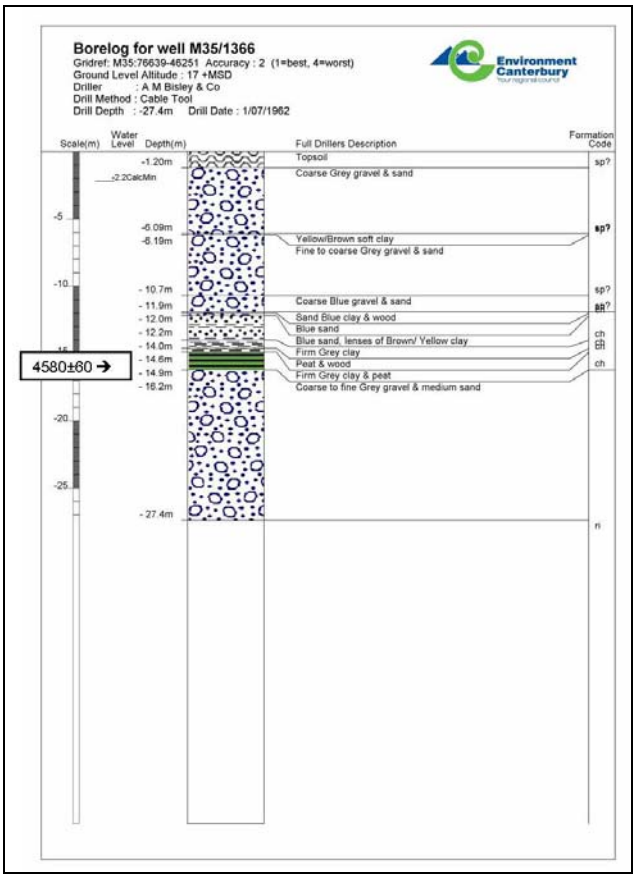

Borelog for well M35/1175
Gridref: M35:825-494 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 3.9 +MSD
Driller : A M Bisley & Co
Drill Method : Cable Tool
Drill Depth : -29m Drill Date : 10/11/1980
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
-0.60m
Soil
Fine Grey sand
-3.40m
Small gravel, grit,fine sand
sp?
-11.8m
Fine sand, grit
-15.6m
Fine sand, some gravel
ch
-17.1m
Sandy Grey clay, some shells
-18.5m
Grey clay, some shells
8030±170
-24.0m
Brown gravel, medium to fine sand
-29.0m
ri

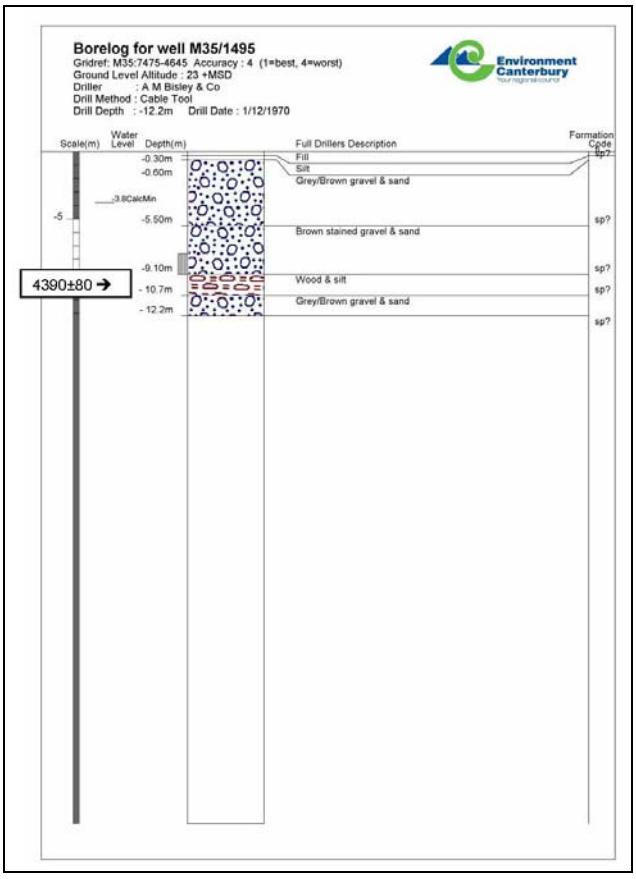

Borelog for well M35/1245
Gridref: M35:847-565 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 3 +MSD
Driller : A M Bisley & Co
Drill Method : Cable Tool
Drill Depth : -12.2m Drill Date : 17/03/1962
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
1.0CalcMin
-1.80m
Fill & Grey silt
fi
Blue sand
-5.19m
ch
2180±55
-6.09m
Fine to medium Grey sand & shells
ch
Grey fine sand
-10.
-12.2m
ch


Borelog for well M35/1246
Gridref: M35:851-565 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 3 +MSD
Driller : A M Bisley & Co
Drill Method : Cable Tool
Drill Depth : -9.8m Drill Date : 17/03/1962
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
0.8CalcMin
Clay fill
-2.70m
fi
Grey silt & some silt
-5.19m
ch
2180±55
Fine to medium sand.
-8.80m
ch
-9.80m
Fine sand, small amount of shells
ch

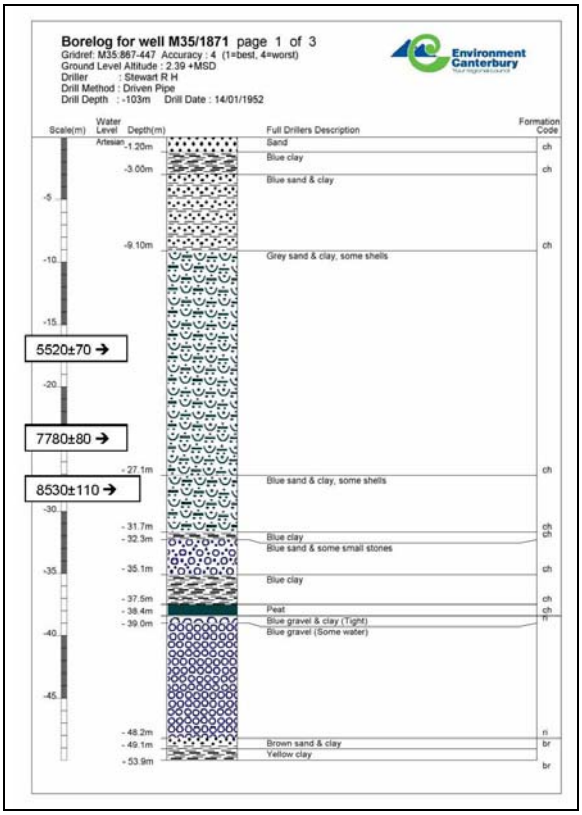

Borelog for well M35/1358
Gridref: M35:7809-4770 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 14.1 +MSD
Driller : Shennan, W D & Co
Drill Method : Driven Pipe
Drill Depth : -30.5m Drill Date :
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
-0.7CalcMin
-1.50m
Peat
sp?
Sand & fine gravel
-5
-6.09m
sp?
-6.69m
Cobbles
sp?
Sand & fine gravel
-10
-15
- 15.2m
sp?
Clay
- 18.3m
ch
- 19.2m
Sand
ch
6600±140
Pug, shells & shingle
- 21.3m
ch
Gravel
-25
-30
- 30.5m
ri


Borelog for well M35/1364
Gridref: M35:7638-4914 Accuracy : 3 (1=best, 4=worst)
Ground Level Altitude : 15.75 +MSD
Driller : not known
Drill Method : Driven Pipe
Drill Depth : -15.2m Drill Date : 22/07/1962
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
Fine medium gravel & sand
-2.8CalcMin
-5
-9.30m
sp?
4020±70
Blue clay with vegetation
- 10.8m
sp?
- 11.9m
Small medium gravel
ri
- 12.5m
Sand with fine gravel
ri
Fine medium gravel with sand Brown stained
-15
- 15.2m
ri

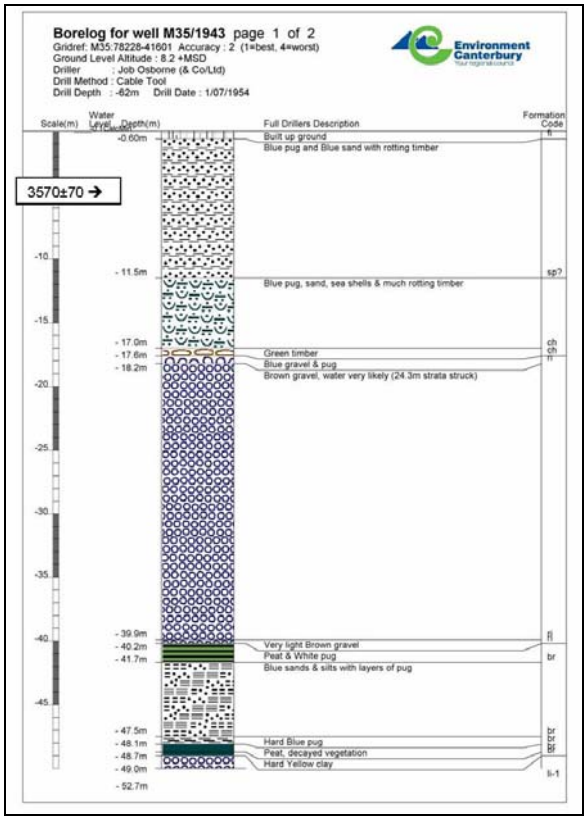

Borelog for well M35/1366
Gridref: M35:76639-46251 Accuracy : 2 (1=best, 4=worst)
Ground Level Altitude : 17 +MSD
Driller : A M Bisley & Co
Drill Method : Cable Tool
Drill Depth : -27.4m Drill Date : 1/07/1962
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
-1.20m
Topsoil
sp?
-2.2CalcMn
Coarse Grey gravel & sand
-5
-6.09m
sp?
-6.19m
Yellow/Brown soft clay
Fine to coarse Grey gravel & sand
-10
- 10.7m
sp?
Coarse Blue gravel & sand
- 11.9m
sp?
- 12.0m
Sand Blue clay & wood
- 12.2m
Blue sand
ch
- 14.0m
Blue sand, lenses of Brown/ Yellow clay
sh
4580±60
- 14.6m
Firm Grey clay
Peat & wood
ch
- 14.9m
Firm Grey clay & peat
- 16.2m
Coarse to fine Grey gravel & medium sand
-20
-25
- 27.4m
ri

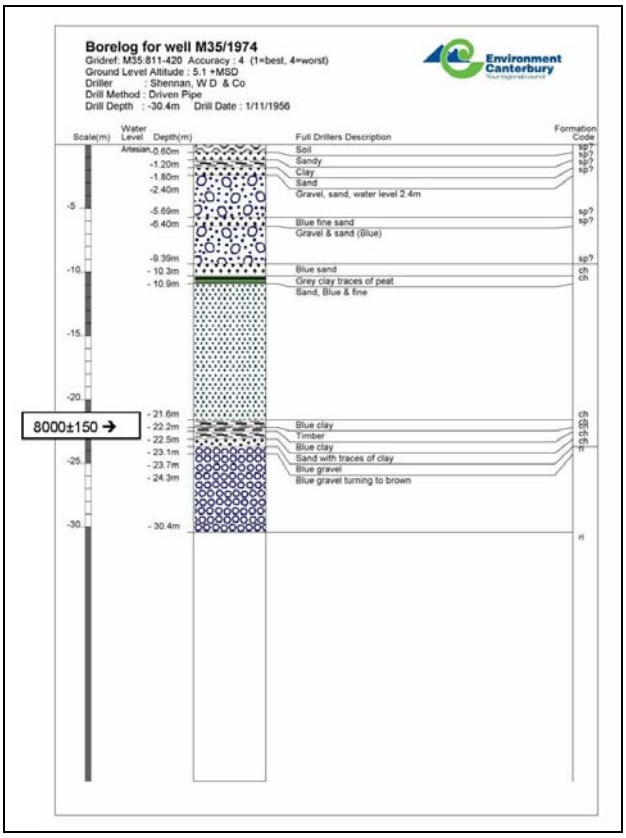

Borelog for well M35/1495
Gridref: M35:7475-4645 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 23 +MSD
Driller : A M Bisley & Co
Drill Method : Cable Tool
Drill Depth : -12.2m Drill Date : 1/12/1970
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
-0.30m
Fill
sp?
-0.60m
Silt
Grey/Brown gravel & sand
-3.8CalcMn
-5
-5.50m
sp?
Brown stained gravel & sand
-9.10m
sp?
4390±80
Wood & silt
- 10.7m
sp?
Grey/Brown gravel & sand
- 12.2m
sp?

M35/1871 – partial geological log

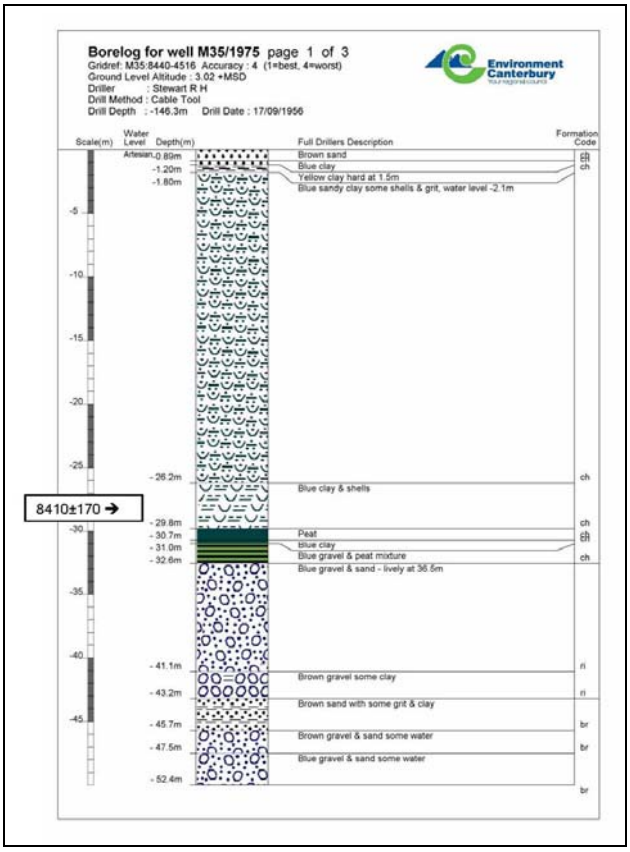


M35/1943 – partial geological log

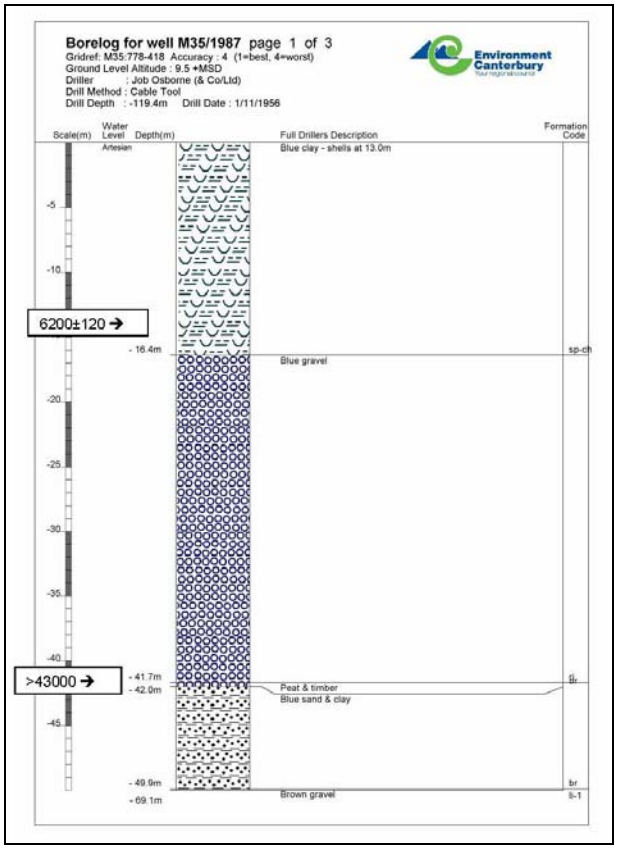


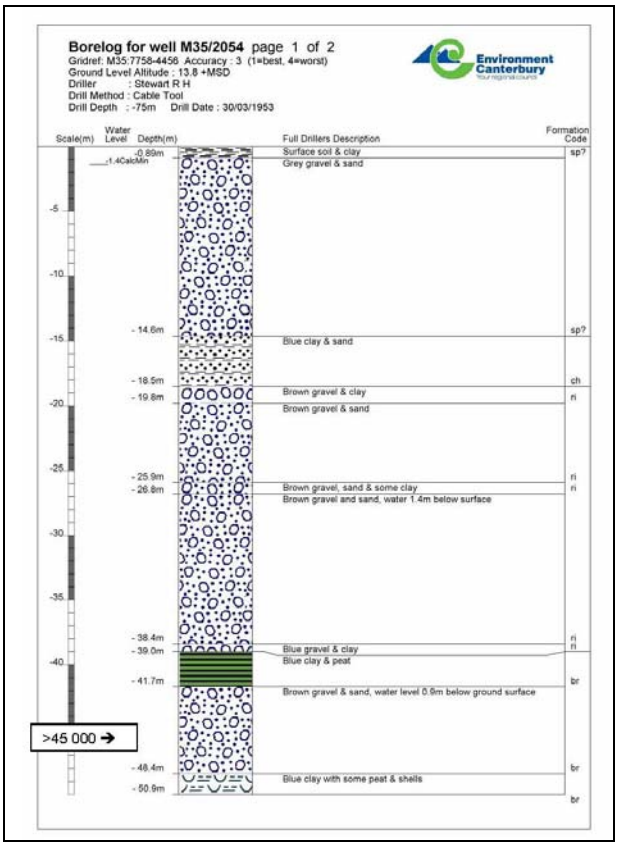


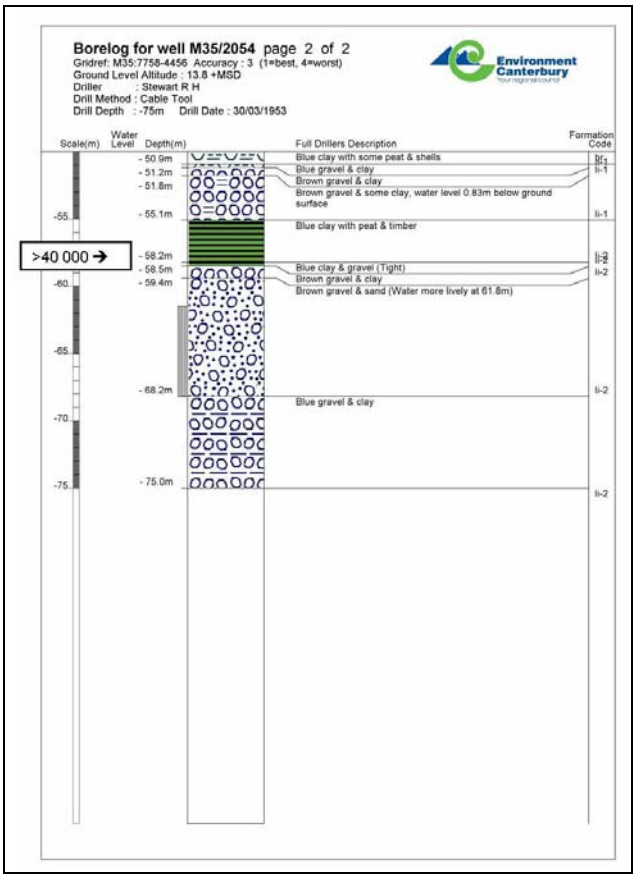
M35/1975 – partial geological log

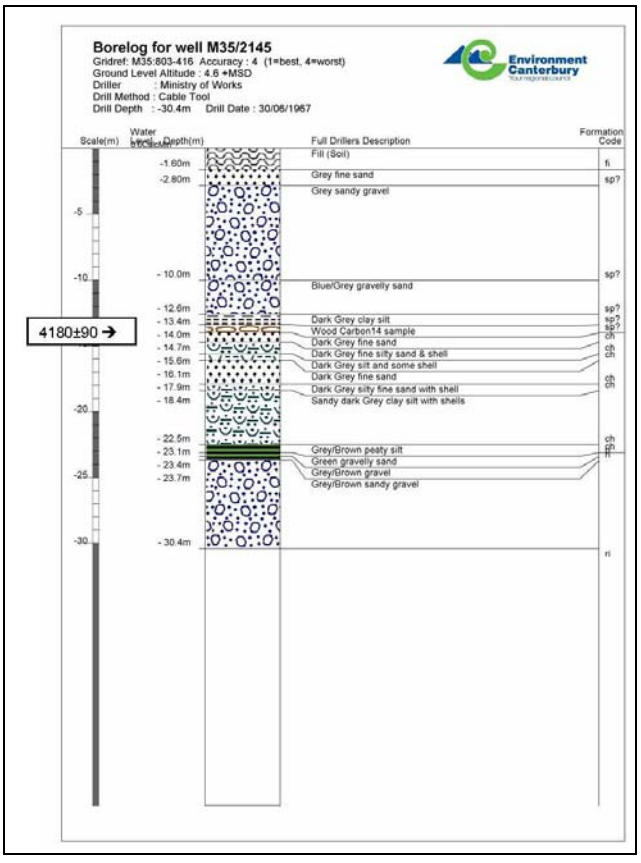


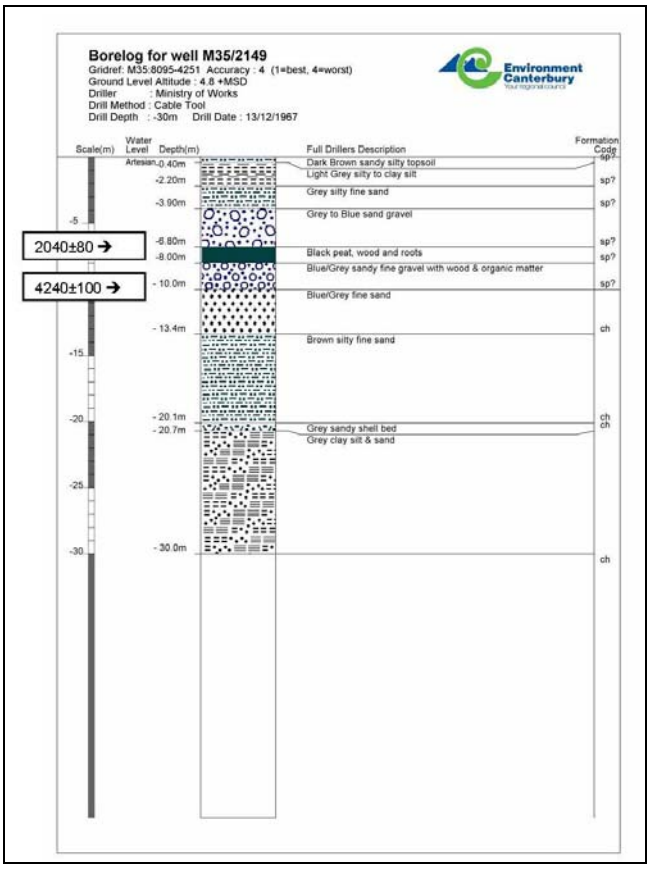
M35/1987 – partial geological log

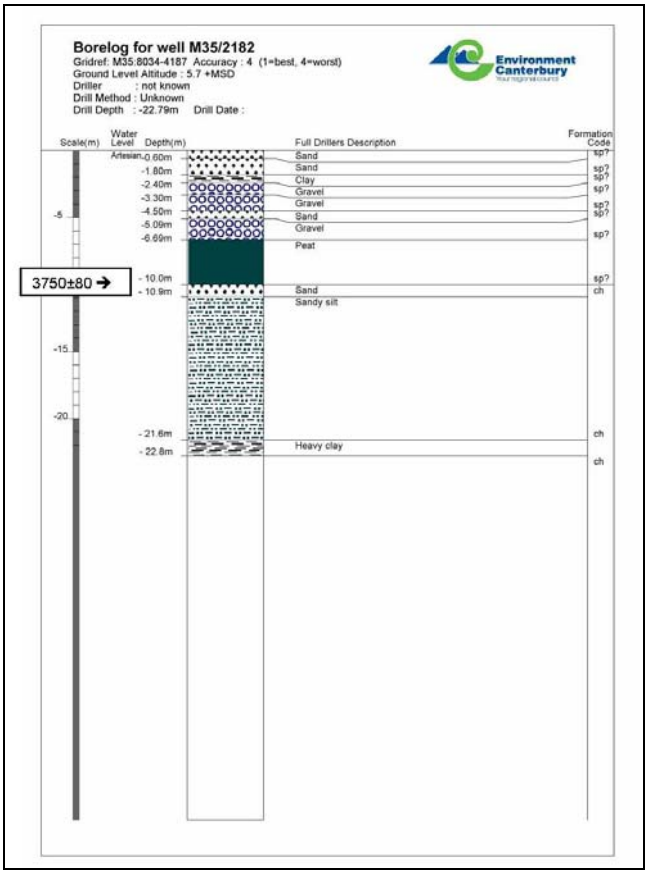


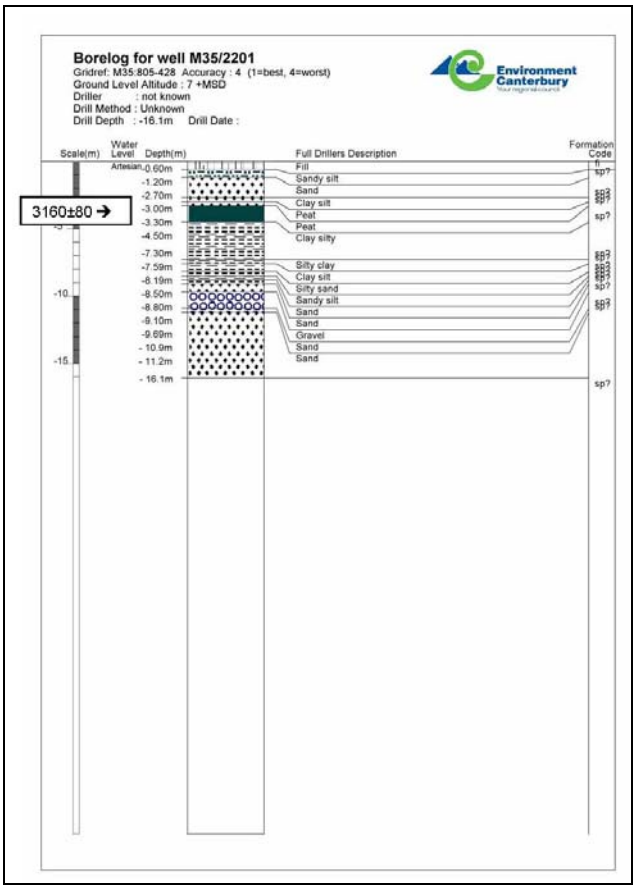


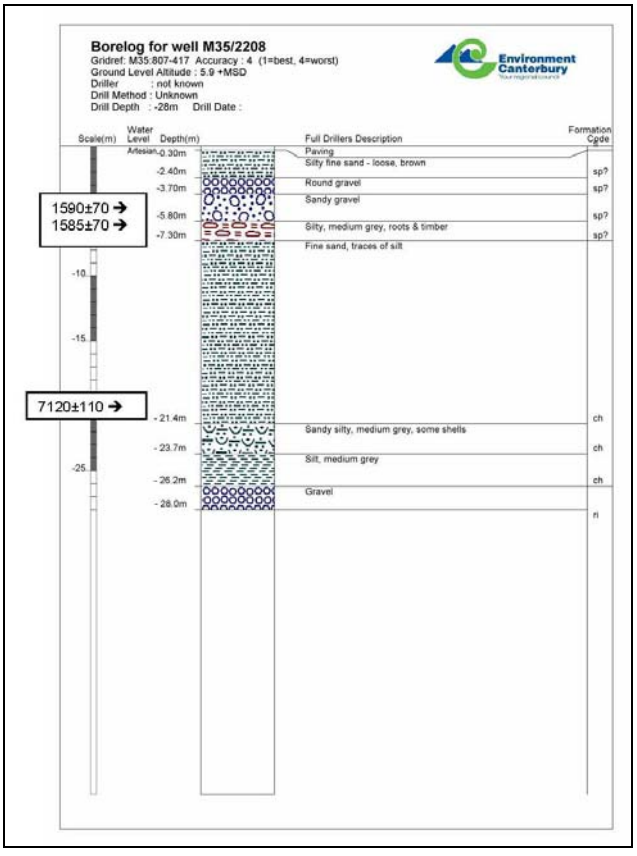

Borelog for well M35/2054 page 2 of 2
Gridref: M35:7758-4456 Accuracy : 3 (1=best, 4=worst)
Ground Level Altitude : 13.8 +MSD
Driller : Stewart R H
Drill Method : Cable Tool
Drill Depth : -75m Drill Date : 30/03/1953
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
- 50.9m
- 51.2m
- 51.8m
- 55.1m
- 58.2m
- 58.5m
- 59.4m
- 68.2m
- 75.0m
Blue clay with some peat & shells
Blue gravel & clay
Brown gravel & clay
Brown gravel & some clay, water level 0.83m below ground surface
Blue clay with peat & timber
Blue clay & gravel (Tight)
Brown gravel & clay
Brown gravel & sand (Water more lively at 61.8m)
Blue gravel & clay
>40 000 ➔


Borelog for well M35/2145
Gridref: M35:803-416 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 4.6 +MSD
Driller : Ministry of Works
Drill Method : Cable Tool
Drill Depth : -30.4m Drill Date : 30/08/1967
Environment Canterbury
Scale(m)
Depth(m)
Full Drillers Description
Formation Code
-1.60m
-2.80m
- 10.0m
- 12.6m
- 13.4m
- 14.0m
- 14.7m
- 15.6m
- 16.1m
- 17.9m
- 18.4m
- 22.5m
- 23.1m
- 23.4m
- 23.7m
- 30.4m
Fill (Soil)
Grey fine sand
Grey sandy gravel
Blue/Grey gravelly sand
Dark Grey clay silt
Wood Carbon14 sample
Dark Grey fine sand
Dark Grey fine silty sand & shell
Dark Grey silt and some shell
Dark Grey fine sand
Dark Grey silty fine sand with shell
Sandy dark Grey clay silt with shells
Grey/Brown peaty silt
Green gravelly sand
Grey/Brown gravel
Grey/Brown sandy gravel
4180±90 ➔

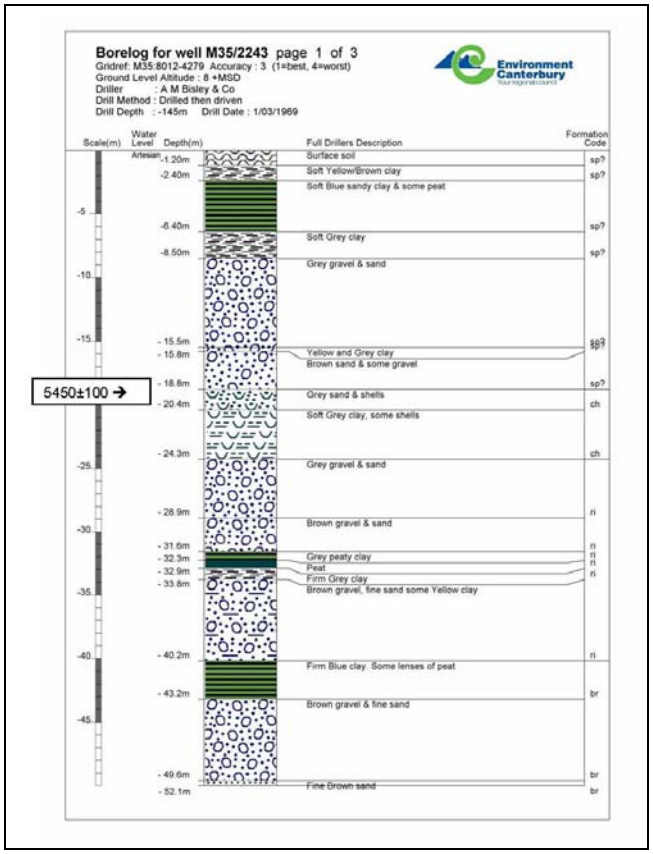

Borelog for well M35/2149
Gridref: M35:8095-4251 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 4.8 +MSD
Driller : Ministry of Works
Drill Method : Cable Tool
Drill Depth : -30m Drill Date : 13/12/1967
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
Artesian
0.40m
Dark Brown sandy silty topsoil
-2.20m
Light Grey silty to clay silt
sp?
-3.90m
Grey silty fine sand
sp?
-5
Grey to Blue sand gravel
-6.80m
sp?
2040±80
-8.00m
Black peat, wood and roots
sp?
4240±100
- 10.0m
Blue/Grey sandy fine gravel with wood & organic matter
sp?
Blue/Grey fine sand
- 13.4m
ch
-15
Brown silty fine sand
-20
- 20.1m
ch
- 20.7m
Grey sandy shell bed
ch
Grey clay silt & sand
-25
-30
- 30.0m
ch

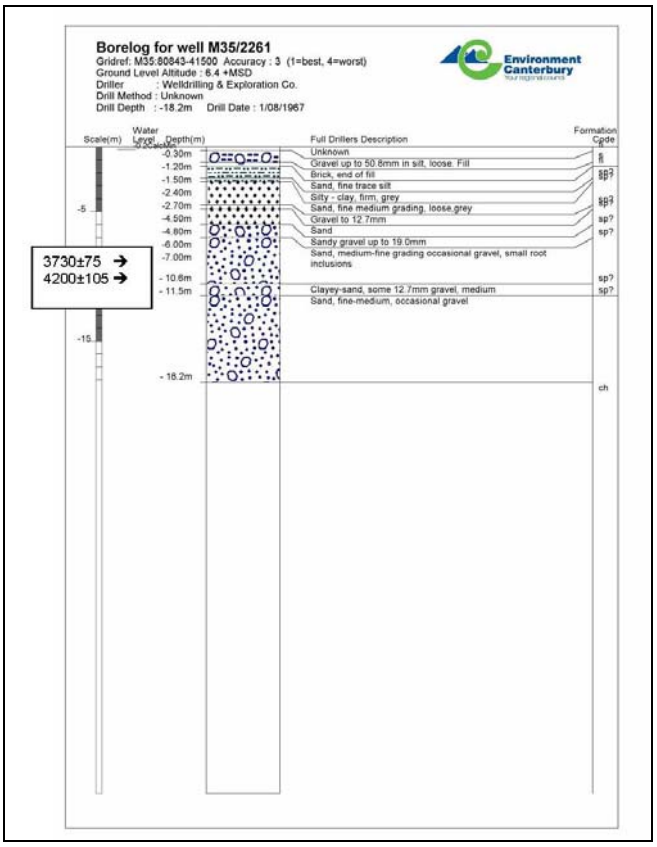

Borelog for well M35/2182
Gridref: M35:8034-4187 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 5.7 +MSD
Driller : not known
Drill Method : Unknown
Drill Depth : -22.79m Drill Date :
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
Artesian
0.60m
Sand
sp?
-1.80m
Sand
sp?
-2.40m
Clay
sp?
-3.30m
Gravel
sp?
-4.50m
Gravel
sp?
-5
-5.09m
Sand
sp?
-6.69m
Gravel
sp?
Peat
3750±80
- 10.0m
sp?
- 10.9m
Sand
ch
Sandy silt
-15
-20
- 21.6m
ch
- 22.8m
Heavy clay
ch

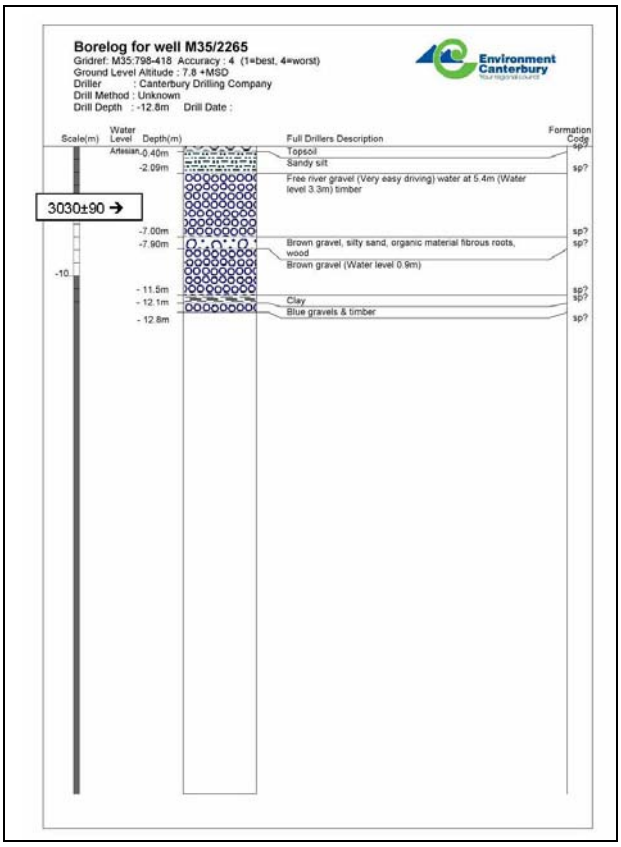

Borelog for well M35/2201
Gridref: M35:805-428 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 7 +MSD
Driller : not known
Drill Method : Unknown
Drill Depth : -16.1m Drill Date :
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
Artesian
0.60m
1.20m
2.70m
3.00m
3.30m
4.50m
7.30m
7.59m
8.19m
8.50m
8.80m
9.10m
9.69m
10.9m
11.2m
16.1m
Fill
Sandy silt
Sand
Clay silt
Peat
Peat
Clay silty
Silty clay
Clay silt
Silty sand
Sandy silt
Sand
Sand
Gravel
Sand
Sand
fl
sp?
sp?
3160±80


Borelog for well M35/2208
Gridref: M35:807-417 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 5.9 +MSD
Driller : not known
Drill Method : Unknown
Drill Depth : -28m Drill Date :
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
Artesian
0.30m
2.40m
3.70m
5.80m
7.30m
21.4m
23.7m
26.2m
28.0m
Paving
Silty fine sand - loose, brown
Round gravel
Sandy gravel
Silty, medium grey, roots & timber
Fine sand, traces of silt
Sandy silty, medium grey, some shells
Silt, medium grey
Gravel
sp?
sp?
sp?
sp?
ch
ch
ch
ri
1590±70
1585±70
7120±110

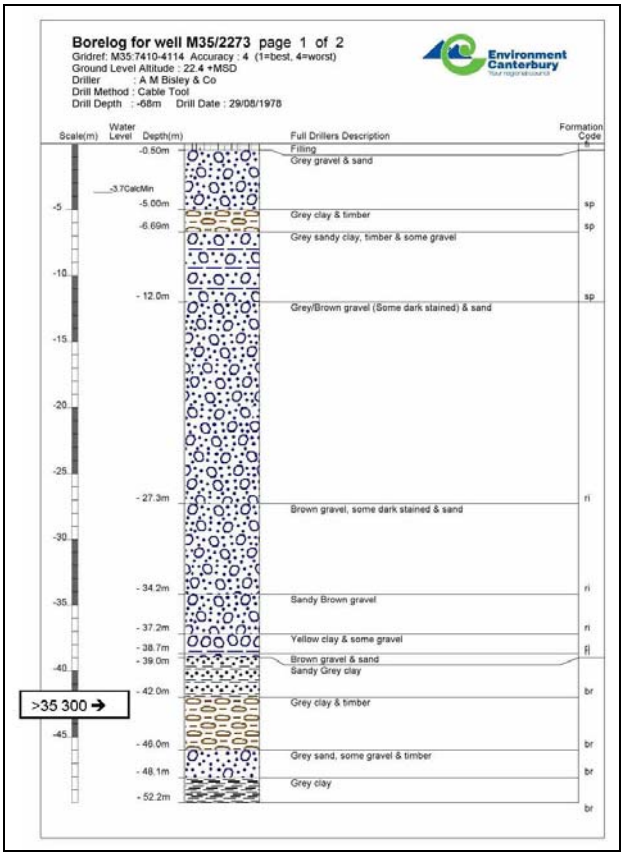
M35/2243 – partial geological log

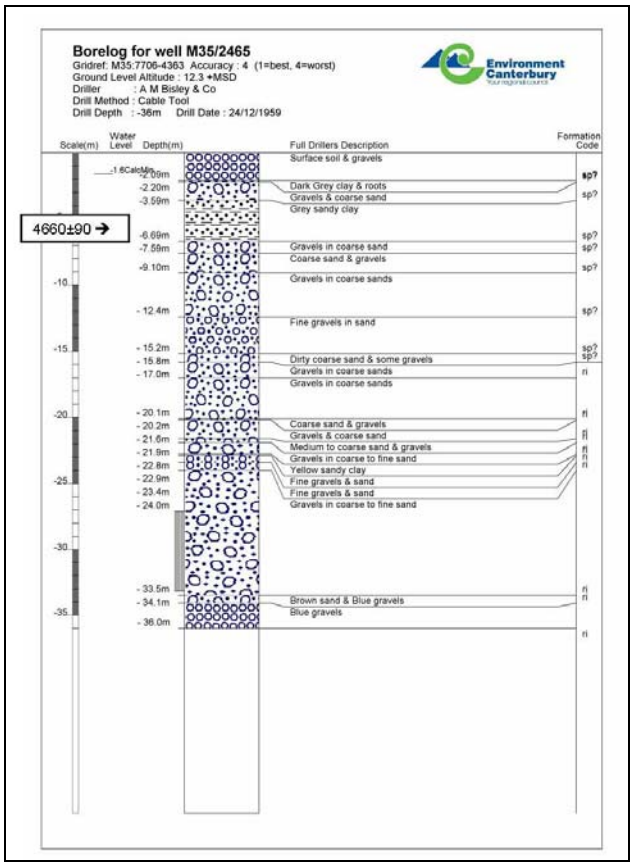




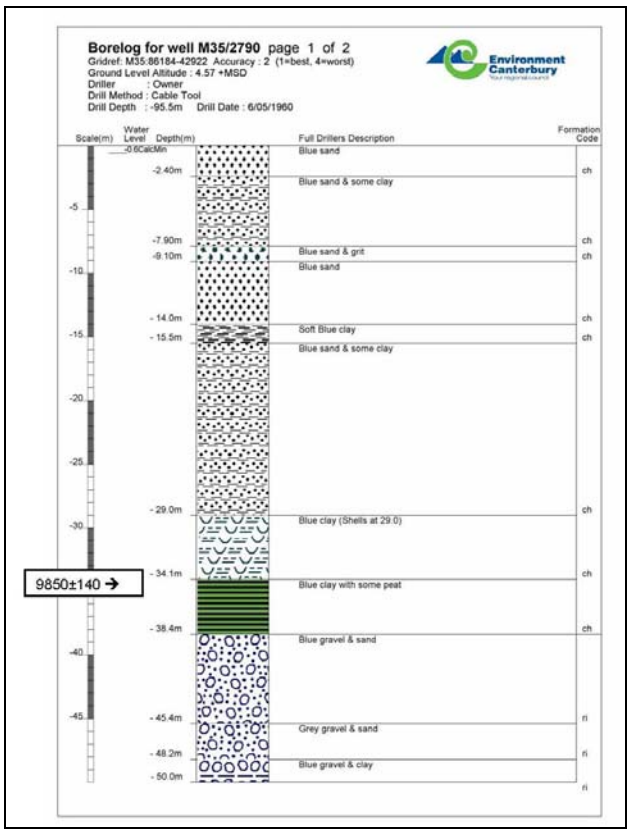


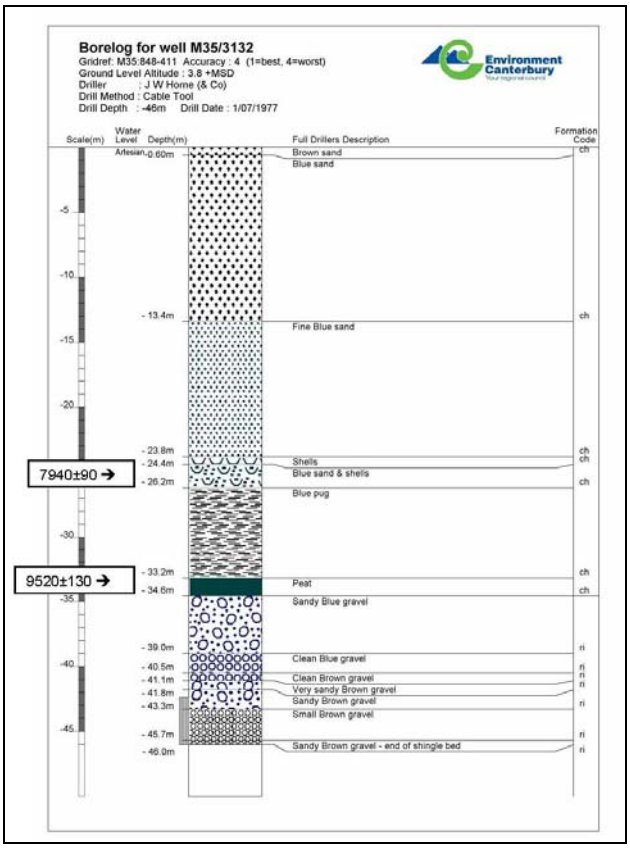
M35/2273 – partial geological log



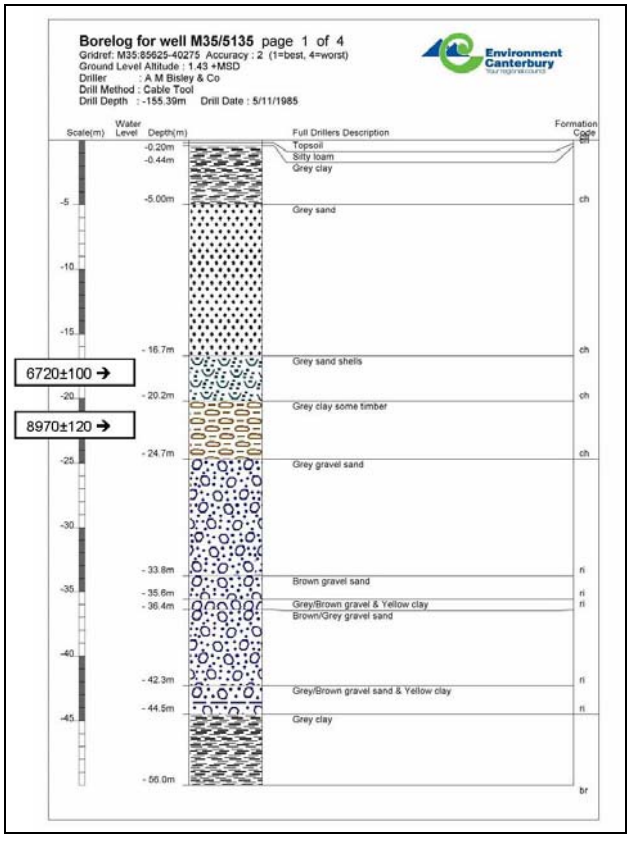


M35/2790 – partial geological log

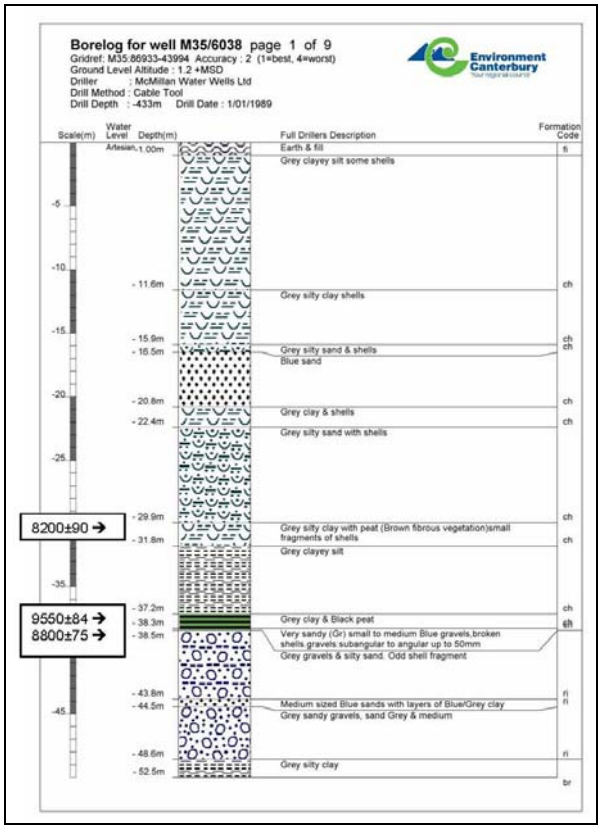


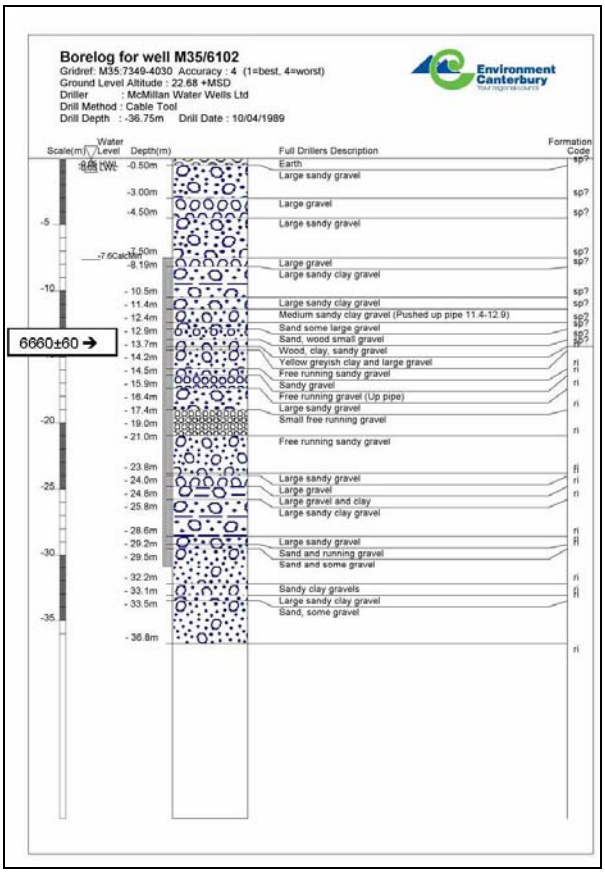


M35/5135 – partial geological log

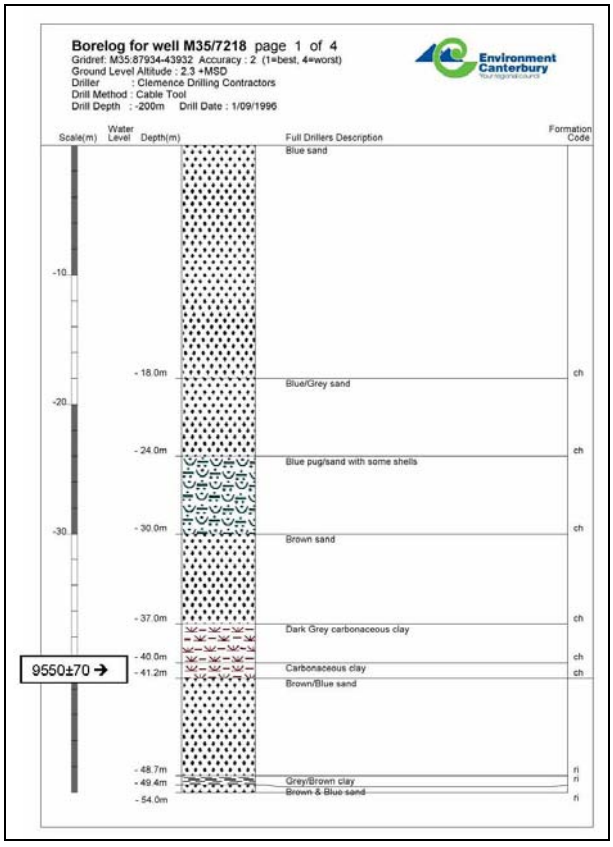


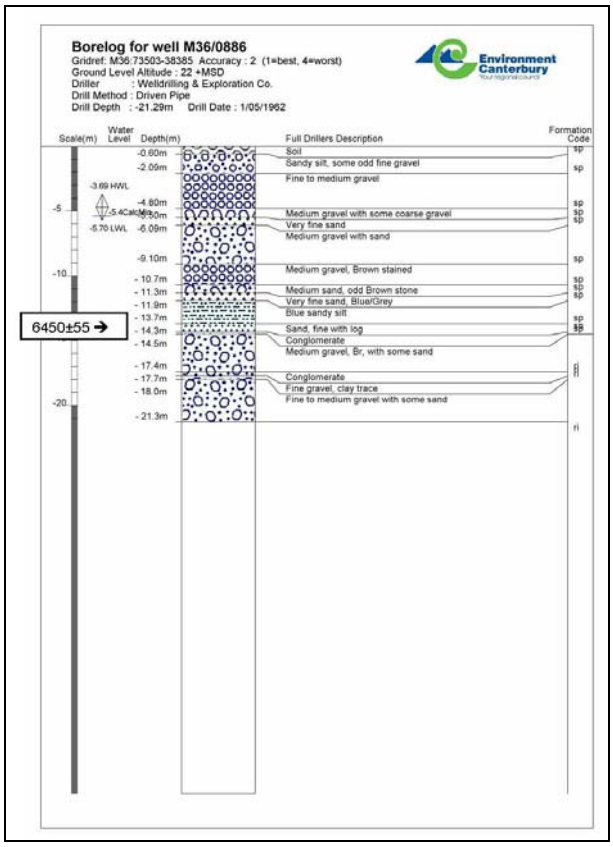
M35/6038 – partial geological log



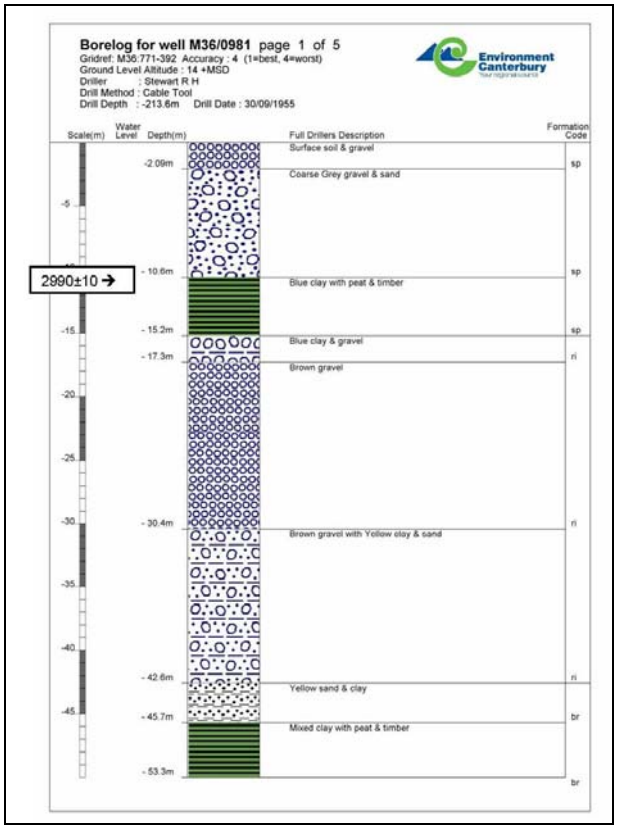


M35/7218 – partial geological log

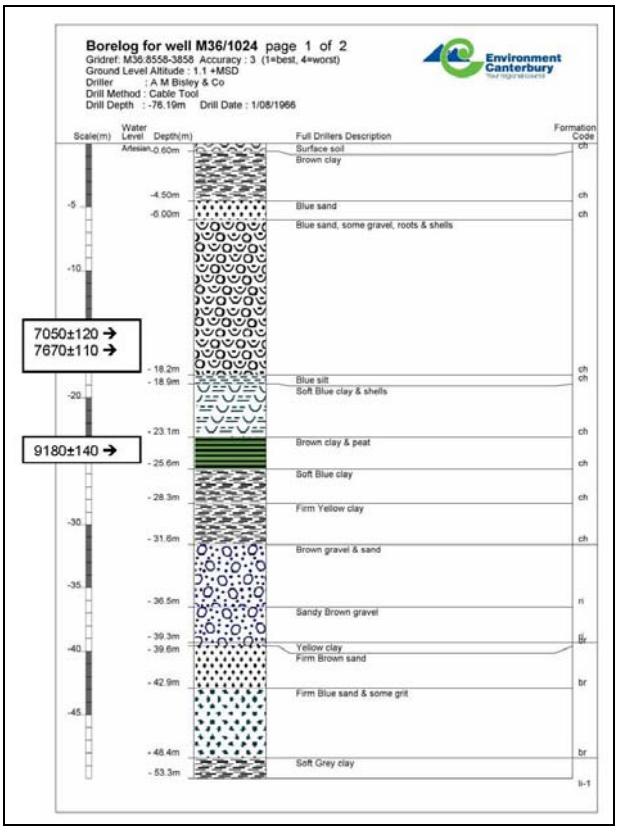


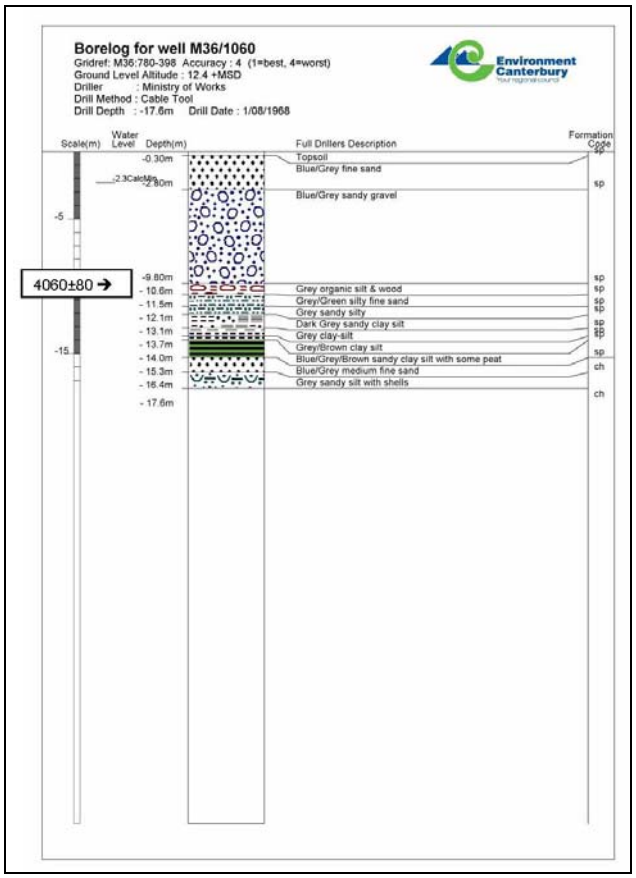


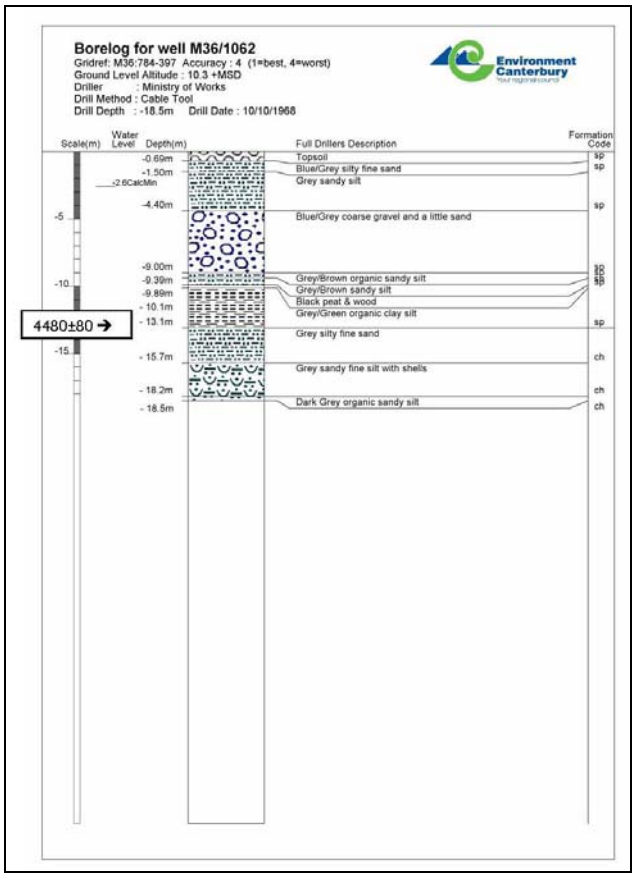
M36/0981 – partial geological log

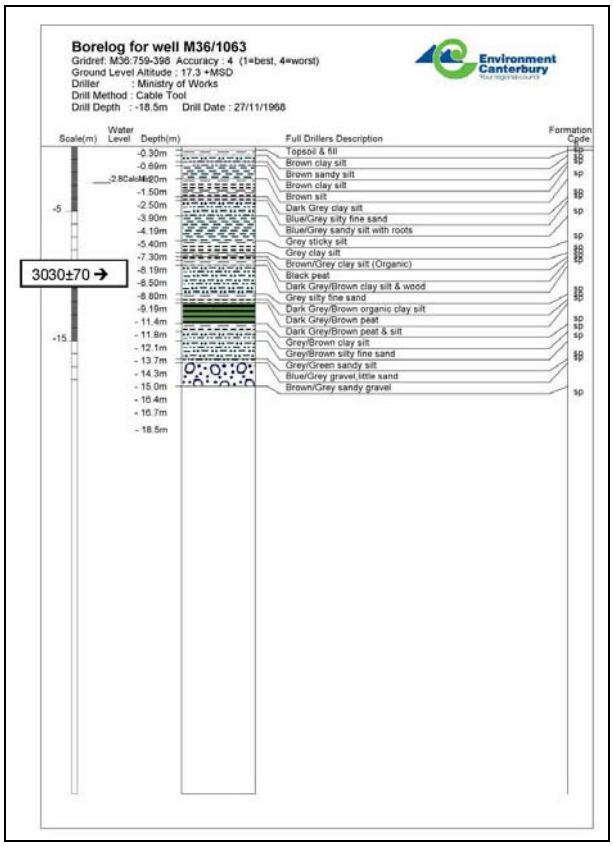


M36/1024 – partial geological log

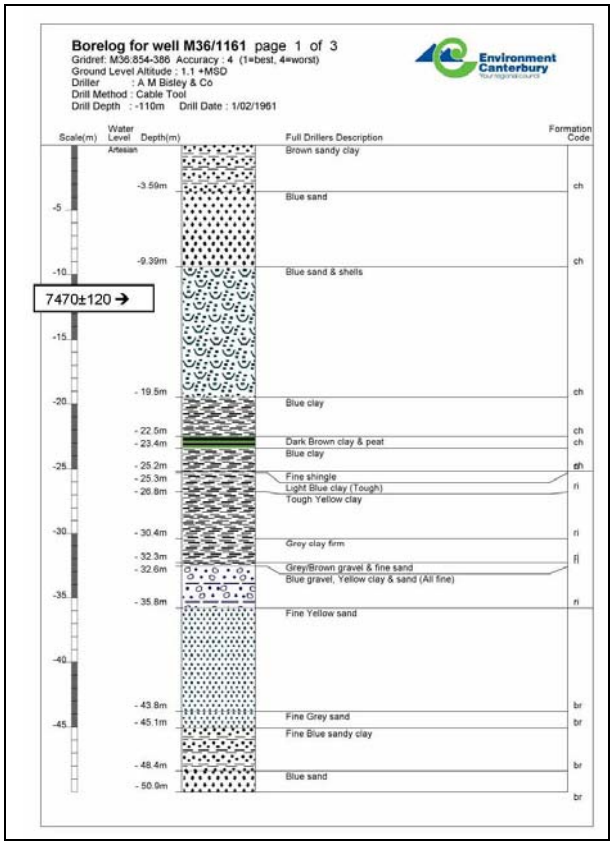



Borelog for well M36/1060
Gridref: M36:780-398 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 12.4 +MSD
Driller : Ministry of Works
Drill Method : Cable Tool
Drill Depth : -17.6m Drill Date : 1/08/1968
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
-0.30m
Topsoil
sp
-2.80m
Blue/Grey fine sand
sp
Blue/Grey sandy gravel
-5
-9.80m
sp
4060±80
-10.6m
Grey organic silt & wood
sp
-11.5m
Grey/Green silty fine sand
sp
-12.1m
Grey sandy silty
sp
-13.1m
Dark Grey sandy clay silt
sp
Grey clay-silt
-15
-13.7m
Grey/Brown clay silt
sp
-14.0m
Blue/Grey/Brown sandy clay silt with some peat
ch
-15.3m
Blue/Grey medium fine sand
-16.4m
Grey sandy silt with shells
ch
-17.6m

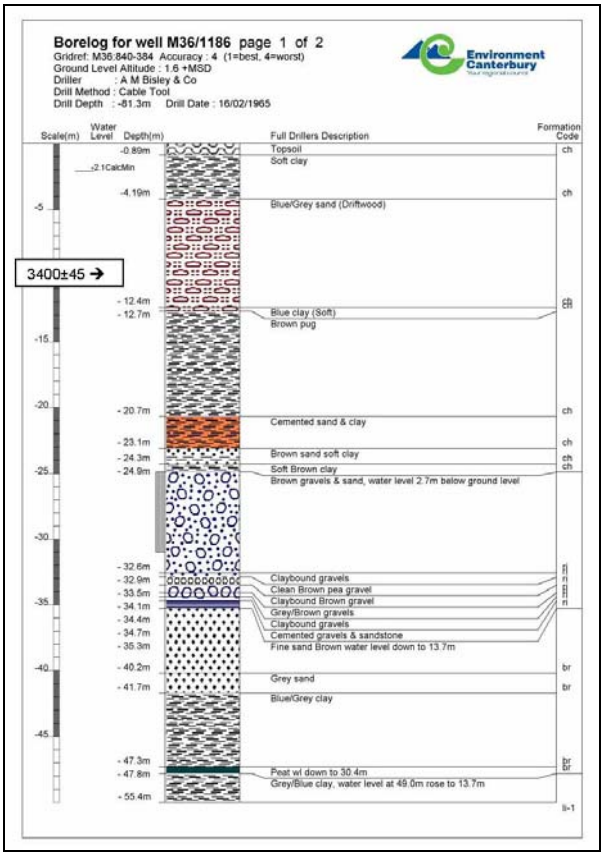

Borelog for well M36/1062
Gridref: M36:784-397 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 10.3 +MSD
Driller : Ministry of Works
Drill Method : Cable Tool
Drill Depth : -18.5m Drill Date : 10/10/1968
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
-0.69m
Topsoil
sp
-1.50m
Blue/Grey silty fine sand
sp
Grey sandy silt
-4.40m
sp
-5
Blue/Grey coarse gravel and a little sand
-9.00m
-9.39m
Grey/Brown organic sandy silt
-10
-9.89m
Grey/Brown sandy silt
-10.1m
Black peat & wood
4480±80
-13.1m
Grey/Green organic clay silt
sp
Grey silty fine sand
-15
-15.7m
ch
Grey sandy fine silt with shells
-18.2m
ch
-18.5m
Dark Grey organic sandy silt
ch

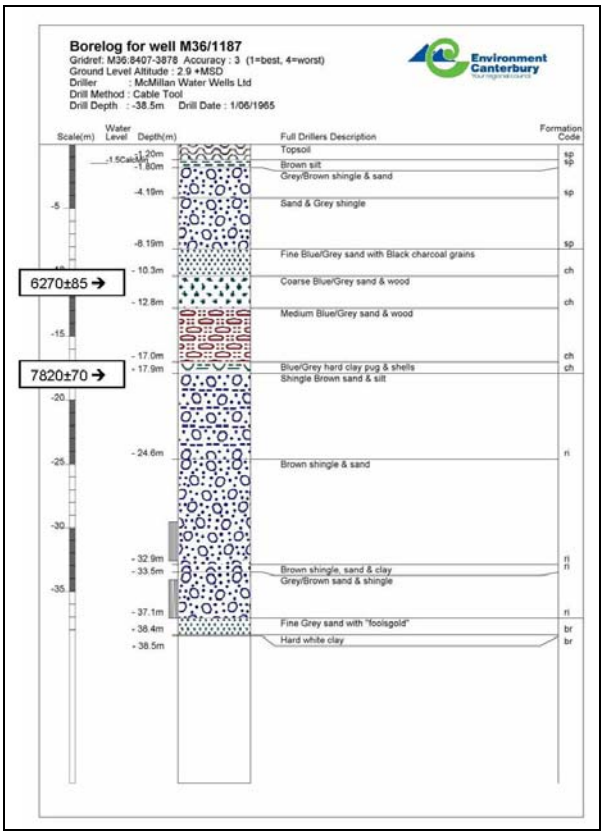


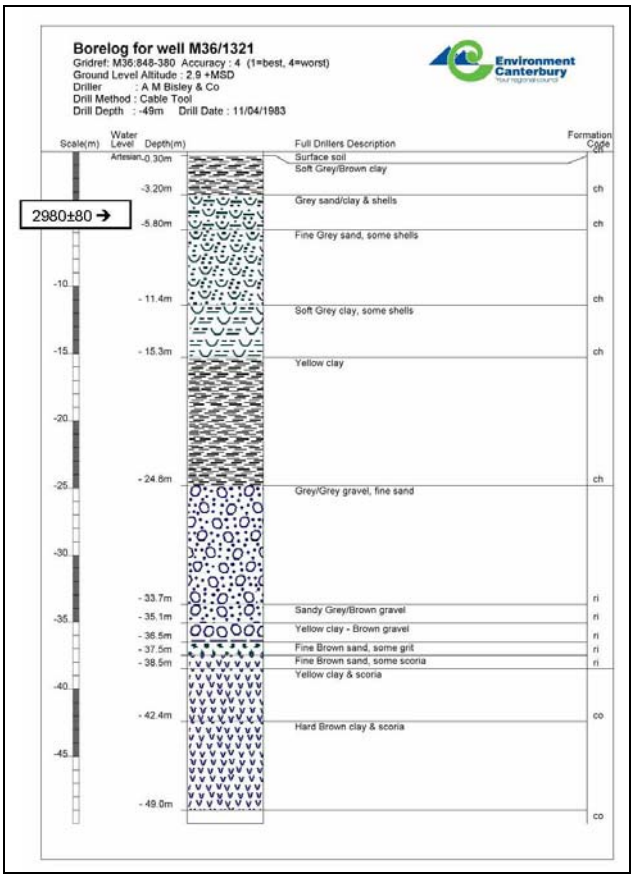
M36/1161 – partial geological log

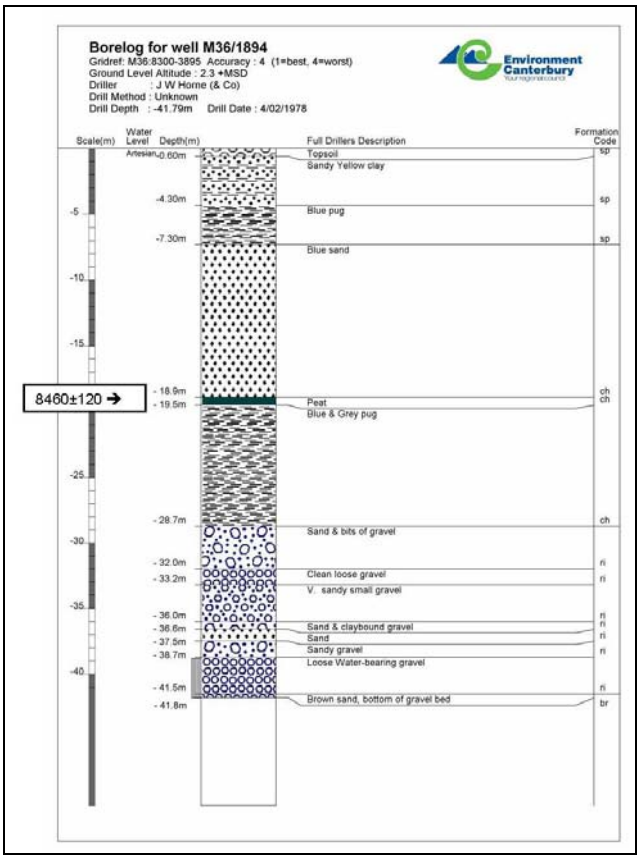


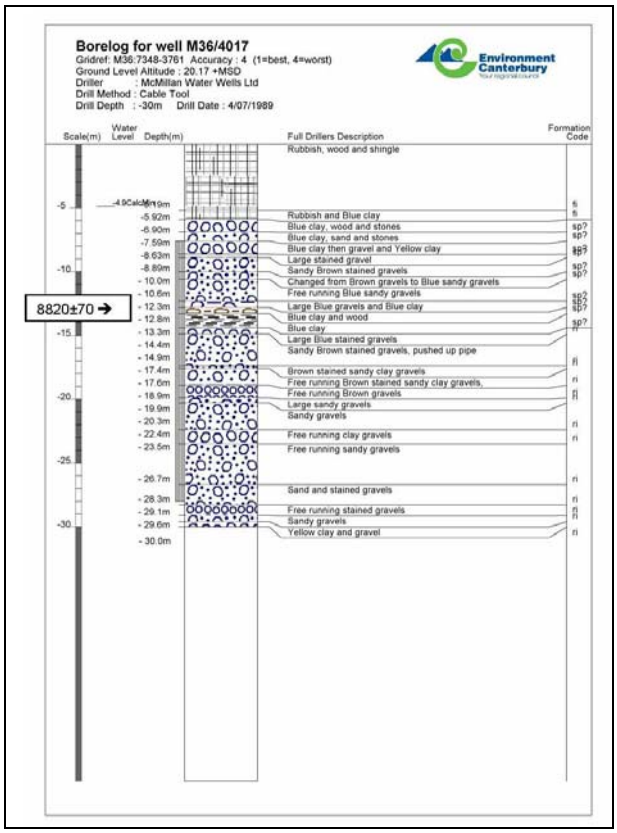
M36/1186 – partial geological log



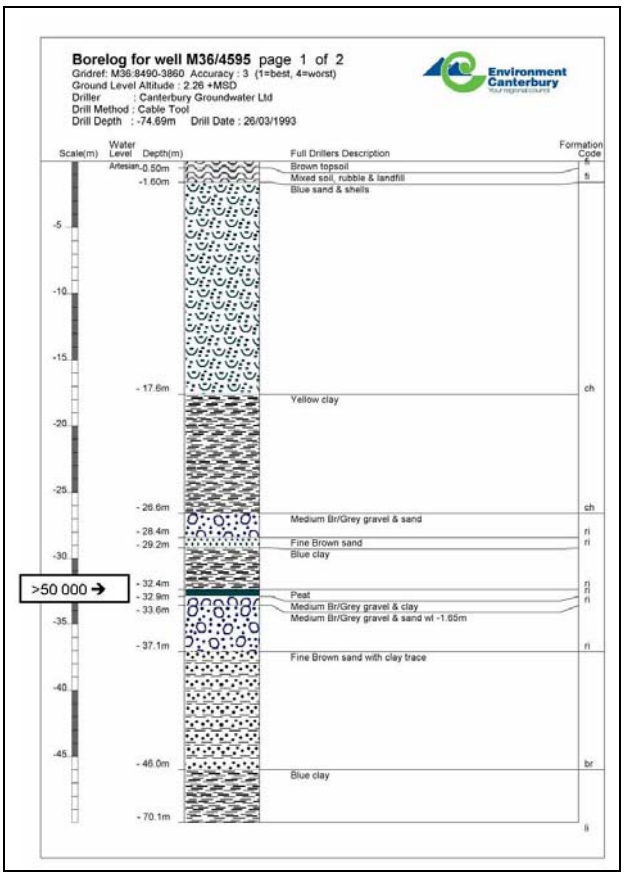


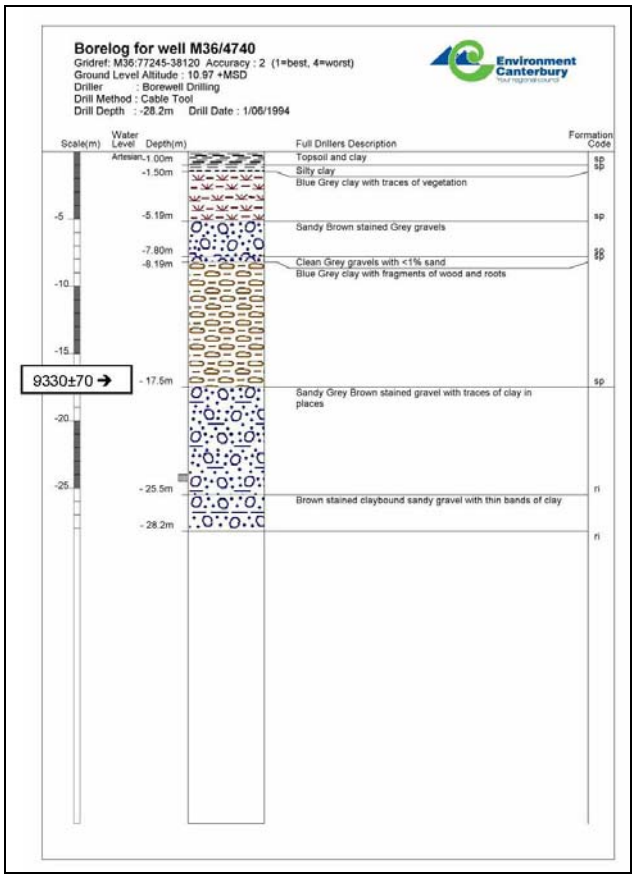

Borelog for well M36/1321
Gridref: M36:848-380 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 2.9 +MSD
Driller : A M Bisley & Co
Drill Method : Cable Tool
Drill Depth : -49m Drill Date : 11/04/1983
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
Artesian
0.30m
Surface soil
Soft Grey/Brown clay
-3.20m
Grey sand/clay & shells
-5.80m
Fine Grey sand, some shells
- 11.4m
Soft Grey clay, some shells
- 15.3m
Yellow clay
- 24.8m
Grey/Grey gravel, fine sand
- 33.7m
Sandy Grey/Brown gravel
- 35.1m
Yellow clay - Brown gravel
- 36.5m
Fine Brown sand, some grit
- 37.5m
Fine Brown sand, some scoria
- 38.5m
Yellow clay & scoria
- 42.4m
Hard Brown clay & scoria
- 49.0m
2980±80 →

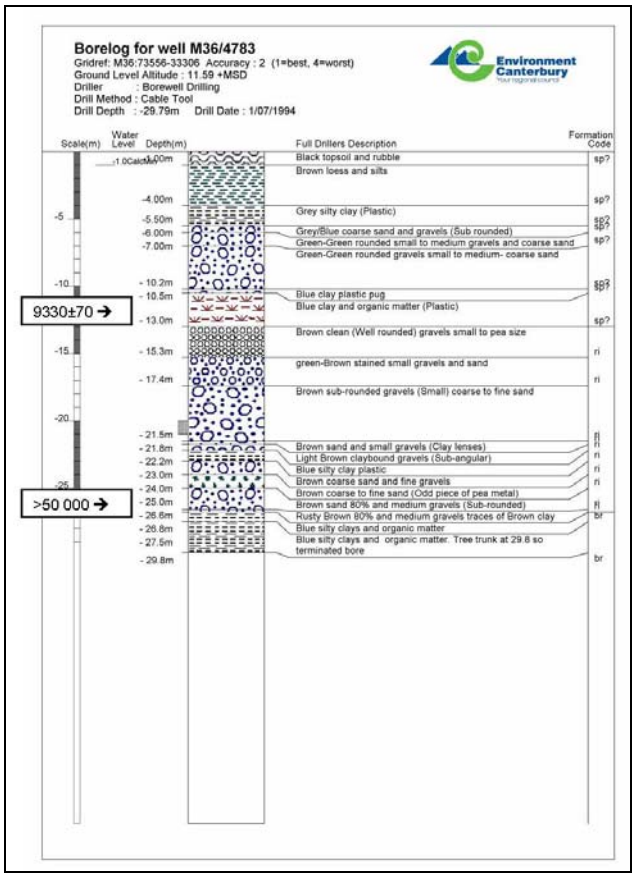

Borelog for well M36/1894
Gridref: M36:8300-3895 Accuracy : 4 (1=best, 4=worst)
Ground Level Altitude : 2.3 +MSD
Driller : J W Horne (& Co)
Drill Method : Unknown
Drill Depth : -41.79m Drill Date : 4/02/1978
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
Artesian
0.60m
Topsoil
Sandy Yellow clay
-4.30m
Blue pug
-7.30m
Blue sand
- 18.9m
Peat
- 19.5m
Blue & Grey pug
- 28.7m
Sand & bits of gravel
- 32.0m
Clean loose gravel
- 33.2m
V. sandy small gravel
- 36.0m
- 36.6m
Sand & claybound gravel
- 37.5m
Sand
- 38.7m
Sandy gravel
Loose Water-bearing gravel
- 41.5m
- 41.8m
Brown sand, bottom of gravel bed
8460±120 →



M36/4595 – partial geological log




Borelog for well M36/4740
Gridref: M36:77245-38120 Accuracy : 2 (1=best, 4=worst)
Ground Level Altitude : 10.97 +MSD
Driller : Borewell Drilling
Drill Method : Cable Tool
Drill Depth : -28.2m Drill Date : 1/06/1994
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
Artesian
-1.00m
-1.50m
-5.19m
-7.80m
-8.19m
- 17.5m
- 25.5m
- 28.2m
Topsoil and clay
Silty clay
Blue Grey clay with traces of vegetation
Sandy Brown stained Grey gravels
Clean Grey gravels with <1% sand
Blue Grey clay with fragments of wood and roots
Sandy Grey Brown stained gravel with traces of clay in places
Brown stained claybound sandy gravel with thin bands of clay
9330±70


Borelog for well M36/4783
Gridref: M36:73556-33306 Accuracy : 2 (1=best, 4=worst)
Ground Level Altitude : 11.59 +MSD
Driller : Borewell Drilling
Drill Method : Cable Tool
Drill Depth : -29.79m Drill Date : 1/07/1994
Environment Canterbury
Scale(m)
Water Level
Depth(m)
Full Drillers Description
Formation Code
-1.00m
-4.00m
-5.50m
-6.00m
-7.00m
- 10.2m
- 10.5m
- 13.0m
- 15.3m
- 17.4m
- 21.5m
- 21.8m
- 22.2m
- 23.0m
- 24.0m
- 25.0m
- 26.6m
- 26.8m
- 27.5m
- 29.8m
Black topsoil and rubble
Brown loess and silts
Grey silty clay (Plastic)
Grey/Blue coarse sand and gravels (Sub rounded)
Green-Green rounded small to medium gravels and coarse sand
Green-Green rounded gravels small to medium- coarse sand
Blue clay plastic pug
Blue clay and organic matter (Plastic)
Brown clean (Well rounded) gravels small to pea size
green-Brown stained small gravels and sand
Brown sub-rounded gravels (Small) coarse to fine sand
Brown sand and small gravels (Clay lenses)
Light Brown claybound gravels (Sub-angular)
Blue silty clay plastic
Brown coarse sand and fine gravels
Brown coarse to fine sand (Odd piece of pea metal)
Brown sand 80% and medium gravels (Sub-rounded)
Rusty Brown 80% and medium gravels traces of Brown clay
Blue silty clays and organic matter
Blue silty clays and organic matter. Tree trunk at 29.8 so terminated bore
9330±70
>50 000

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