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Urban Geochemistry: from 2D to 3D

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Abstract

The current state of knowledge in relation to soil and subsoil geochemistry (when available) is overwhelmingly based on surface (topsoil) and very near surface sampling of subsoils. This is expressed in the form of 2D mapping, based on interpolation between sample sites. 2D topsoil acquisition is particularly well suited for addressing health issues; deeper geochemical sampling is required more typically in relation to urban (re)development, construction work and remediation of contamination. 3D geochemical knowledge, although as yet uncommon, could be very useful in optimizing urban redevelopment projects, anticipating contamination problems, and managing excavated materials (e.g. local reuse possibilities, disposal costs etc.). Because all of these aspects can have important economic, environmental and social consequences, they are considered essential for urban sustainable development. To meet these future 3D, and potentially even 4D (temporal and predictive) needs, improved development of data acquisition, management, visualisation and use of these are crucial steps.

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Keywords: geochemistry; urban; subsoils; quarter; city; data visualization; gaps

1. Introduction

Urban geochemistry is relevant to a variety of issues including health, contamination, urban planning, urban development, economy, resource management (soil, water), and the use of soils and subsoils (urban agriculture, etc.). It needs to be considered at a wide range of scales - from sample to site, quarter, and city - and in relation to the various components of the urban system: soils, subsoils, the deeper sub-surface, (ground)water, sediments, air ,etc.

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The geochemistry of urban soils and subsoils may have natural (geogenic) and/or man-made (anthropogenic) origins. Industry and mining activities are frequent sources of point source and diffuse contamination of soils and subsoils. Service activities, agriculture, traffic, leakage from sewers, leakage from individual domestic fuel tanks, waste deposits etc. are other sources, and the use of pesticides in paved areas, gardens, football fields, golf courses etc. is a further significant source of contamination. Some anthropogenic deposits are used as filling materials, such as demolition waste (containing e.g. paintings, plaster, PCB in transformer oils). In particular, industrial and mining waste has been frequently used in construction or civil works in the neighbourhood of the industry, or even elsewhere in the city. However, there is often little or no traceability of these uses of waste materials within cities; and they may represent important sources of diffuse contamination.

In recent years, European cities have often undergone major changes as a result of industrial closures on the one hand, and population increase on the other hand. Industrial closures often result in large areas of brownfield land being available for redevelopment and regeneration. Although many former industrial areas can be attractive for housing due to their location (in proximity to city centres and riversides), their soils and subsoils are often significantly contaminated and potentially harmful to human health and the wider environment. There is a need, therefore, if these sites are to be reused, to take into account the contamination of their soils, through improved knowledge of the geochemistry, in 3D and even 4D, as well as 2D.

Subsoil geochemistry is therefore an important element of urban management, development and planning. Knowledge of subsoil geochemistry is particularly relevant during the earlier phases of urban planning: a) enabling the compatibility between planned uses of the subsurface and the chemical quality of the subsoil to be anticipated; for example, the building of schools or other sensitive underground infrastructure (metro, drinkable water buried networks,…) in heavily contaminated and potentially unhealthy areas can and should be avoided. b) Knowledge of subsoil geochemistry and soil quality can inform appropriate adaptations of urban plans, and during redevelopment projects, it is essential to anticipate contamination problems if excessive costs, delays, and adverse public relations, are to be avoided. 3D geochemistry is equally valuable in the management of excavated materials, facilitating their reuse in zones of equivalent geochemistry. Optimized management of excavated materials can have substantial cost benefits. All of these aspects have important economic, environmental and social consequences such that subsurface geochemistry is an essential component of urban sustainable development.

A key need of city planners in relation to the geochemical quality of soils and subsoils is to have reasonable and representative visualisation of the data in forms which enables their effective use, and in a way which can be integrated with other datasets (socio-economic, health, etc.). This paper illustrates the current visualization of soil and subsoil geochemical data, discusses future trends in the use of urban geochemical data, and identifies some gaps that need to be overcome. The paper has been inspired by COST Action TU1206 – Sub-Urban (see Campbell et al., this volume)[1]

2. Current practice of soil and subsoil geochemical data visualizations

Visualisation of geochemical information may relate both to statistical and/or spatial treatment of the data, and may illustrate either validated data or interpreted data.

Various end-users with no particular expertise in geochemistry (developers, urban planners) need representations that are easy to understand, and to use. In this context, the use of raw data appears inappropriate, and interpreted data sets should be provided, and used instead. The visualisation of data should also be appropriate, and linked, to the objectives or intended use(s) of the data.

Preliminary statistical treatment allows a general overview, including: minimum and maximum percentiles, and data distribution (histograms). As data distribution is generally non-Gaussian, classical statistics cannot be used. The most commonly used statistical approaches therefore include: box plots, PCA, and cluster analysis.

2.1. 2D visualization

The current state of knowledge in relation to soil geochemistry (when available) is overwhelmingly based on the surface (topsoil) and very near surface sampling of subsoils. This is expressed in the form of what is in essence 2D mapping. 2D topsoil geochemical acquisition is particularly well suited for addressing issues related to human health.

There are many examples of subsurface data representations in the literature. Mapping of soil geochemical quality is particularly well developed in Europe, and many examples have been compiled by Johnson et al. (2011) [2].

Spatial visualisation can show point location data with or without interpretation (e.g. referring to a threshold value) (Fig.1). Data interpretation may also be applied to build continuous spatial representations, thanks to interpolation (Fig. 2 and 3). The advantage of interpolation is that it enables coverage of the whole of the studied area. However, the accuracy of such a treatment needs to be verified: the spatial relationship between data must be verified by a geostatistical approach through the use of variographic analysis. An alternative to interpolation is the use of grids, where a sample is represented by a cell (square portion of the territory, supposedly homogeneous). Examples of grid representations are available on the internet, e.g. in the advanced geochemical atlases of the British Geological Survey (BGS)[3]. Due to the heterogeneity of urban soils, the data used for interpolation or grid representation are inferred to be more or less representative of the system under study. Uncertainty maps should therefore be provided in addition to spatial interpretations.

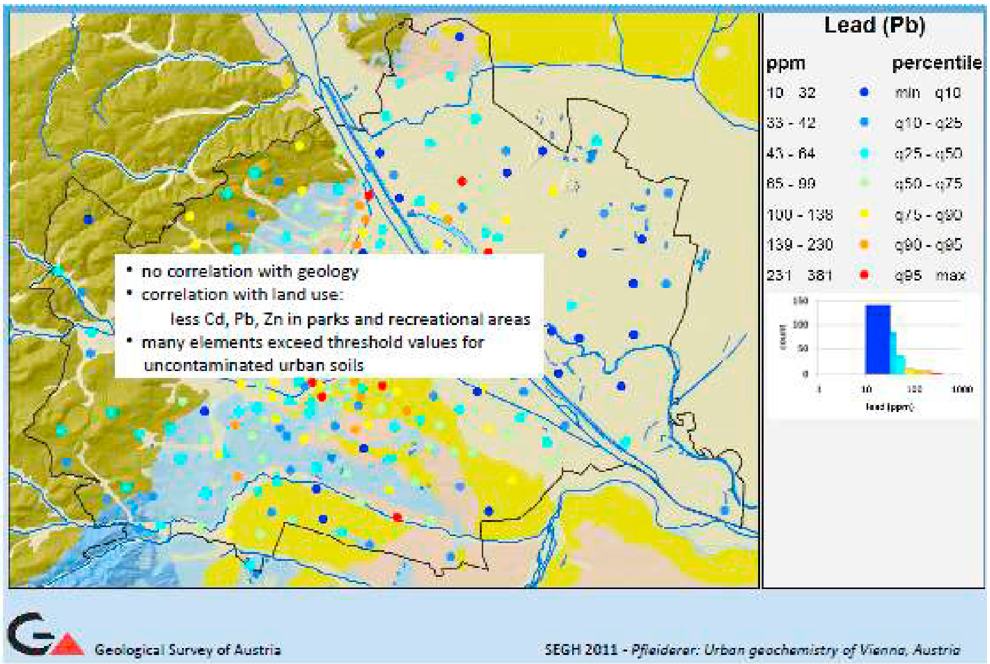

Fig. 1: Geochemical map showing the spatial distribution of lead in urban, peri-urban and forest soils (Vienna, Austria), Pfleiderer et al. 2011 [4]

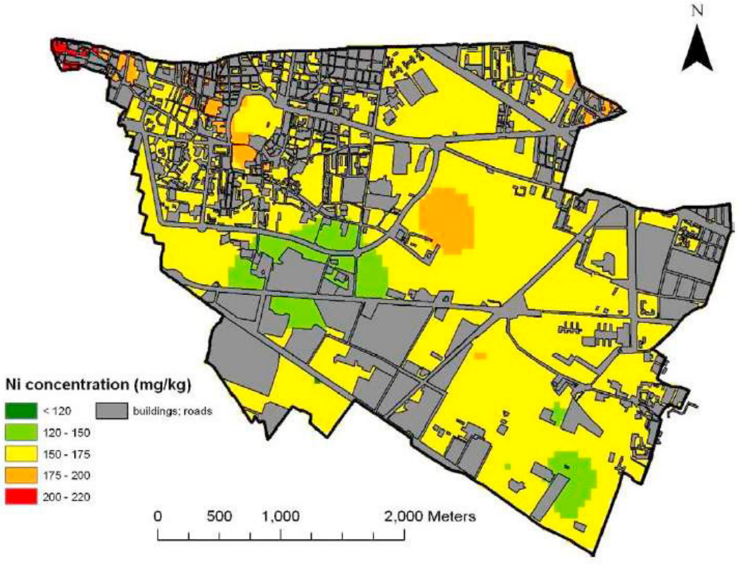

Fig. 2: Spatial distribution of nickel concentration around Grugliasco (Italy) calculated by log-normal ordinary kriging. (Poggio & Vrščaj, 2009) [5]

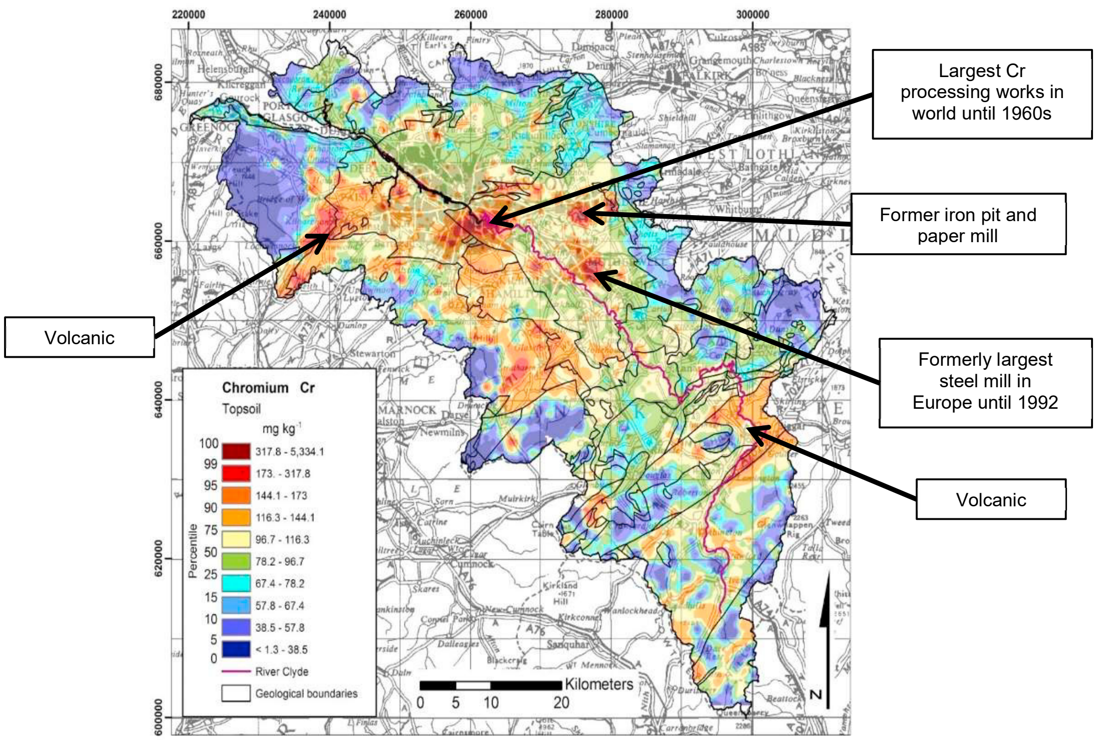

Fig. 3 : Chromium content in (near-surface) soils in the Glasgow area and the river Clyde catchment, reflecting combined influences of geology (volcanic bedrock) and urban pollution (metal processing) (after Fordyce et al., 2012)[6] (Topography Crown Copyright held by BGS under license 100017897/2012. All right reserved BGS)

2.2. 3D visualisation

3D geochemical modelling of urban subsoils is relatively uncommon at the quarter to city scale, compared with 2D approaches that map soil geochemical quality. The use of 3D urban geochemical data is mainly associated with management of contamination, at the site scale. 3D representations, where undertaken, are carried out mainly in relation to redevelopment projects, including brownfield sites, where subsoil contamination (e.g. by former industrial or mining activities) may affect the management of excavated materials. As 3D geochemical modelling is very expensive, its use generally has to be determined by economic need.

There are very few examples thus far of 3D geochemical modelling and visualisation of urban subsoils having been carried out at a larger scale (Rotterdam, Nantes, Oslo), and published (Nantes, Le Guern et al, 2016 &2017[7][8][9]). It is difficult therefore in this context to define good practice. The example of Nantes is proposed instead as an example of best effort (see Fig.4).

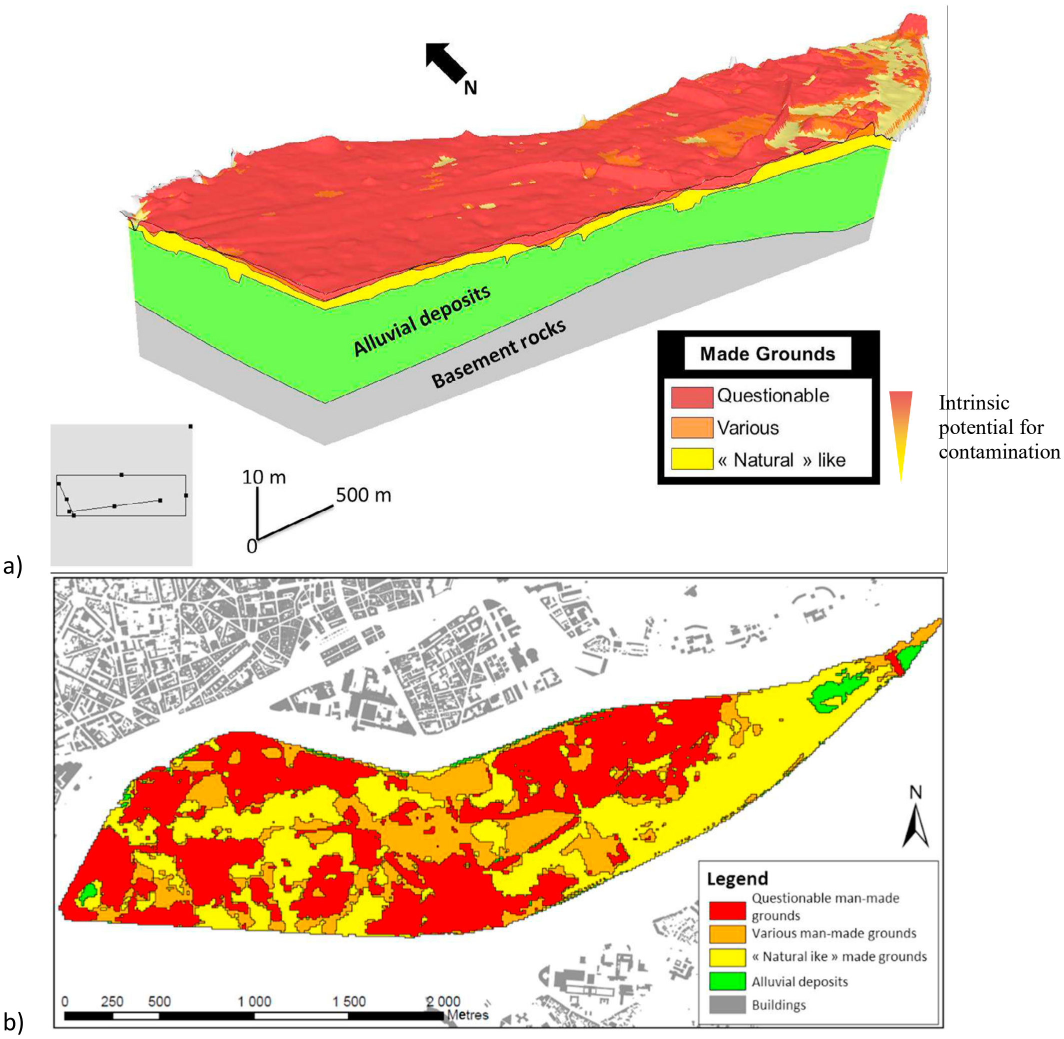

Fig. 4. Presentation of geochemical subsoil quality of Nantes Island, France a) 3D model integrating several classes of made ground, defined according to their intrinsic potential of contamination (from high for questionable made ground containing industrial residue to low for the more “natural” made grounds present on the island); b) 2D representation of made ground at 1 m depth, according to their intrinsic potential for contamination, extracted from the 3D model – Ile de Nantes, France (Le Guern et al, 2016&2017)[7][8][9]

3. Future needs and corresponding gaps

It is contended that the prevailing 2D state of knowledge of topsoil geochemistry (when available) and of geology, cannot provide an adequate basis for 3D urban redevelopment due to the lack of knowledge of the depth dimension. City needs should therefore include better knowledge of the soils and subsoils (geometry and structure) associated with their geochemical quality, and taking into account both natural baseline and anomalies, as well as diffuse and point source anthropogenic contamination. To meet these future 3D and potentially even 4D (temporal and predictive) needs, improved development of data acquisition, management, visualization and (combined or joined) use of these are essential.

3.1. Development of 3D and 4D mapping technology

A major difficulty in developing a 3D representation of the "geological" structure of urban soils and subsoils lies in their heterogeneity and especially in the lack of geological logic in the internal structure of their anthropogenic made-ground/deposits. In addition, urban soils and subsoils are also constantly evolving: in situ subsoils may be removed or modified (e.g. removal of contaminated subsoils); and new materials may be introduced. The evolution may be particularly rapid in (re)development zones and may result in major changes in the properties of the subsoils (e.g. geotechnics, permeability, geochemistry, organic carbon). Subsoil dynamics should therefore be monitored over time, to provide the basis for their 4D representation.

3.2. Geochemical data acquisition and management

To meet these objectives, there is a need to build a general knowledge of soil and subsoils. This should address the following:

- Collation of existing geochemical data in local and/or national databases, taking into account: 3D to 4D data, database structure, management-verification, validation, updating, etc.,
- Protocols to ensure compatability of data. This is already available/published in the case of 2D geochemistry of soils (Demetriades and Birke, 2015)[10][11], but proposals need to be developed and tested for 3D data (e.g. dry drilling, sampling according to lithology rather than depth). Protocols should also be adaptable to local site conditions,
- Harmonisation of descriptions is essential (Le Guern et al., 2016)[7].
- Because legacy data have been acquired in a range of ways (different extraction methods and/or detection limits), methods to exploit legacy data need to be developed if they are to be used more reliably and robustly.

3.3. 3D representation and use of geochemical data

Geostatistics are useful in helping to identify data gaps, in selecting datasets for interpolation, in identifying the best method for interpolation of data, and in interpolating data when their spatial correlation is confirmed. There has been considerable research and development in geostatistics of 3D subsoil geochemistry, e.g. on the following aspects: interpolation methods (linear, non-linear, voxel - Schokker et al, 2016 [12]), management of heterogeneity, analysis and management of uncertainty). It could also be useful to build integrated spatial or even spatio-temporal representations (GeoCity Information Modelling (GeoCIM; Mielby et al., 2016) [13]).

Research is needed to develop more helpful geochemical data representations for end-users. In this regard, the development of indicators of geochemical quality versus potential use of soil and subsoils could be useful. Cost/benefit analysis also needs to be demonstrated.

Useful representations for end-users should include the notion of indicators; these appear to be relatively under developed at present. The example presented by Guillèn, 2011 [14] (Fig. 5) is a useful step towards such a representation, as well as the mapping of made-ground according to their intrinsic potential for contamination (Fig. 4) and the degree of potential pollution of soils and subsoils linked to former industrial uses and other activities (Fig. 6) by Le Guern et al. (2016&2017)[8][9].

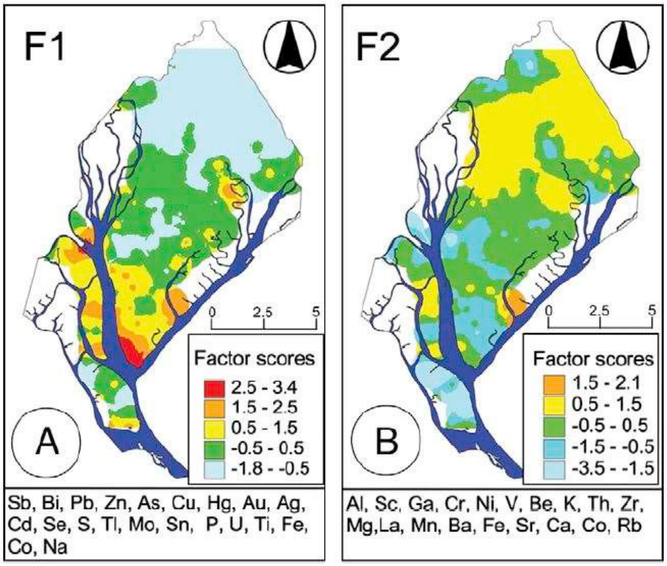

Fig. 5. Maps showing the F1 and F2 factor scores obtained by factorial analysis of geochemical soil samples from Huelva Municipality (Spain) (Guillén, 2011)[14]

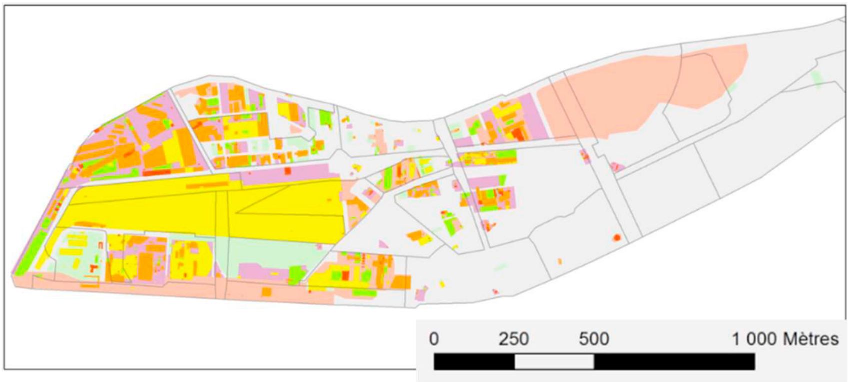

Fig. 6. Indicator of potential contamination of subsoils by lead, linked to former industrial and other activities (from very low to absent in green to very high in purple) – Ile de Nantes, France (Le Guern et al., 2016&2017)[8][9]

4. Conclusions

The 2D mapping of topsoil geochemistry, driven substantially by human health issues, is already well documented (Johnson et al, 2011, Demetriades and Birke, 2015) [2][10][11]. However 3D representation of subsoil geochemistry is poorly developed by comparison. This would explain the many unforeseen contamination problems encountered during site re-developments, and resulting unanticipated cost burdens, delays and adverse public relations.

A new approach, underpinned by appropriate research and development, and improvements in subsurface geochemical data acquisition and management, is therefore required if redevelopment projects scales of understanding, 3D and potentially 4D modelling (temporal and predictive), and appropriate visualizations of soil/subsoil geochemistry and quality are to be realized, and made available to and taken into account by a wide range of end-users (developers, consultants, urban planners, and others). This will need to take adequate account of the organization of the subsoils (especially the complex anthropogenic deposits and their quality) and full account of: natural baseline and anomalies; and diffuse and point source anthropogenic contamination.

This 3D knowledge of the geochemistry of the soils/subsoils is needed at the early stages of urban planning if urban redevelopment projects are to be optimized; contamination problems anticipated; and successful management of excavated materials (including local reuse possibilities, disposal costs etc.) achieved. All of these considerations are relevant to the sustainable development of cities.

Acknowledgements

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