Comments on "Gale, A S., Norman Berry Peake, 1921-2010, a chalk revolutionary" [Proc. Geol. Assoc. 128 (2017), 829-839], and "Gale, A S & Lovell, B., The Cretaceous-Paleogene unconformity in England: Uplift and erosion related to the Iceland mantle plume" [Proc. Geol. Assoc. (2017) doi.org/10.1016/j.pgeola.2017.04.002].

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Abstract

Certain misunderstandings expressed in two recent papers about the status of the ongoing revision of the geological maps of the Chalk in a large area of southern England, and about the methodology being used in that process, are here corrected.

The contrast between a 'lithostratigraphical' and a 'biostratigraphical' approach to Chalk mapping is illustrated with an example area in the North Downs of eastern Surrey, western Kent and the adjacent part of Greater London.

It is likely that significant faulting is present in the Chalk of this area, including a normal fault with a throw of about 30 m that passes under Croydon. The area provides the best available opportunity to observe in the field, and to map in exposed Chalk, structures that are likely to be similar to those that occur down-dip under London, concealed beneath Palaeogene cover.

Keywords: Norman Peake; Chalk; geological mapping; Chalk structure; North Downs; London

Gale (2017) presents a very interesting and informative tribute to the late Norman Peake, who was evidently a geologist of remarkable talent, perception and knowledge. However, amongst much else that is arguably of greater significance, Gale (p. 835) observes that in 2002 Peake published '*a plea for BGS maps to include the wealth of information on chalk zonal boundaries which had accumulated through the patient studies of amateur geologists through the 20th C*'. Peake (2002, p. 346) thought that BGS should show biozonal boundaries on their published maps of the English Chalk. While this is undeniably an element of Peake's work, it seems unfortunate that Gale has chosen to draw further attention to an issue that is apparently based on misunderstanding of how BGS creates geological maps of the Chalk.

As explained by Woods et al. (2002), biozonal boundaries in the Chalk outcrop cannot be mapped with acceptable accuracy at medium (1:50 000 or thereabouts) or large (1:10 000 or greater) map scales using biostratigraphical information alone. While it is possible to locate them in some exposures, they cannot be observed in unexposed ground and there their position must be interpolated from the distribution of surrounding exposures for which there is a biostratigraphical determination. By contrast, lithostratigraphical boundaries in the Chalk outcrop can commonly be traced with adequate accuracy across unexposed ground, by reference to topographic features and to rock fragments (brash) in the soil (Bristow et al., 1997; Aldiss et al., 2012). If BGS were to include biozonal boundaries on published geological maps, then their position would, in general, be inferred from the lithostratigraphical mapping, much as Gale and Lovell (2017, fig. 4) have inferred the position of chronostratigraphical boundaries from biozonal information.

In situations where the Chalk is mostly or entirely covered by younger deposits, then the conventional methods of lithostratigraphical mapping are not available. Here it is expedient to use lithostratigraphical and biozonal data from cored boreholes, or to infer the position of lithostratigraphical boundaries from biozonal data, as has been done by BGS in parts of Norfolk, for example (Woods et al., 2002). Gale and Lovell (2017) refer to the work of Mortimore et al. (2011), who elucidated details of the structure of the Chalk from cored boreholes in east London, where the Chalk is extensively buried by younger cover. This exemplifies a 'total-rock' approach to the Chalk, considering lithostratigraphical units, including lithological marker beds, together with macrofossils and other biozonal markers, as well as structural elements and engineering properties (Mortimore, 2012). BGS chalk surveyors also take a 'total-rock' approach, complementing their geomorphological interpretation of the Chalk outcrop.

Gale (2017) and Peake (2002) refer to the abundant biozonal information recorded in the literature describing the Chalk. Peake's (2002) plea arose in part from his view that there is a risk that this valuable resource, especially the older material (much of it compiled by amateur geologists, as by Peake himself), would be '*consigned to historical junk-bins'*. In reality, BGS chalk surveyors make full use of existing biostratigraphical records of any vintage (Woods, 2015; Woods et al., 2002), as well as routinely commissioning new macrofossil and microfossil determinations, such as those cited in this paper (Woods, 1994, 1995a, 1995b, 1997). Although many of the old chalk pits recorded in the 19th and early 20th centuries are now degraded or infilled, BGS surveying has yielded a huge amount of new biostratigraphical and lithological data from field brash, animal burrow spoil, and from relatively modern exposures, commonly at far greater densities than found by any of the earlier surveyors. For example, this approach was recently used to help map out the phosphatic channel around Stonehenge (Mortimore et al., 2017), in an area with very little historical locality data.

The use of biostratigraphical data by BGS chalk mappers can also be illustrated by an example of recent work in an area where Gale (2017, p. 835) claims '*a considerable problem exists where the Newhaven Chalk equivalent lacks marls and cannot therefore be identified as a separate unit; BGS have had to map an undivided Seaford:Newhaven:Culver Chalk, corresponding to five zonal divisions. This is the case across large regions of the outcrop north of Hampshire* …'. He continues: '*A similar problem exists in the outcrop pattern of the chalk beneath the Paleogene along the southern margin of the London Basin (Kent, Surrey, Berkshire)*'. Similarly, Gale and Lovell (2017, Section 4.3) state that the boundary between the Seaford Chalk Formation and the overlying Newhaven Chalk Formation '*cannot be identified in much of the critical region* [west Kent, Surrey, Berkshire, north Hampshire], *because marl seams are absent in the equivalent of the Newhaven Chalk, which cannot therefore be mapped as an independent unit (BGS online digimap)*.'

These statements indicate misunderstandings of the current state of BGS mapping. The Newhaven Chalk can be identified as a separate unit across Hampshire, Berkshire and western Surrey, including the Guildford district (British Geological Survey, 2001). In these areas, the base of the Newhaven Chalk has been successfully mapped on the basis of a change in lithology from soft chalks with large nodular flints, to soft, very smooth chalks with smaller finger-type flints and marl seams. This change is often associated with a prominent break of slope and gives rise to distinctive geomorphological features: contrasts in the geomorphology associated with the Seaford Chalk and with the Newhaven Chalk implies that there is a consistent, significant contrast in their bulk lithological composition (Aldiss et al., 2012). The mapped position of the Newhaven Chalk outcrop has been corroborated in numerous places by the occurrence of the zone fossils *Uintacrinus socialis* and *Marsupites* *testudinarius*. The Culver Chalk, which is younger than the Newhaven Chalk, is absent from this region.

In the remainder of the area referred to by Gale (2017) and Gale and Lovell (2017) – the North Downs in eastern Surrey (east of the Guildford district), western Kent and the adjacent portion of the Greater London Authority area – the Seaford and Newhaven chalk formations have not been separated simply because the corresponding geological maps have yet to be resurveyed using the modern Chalk lithostratigraphy. The most recent field surveys of the Chalk in the Reigate, Sevenoaks and South London districts (British Geological Survey, 1971, 1978, 1998a), along with the western half of the Dartford district (British Geological Survey, 1998b; Figure 1) predate its formulation. When the corresponding geological maps were digitised, the new lithostratigraphy was applied by reclassifying the previously mapped Chalk divisions without resurvey. The base of the Lewes Chalk was placed at the previously mapped base of the Upper Chalk but for the most part the area previously assigned to the Upper Chalk unit remained undivided, being classified as 'Lewes Nodular, Seaford and Newhaven chalk formations (undifferentiated)'. The mistaken inference concerning the 'non-mappability' of the Newhaven Chalk in these areas demonstrates why users of geological maps are well-advised to check the date of the surveys on which the maps are based. This information is given in the marginalia of the maps.

During 2013, DTA attempted to map the base of the Newhaven Chalk eastwards from the Guildford district through the Reigate, South London and Dartford districts by digital desk study. The area that he examined covers most of the inferred subcrop of the Zones of *Uintacrinus socialis* and *Marsupites testudinarius* (the 'crinoid zones') on the sub-Palaeogene surface shown by Gale (2017, fig. 11) and Gale and Lovell (2017, fig. 3). The desk study included a geomorphological interpretation of the base of the Newhaven Chalk using modern 3D geological visualisation software (GeoVisionary; Jordan and Napier, 2016, www.bgs.ac.uk/research/environmentalModelling/3dVisualisation.html) (Figure 1).

This interpretation was controlled by the existing geological mapping, and by biozonal determinations for Chalk exposures in the region provided by the independent work of Young (1905, 1908); and Young and Williams (1906), which was collated with some other data by John (1980), by early BGS memoirs for the South London (Dewey and Bromehead, 1921), Reigate (Dines and Edmunds, 1933) and Dartford districts (Dewey et al., 1924) and by more recent locality descriptions by Woods (1994, 1995a, 1995b, 1997), which also include lithostratigraphical classification. Particular care was taken to identify the position of the described fossil localities accurately using contemporary large-scale Ordnance Survey topographic maps and, where relevant, geologists' field slips. The stratigraphically classified localities, together with the existing geological line work (Figure 1), were overlain on the 3D topographic view in GeoVisionary (which has GIS capability).

In the Guildford district, the base of the Newhaven Chalk lies close to the base of a minor escarpment, analogous to that seen in the South Downs (Aldiss et al., 2012), although rather more subdued (Woods, 2015, fig. 4). The desk study found that this clear, mappable topographic feature continues east to the vicinity of Langley Bottom, between Ashtead and Banstead, less than 2 km from the base of the Palaeogene. This interpretation is corroborated by the distribution of stratigraphically-controlled localities in the Newhaven Chalk/crinoid zones and the Seaford Chalk/*M. coranguinum* Zone. This analysis also indicates the presence of an outlier of Newhaven Chalk beneath the Nower Wood Palaeogene outlier (Figure 1). To the east of Langley Bottom, as far as Croydon, the topographic feature is less clear, and its position is generally equivocal. The abrupt lateral disappearance of such a distinct topographic feature suggests that it has passed into an area with a different geological structure, probably one of greater complexity. To investigate this possibility, structural contours were then constructed for the mapped base of the Thanet Formation, with reference to the Ordnance Survey 5 m contour dataset. The structure contours were drawn manually within an ArcMap (GIS) project (Figure 2). Time was not available to consider borehole data from within the Palaeogene outcrop to complement this exercise.

Aldiss (2013) argues that faults are under-represented on the published geological maps of south-east England in general, and the number of discontinuities and inflections that were found in the structure contours shown in Figure 2 seems to confirm that the local tectonic structure is complicated by faulting, possibly with some gentle folding. Possible lines of faulting (Figure 3) were inferred from:

1. Offsets in the structure contours for the base of Thanet Formation (Figure 2)
2. Mapped offsets, and zones of narrowing, in the Palaeogene outcrop patterns (BGS medium- and large-scale geological maps)
3. The distribution of stratigraphically-controlled Chalk localities (Figures 1 and 4)
4. Offsets in topographical features (including those marking the basal Newhaven Chalk Formation boundary), especially where coincident with linear valleys (Ordnance Survey topographic information)
5. Locality observations in the old memoirs for Sheets 270, 271, 286 and 287 (Dewey and Bromehead, 1921; Dewey et al., 1924; Dines and Edmunds, 1933; Dines et al., 1969), some of which record exposed faults

In addition, the inferred fault in Langley Bottom plausibly extends north-west to The Wells, west of Epsom, there controlling the position of the spring that was the 'type locality' of Epsom salts. In a structural block between this inferred fault, and that which appears to pass south-south-west under Croydon (with an apparent displacement of approximately 30 m, down-to-the-west), the Newhaven Chalk seemingly extends for as much as 5 km up the regional dip-slope, possibly forming outliers. One consequence is that in parts of this block, the Newhaven Chalk occurs high on the dip slope but gives way to the Seaford Chalk down-slope to the north, as indicated by the biostratigraphical locality information (Figures 1 and 4). To the east of Croydon, as far as the Cray valley, the Newhaven Chalk outcrop is again confined to a narrow zone close to the base of the Palaeogene (Figure 3).

This desk-based interpretation was considered too speculative, and incomplete, to incorporate in the published digital geological map without extensive corroboration by detailed field work. The necessary field work has not yet been carried out. The interpretation is presented here to illustrate some of the procedures adopted in the course of BGS chalk mapping, making extensive use of existing biostratigraphical information. It is an unusual instance where an early stage of geological map revision has been preserved digitally, but so far not carried forward to a publishable version. It also serves to indicate the kinds of structures and outcrop patterns that can be expected to occur in this area, although the details of the structural interpretation should be regarded by potential map-users with considerable caution.

Gale (2017, p. 835-836) states '*I spent a considerable time plotting structures in the chalk along this tract* [the southern margin of the London Basin] *beneath the Paleogene unconformity (Gale and Lovell, 2017).* ***Detailed mapping*** [our emphasis] *of the* Uintacrinus socialis *and* Marsupites testudinarius *Zones from records in papers and old BGS sheet memoirs made it possible to identify a synclinal fold in the chalk predating the earliest Paleogene (Thanetian) sediments (Fig. 11). So, Norman was correct; the absence of zonal data on maps significantly reduces the precision which can be achieved in some regions, and structures sometimes simply disappear within the relatively coarse framework provided by lithostratigraphy.*'

A comparison with the BGS desk study in this area reveals that the line for the base of the crinoid zones, as inferred to have occurred at subcrop beneath the basal Palaeogene unconformity by Gale (2017, fig.11) and Gale and Lovell (2017, fig. 3), also encloses the positions of numerous occurrences of *coranguinum* Zone chalk described by Young (1905) that have been omitted by those authors but which are as close to the base of the Palaeogene (or to the base of the clay-with-flints) as most of the *coranguinum* Zone chalk localities that they *do* show (Figure 4). There is no sense in which their line can be regarded as 'detailed mapping'; it is no more than a sketch indicating in simplified form a possible, large, gently-plunging syncline in the Chalk.

Indeed, the evidence cited by Gale (2017, fig. 11) and Gale and Lovell (2017, fig.3) for this inferred large-scale structure seems rather sparse, and it is ambiguous. A similar distribution of data points would arise if the local structure was controlled principally by faulting, rather than by folding. As already noted, a major fault trending NNE-SSW beneath Croydon can be inferred (Figures 3 and 4). Another large fault (or fault zone) of similar orientation and throw (down-to-the-west) might exist in the valley through which the River Darent flows across the Chalk outcrop, perhaps as far north as South Darenth (Figure 3). Such a fault would explain the local offsets in both lithostratigraphy and biostratigraphy apparent in Figures 3 and 4; it could possibly truncate the eastern side of the Farningham Wood Palaeogene outlier and also control the eastern extent of the Newhaven Chalk in that vicinity. The northern extent of the Newhaven Chalk in the Cray valley, eastwards to the Darent valley, could as equally well be controlled by down-to-the-south pre-Palaeogene faulting that repeats the Chalk succession, as by the pre-Palaeogene fold postulated by Gale (2017) and Gale and Lovell (2017), particularly as the Newhaven Chalk also occurs further north in the Cray valley, in the Bexley water borehole, near North Cray (Woods, 1997). The kinds of reason why these inferred faults, if real, are not shown on the existing geological maps are discussed by Aldiss (2013).

Furthermore, as the base of the Thanet Formation in the Chislehurst Inlier stands at about 60 m above OD, approximately 20 m higher than in the Cray valley along strike to the east (Figure 3), it is likely that the inlier is separated from the nearby Chalk outcrop to the east and south by one or more faults, which plausibly cut across the nose of the pre-Palaeogene syncline inferred by Gale (2017) and Gale and Lovell (2017) (Figure 4). As these authors show no other data points controlling the northern limb of this structure, its existence must be regarded as highly speculative.

The ambiguity of this local structure illustrates an inherent inadequacy of attempting to construct a geological map from an array of biozonal control points, rather than by tracing formation boundaries. A far more accurate, and unambiguous, map could be created by mapping using topographic features, together with lithostratigraphy and biostratigraphy where available, and we hope that resources become available to undertake this work. However, whether the extent of the Newhaven Chalk near the southern margin of the London Basin is controlled mainly by large-scale folding or by faulting has little, if any, bearing on the main conclusion of Gale and Lovell (2017), concerning the effects of mantle heat flow during the Paleocene.

We agree with these authors that careful mapping of the Chalk, leading to a better appreciation of its structure, can yield valuable insights to the geological development of the region. We note, though, that contrary to their assertion (their Section 4.3) that '*for our present purposes* [the modern Chalk lithostratigraphy] *lacks sufficient biostratigraphical definition'*, the same overall pattern shown in their Figure 4 is also revealed using the lithostratigraphical divisions: an overall tilt to the east and south, with the oldest Chalk at the basal Palaeogene surface in the north-west. A simple substitution of lithostratigraphy for chronostratigraphy (or biostratigraphy) in this map, inserting the bases of the Seaford, Newhaven/Margate and Trimingham chalk formations at levels in the mid-Coniacian, mid-Santonian and basal Maastrichtian, respectively, reveals essentially the same pattern (Figure 5); there is no essential gain, so far as their main conclusion is concerned, in using the additional subdivisions of Chalk biostratigraphy.

There would, however, be a wider benefit from detailed field survey of the Chalk in the area of the North Downs shown in Figures 1-4, particularly to hydrogeologists, engineering geologists and makers of 3D geological models working in the London region. This area provides the best available opportunity to observe in the field, and to map in exposed Chalk, structures that are likely to be similar to those that occur down-dip under London, concealed beneath Palaeogene cover. If we understand the structure of the Chalk outcrop south of London, then we will have a better understanding of the structure of the Chalk in the concealed aquifer under London, which is essential for a better understanding of the hydrogeology of the London Basin. The detailed mapping of the Chalk required for these purposes cannot be achieved using biostratigraphical criteria alone.

In conclusion, we agree with Peake (2002) and with Gale (2017) to the extent that in preparing a geological map full use should be made of all available data, including biostratigraphical data, and we expect that BGS mappers will continue to do so, as they have in the past. We do not agree with these authors that biozonal boundaries within the Chalk should be shown on BGS geological maps.

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Figures

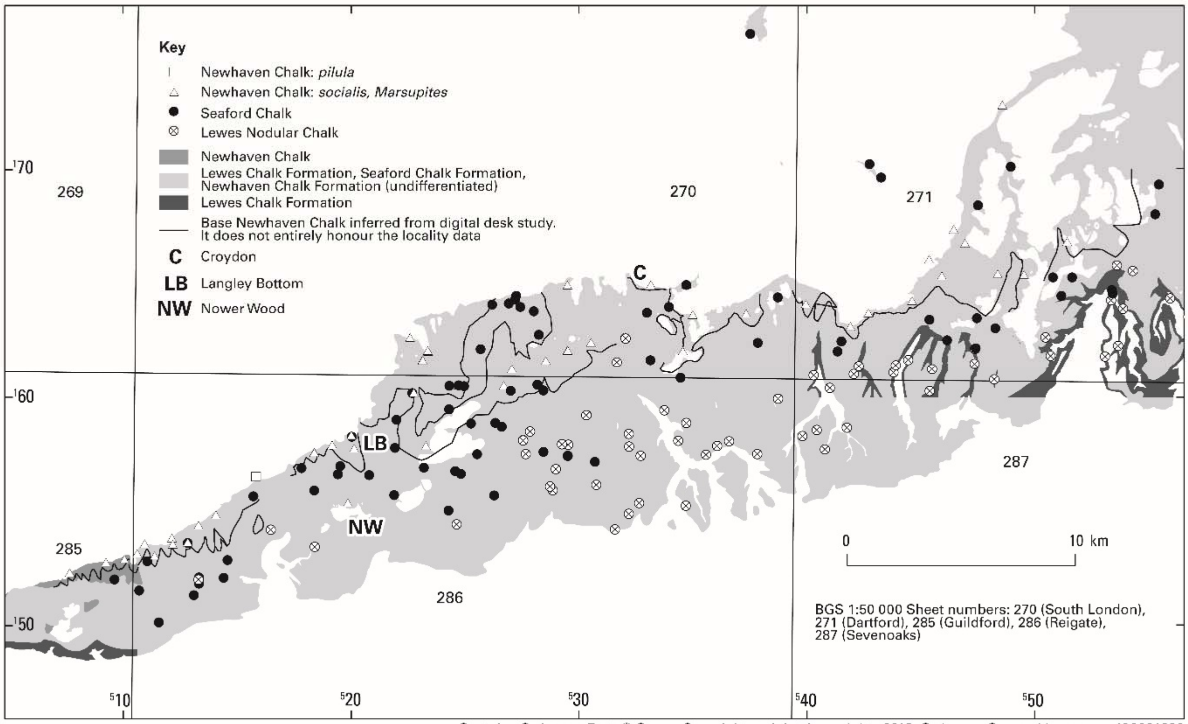

Figure 1: North Downs of Surrey, south London and west Kent with stratigraphically-controlled Chalk localities

Locality information is taken from sources mentioned in the text. Localities with Chalk older than the Lewes Nodular Chalk Formation, or which have an uncertain attribution, have been omitted. Details of bedrock geology in the unornamented portions of this figure can be found in the BGS 1:50 000 digital geological map at http://mapapps2.bgs.ac.uk/geoindex/home.html

Note that the inferred base of the Newhaven Chalk is approximate and has not been checked on the ground.

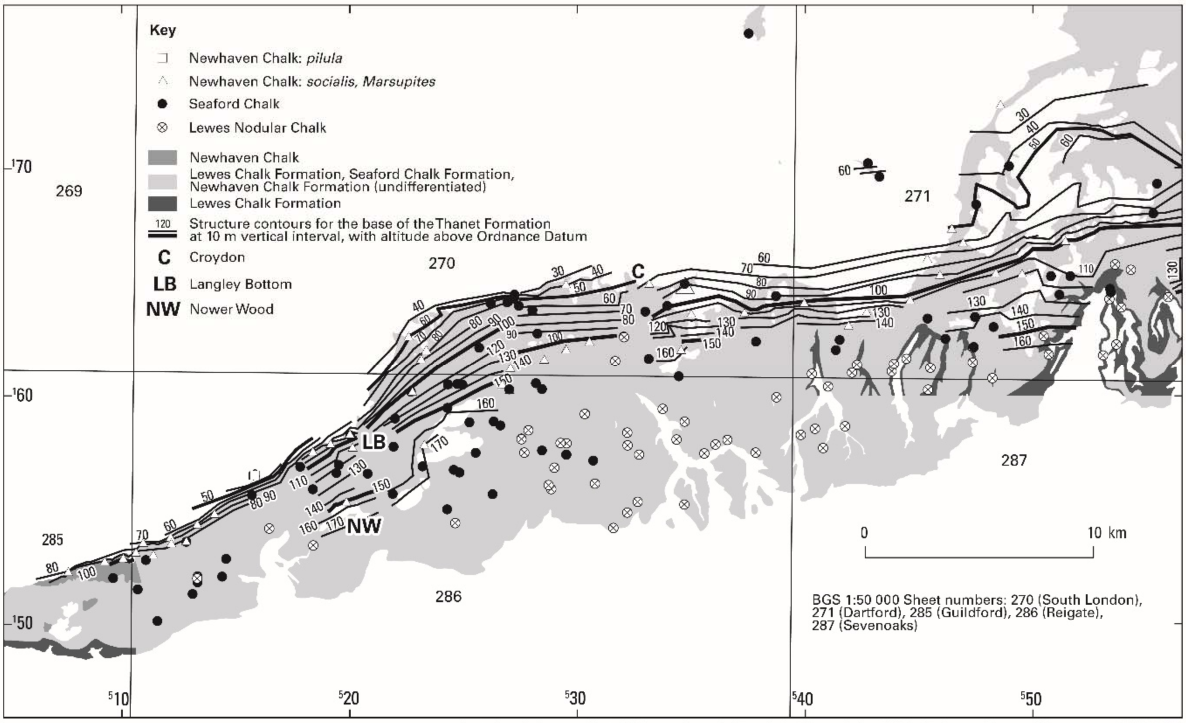

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Figure 2: As Figure 1, with structure contours for the base of the Thanet Formation

The Thanet Formation is the basal Palaeogene formation in this area. The structure contours are at 10 m vertical interval, interpreted from the intersection of the Ordnance Survey 5 m contours with the base of the Thanet Formation as shown on the BGS 1:50 000 digital geological map.

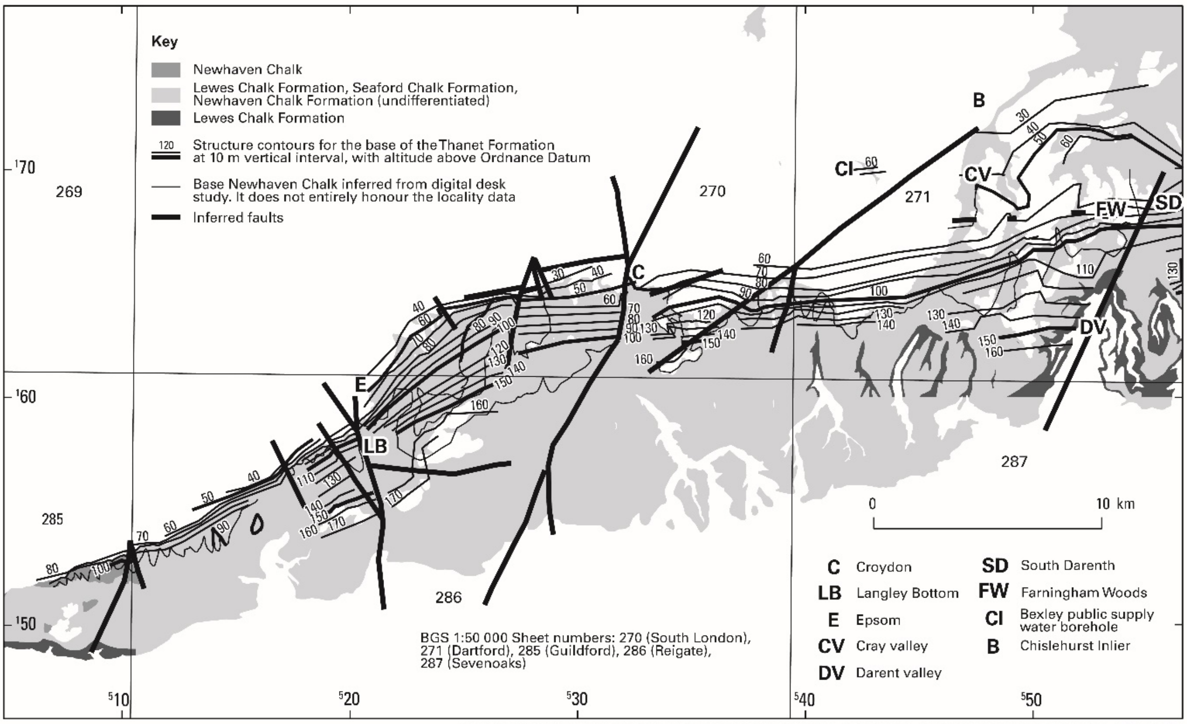

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Figure 3: As Figure 2, with inferred lines of faulting

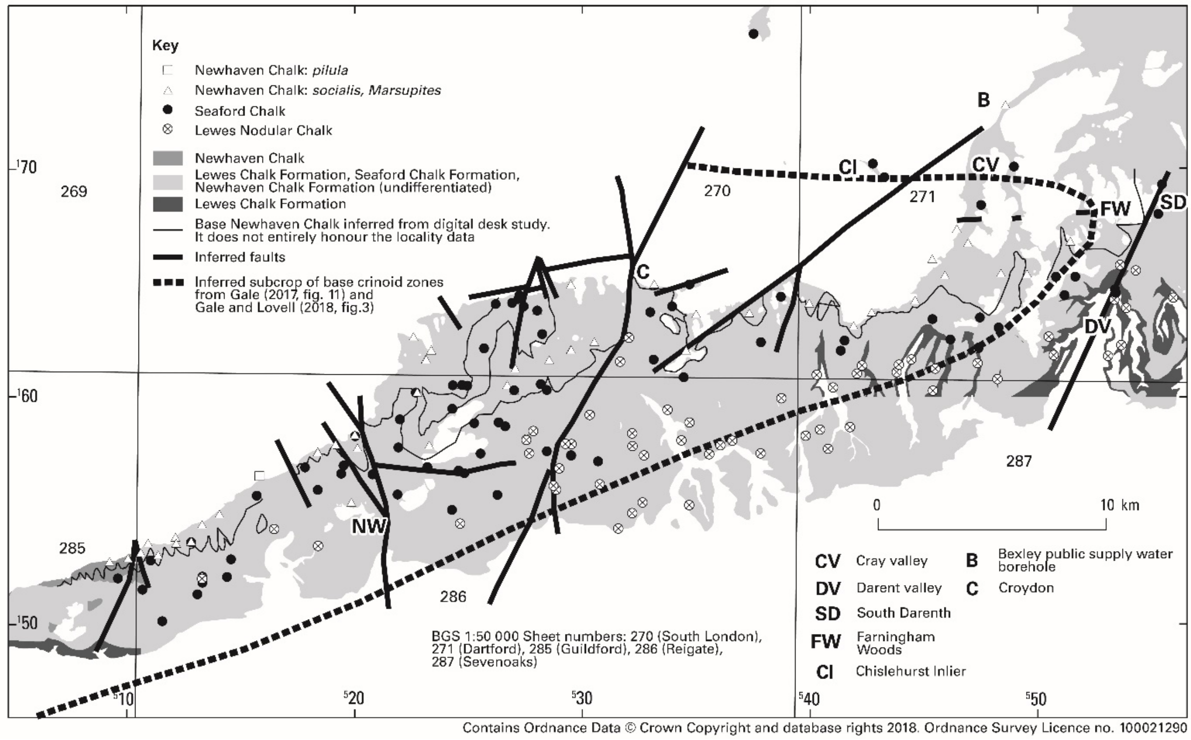

Figure 4: As Figure 3, with inferred subcrop of base of 'crinoid zones' at sub-Palaeogene surface

Base of crinoid zones taken from Gale (2017, fig.11) and Gale and Lovell (2017, fig.3).

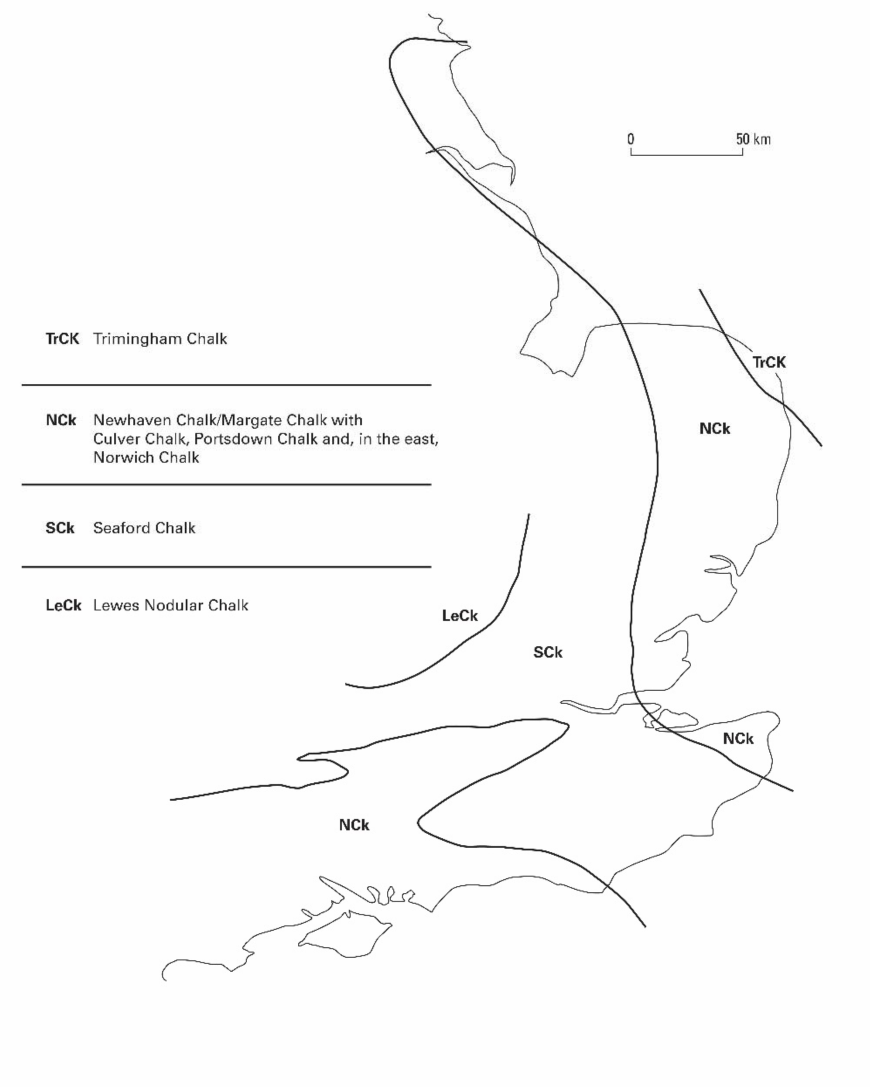

Figure 5 Inferred subcrop pattern of English Chalk formations on sub-Palaeogene unconformity

Derived from Gale and Lovell (2017, fig.4), which quotes additional information sources, with lithostratigraphical divisions substituted for approximately equivalent chronostratigraphical ones.

The Margate Chalk is the lateral equivalent of the Newhaven Chalk in Kent.