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# GLOBAL GEOCHEMICAL BASELINES: A FUNDAMENTAL INTERNATIONAL PROJECT FOR ENVIRONMENTAL MANAGEMENT

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## ABSTRACT

A high quality data set about the geochemistry of the terrestrial surface layer is required to meet the lemands for sustainable development. International collaboration projects in geochemistry, working owards this goal, aim to produce by the year 2005 a global geochemical terrestrial reference network for he subsequent production of a global geochemical atlas for 78 chemical elements. The terms geochemical ackground and geochemical baselines are defined for it is significant to understand the differences etween them.

Greece is participating in these international projects, and the Institute of Geology and Mineral Exploration is also carrying out regional geochemical surveys at different sample densities.

**KEY WORDS**: Geochemical mapping, geochemical atlas, geochemical background, geochemical aseline, sustainable development, environmental management

## 1. INTRODUCTION

"***Prevention is better than cure***... *It is the only possible cost-effective way of dealing with potential isks and disasters. It is of vital importance that the world community takes the long-term view and learns o be proactive rather than reactive.*"

"*Because of the growing demands on mineral and energy resources, water, soils and materials, roblems of pollution and waste disposal, on a scale never seen before, and the rise of megacities and uman settlements vulnerable to natural and anthropogenic hazards,* ***we require more knowledge on the*** *tructure,* ***composition*** *and dynamics* ***of the earth's crust*** *and of effects upon human life-support ystems. A better understanding of natural physical and* ***chemical*** *fluctuations influencing the environment s important in order to elucidate the role of the lithosphere in global change.*"

"*There is now a general awareness among policy-makers, planners and the public at large that the nvironment is inextricably interlinked with economic development and the present environmental legradation could threaten our very survival. Fortunately, there also seems to be a widespread political vill to translate these concerns into action necessary to bring about 'sustainable and environmentally ound development', as advocated in the Bruntland Report of 1987*" (Eder and Babuska, 1995, p.iii).

The above comments, introducing the final report of the International Geological Correlation rogramme (IGCP) Project 259 "A Global Geochemical Database for Environmental and Resource Aanagement" (Darnley et al., 1995), show the significance of geochemical data to our present-day needs. This particular report contributes to the scientific knowledge required to achieve sustainable development rom the standpoint of Applied Geochemistry. Its recommendations for a global geochemical database eed to be accommodated within any plans pertaining to the good husbandry and housekeeping of our lanet's environment and resources.

Other contributions towards the compilation of an international geochemical database, but on a

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European scale, is the research work carried out by the Western European Geological Surveys' (WEGS) Working Group on "Regional Geochemical Mapping" (Bolviken et al., 1990, 1993, 1996). The published Pilot Project Report "Geochemical Mapping of Western Europe towards the Year 2000" (Demetriades et al., 1990) is regarded as "... *a landmark. In addition to being of considerable interest and importance in itself, it provides an excellent starting point for future national or international proposals concerned with the systematic geochemical mapping of large areas"* (A.G. Darnley, Project leader of IGCP 259/360, 1990).

Following the recommendations of the WEGS Working Group on Regional Geochemical Mapping, further work was carried out by the Geochemistry Task Group, which produced a report entitled "Forum of European Geological Surveys (FOREGS) Geochemistry Task Group 1994-1996 Report – A contribution to IUGS Continental Geochemical Baselines" (Plant et al., 1996; 1997).

Two significant steps forward, in the realisation of global geochemical mapping, were the September 1996 decision of the FOREGS Directors, and the June 1997 decision of the Directors of the European Geological Surveys (Euro-Geological Surveys), to adopt the recommendations of IGCP 259, and their intention to produce the European Geochemical Terrestrial Network by the Year 2000.

### 1.1. Aims of the Global Geochemical Database

The global geochemical database is intended to serve several purposes (Darnley et al., 1995, p.37):

- provide authoritative documentation concerning the chemical composition of a variety of surficial materials (active stream sediment, soil, surface humus, overbank sediment, floodplain sediment, water, till, lake sediment) at locations evenly spaced over the land surface of the globe;
- provide a supply of locally relevant standard reference materials for on-going use in the region of origin;
- provide reference points for normalising national geochemical databases;
- provide a framework of systematic geochemical baseline data which will make possible the preparation of a World Geochemical Atlas;
- provide samples on which further work can be undertaken, e.g., to undertake isotopic analysis, speciation studies, determine organic pollutants, etc., and
- provide sites for recurrent monitoring in the future to facilitate recognition and measurement of "change," from whatever cause.

The global geochemical maps will show abundance levels, delineate regional trends and geochemical provinces, and permit the recognition of large-scale anomalous features (Darnley, 1990). Primary raw data will be stored in digital form to facilitate geochemical map production at different scales in a variety of formats, for mineral resource, general geological and environmental studies. Geochemical maps will be produced at the same scale as existing international geological and geophysical maps to expedite direct comparison.

### 1.2. IGCP and IUGS projects

Production of a multi-purpose systematic global geochemical database and world geochemical atlas began in 1988 with IGCP 259 project "International Geochemical Mapping." This project is jointly sponsored by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) and the International Union of Geological Sciences (IUGS), through the International Geological Correlation Programme (IGCP).

The first phase of the project ended in 1992 and a detailed report was submitted (Darnley et al., 1995). Project results were also published in two special issues of the Journal of Geochemical Exploration (Darnley and Garrett, 1990; Davenport, 1993a). The IGCP committee, after the successful completion of the first five-year period, approved the extension of the project for another five years (1993-97) as IGCP 360 "Global Geochemical Baselines." At the end of this term, the second phase will continue from 1998, until the completion of the global multi-element geochemical atlas, under the auspices of the IUGS with the same title, "Global Geochemical Baselines."

### 1.3. WEGS-FOREGS regional geochemical projects

The Directors of WEGS established in 1985 a Working Group with the mandate to investigate different aspects of "Regional Geochemical Mapping" (Demetriades and Ottesen, 1990). The Working Group proposed in 1986 a systematic widely spaced regional geochemical mapping programme, with a density of 1 sample site per 500 $km^2$, to obtain baseline information for use in geoscientific and environmental studies. In 1990, the Working Group submitted its pilot project report (Demetriades et al., 1990) and its proposal (Bolviken et al., 1990). The Directors decided that further research work was needed before a decision can be taken. The Working Group submitted its final report and recommendations in 1993 (Bolviken et al., 1993). The Directors, after studying the report, established in 1994 the Geochemistry Task Group with the mandate to collect and evaluate all available European based regional geochemical data sets, and to submit a report with recommendations. The Group submitted its report in 1996 (Plant et al., 1996, 1997). The FOREGS Directors decided in September 1996 to go ahead with the European part of the global geochemical mapping project, and to produce by the year 2000 the European Geochemical Terrestrial Network.

## 2. GEOCHEMICAL BACKGROUND AND GEOCHEMICAL BASELINE

Since, there appears to be confusion between the usage of the terms "geochemical background" and "geochemical baseline", their definition was considered essential.

The ***geochemical background*** of a chemical element may be defined as its natural abundance in a particular material (rock, soil, stream sediment, etc.) determined by a particular analytical method on a particular grain size. Since, even the most homogeneous earth material has minor inhomogeneities, the abundance of an element is represented by a range of values, and is not a single value, e.g., the average content of an element as is conveniently expressed. As pointed out by Govett (1983) the single value approach is reasonable for a statistical normally distributed population. The frequency distribution, however, of a trace element in a particular, fairly uniform earth material, is commonly positively skewed, and the arithmetic mean is clearly biased by scattered numbers. Although the arithmetic mean is a good estimate of the abundance of an element in the particular earth material, it is not necessarily a good estimate of the most commonly occurring concentration. A better approximation to the most commonly occurring value for positively skewed data is the geometric mean (the antilogarithm of the arithmetic average of the logarithm base 10 values). The geometric mean is a more robust estimator of the geochemical background for most trace elements, because it reduces the importance of a few high values in a sample data set from a particular earth material. Nevertheless, this again is a simplification of the actual natural variation of elements in a particular earth material. Hence, the concept of **natural background variation** of an element in a particular earth material determined by a particular analytical method on a particular grain size. A range of values, and not a single value therefore, represent the geochemical background of an individual lithological unit.

In mineralised areas, the matter is further complicated, because the natural distribution of elements is disturbed by the mineralising event. The occurrence of above normal element concentrations in mineralised areas, constituting the geochemical anomaly, are superimposed on a variable natural background. Similarly, in anthropogenically contaminated areas, the pollution is superimposed on the variable natural element concentrations, which in this case include even the above normal element contents ascribed to mineralisation. The following equations may clarify the above concepts:

| | | | | |
|---|---|---|---|---|
| Abnormal element contents (geochemical anomaly) | = | Natural background element variation due to lithology | + | Above normal element concentrations due to lithology or mineralisation |

| | | | | |
|---|---|---|---|---|
| Anthropógenic pollution (neo-anomaly) | = | Natural element variation due to lithology & mineralisation | + | Above normal element concentrations due to anthropogenic activities |

"Baseline" is a new term in geochemistry so it will first be defined by itself. According to the McGraw Hill Dictionary of Scientific and Technical Terms (Lapedes, 1978) in a topographical survey the baseline is "a surveyed line, established with extra care, to which surveys are referred to for co-ordination and correlation", and in science and technology the baseline is "a line drawn in the graphical representation of a varying physical quantity to indicate a reference value". By considering these two definitions the ***geochemical baseline*** of an element is established by the analysis of a particular natural sample medium by a particular analytical method to which the results of other geochemical surveys are referred to for co-ordination and correlation. The geochemical baseline map of Europe, and subsequently that of the World, will in fact be a three-dimensional geochemical reference surface for a particular sample medium, analysed by a particular analytical method, to which national geochemical results from the same sample medium will be linked to by applying suitable correction factors for each element at each sample site. Hence, in three-dimensional space the geochemical baseline of an element will be a reference value at each sample site for the different sample media (e.g., soil, organic material, stream sediment, overbank sediment, floodplain sediment, water) according to the analytical method used.

The natural *geochemical background* of an element, in its simplest form is represented by a range of values, and does not include abnormal element concentrations due to mineralisation. Whereas, the *geochemical baseline* of an element is a variable geochemical reference value, including both the natural geochemical background variation and abnormal element contents of mineralisation. Depending on the sampling medium used, the geochemical baseline of an element will also include abnormal element concentrations due to anthropogenic contamination (e.g., surficial samples of residual soil, overbank and floodplain sediments, stream sediment and stream water). Nevertheless, there are sampling media (e.g., deep samples of residual soil, overbank and floodplain sediment) that can determine the natural geochemical baseline of an element.

## 3. REGIONAL GEOCHEMICAL MAPS AND THEIR SIGNIFICANCE

Anthropogenic influences, regardless of their scale or origin, are superimposed upon a variable natural geochemical background. Natural abundance for trace elements typically range over two or more orders of magnitude in surficial materials directly influencing the chemistry of the biosphere (Davenport, 1993b). This natural variability in geochemical background is determined by approximately five billion years of geological processes. Studies of geochemical change over time due to environmental factors ignore, however, geologically controlled variation, and focus on change compared with the surrounding local background of only a few sites instead of the whole area. It is, therefore, significant to map the geochemical variation of trace elements considered as essential (Cl, Co, Cu, F, I, Mn, Mo, P, S, Se, V and Zn) or as toxic (As, Be, Cd, Hg, Ni, Pb, Sb, Tl and U) to biota. Even essential elements can occur in sufficiently high concentrations to be toxic.

Systematic sampling and determination of chemical elements in representative samples of active stream sediment, soil and water provide the necessary data for building up a picture of the surface chemistry of the earth. The multi-element data provide significant information, on the natural abundance and spatial variation of chemical elements, against which above normal concentrations related to mineralisation (geochemical anomaly) or industrial, agricultural and urban contamination (neo-anomaly) can be compared. Similarly, areas with below normal concentrations of elements, which are significant to plant, animal and human health, can be delineated.

## *4. GLOBAL GEOCHEMICAL BASELINES*

Detailed systematic multi-element regional geochemical atlases are available for only a small part of the terrestrial surface of our globe. This lack of

systematic geochemical data for most of the land surface of the earth will be overcome by establishing a network of reference sites and samples to provide global geochemical baselines. The land surface of the globe has, therefore, been divided into 5000 cells each of 160 x 160 km (area 25.600 km$^2$) (Fig. 1).

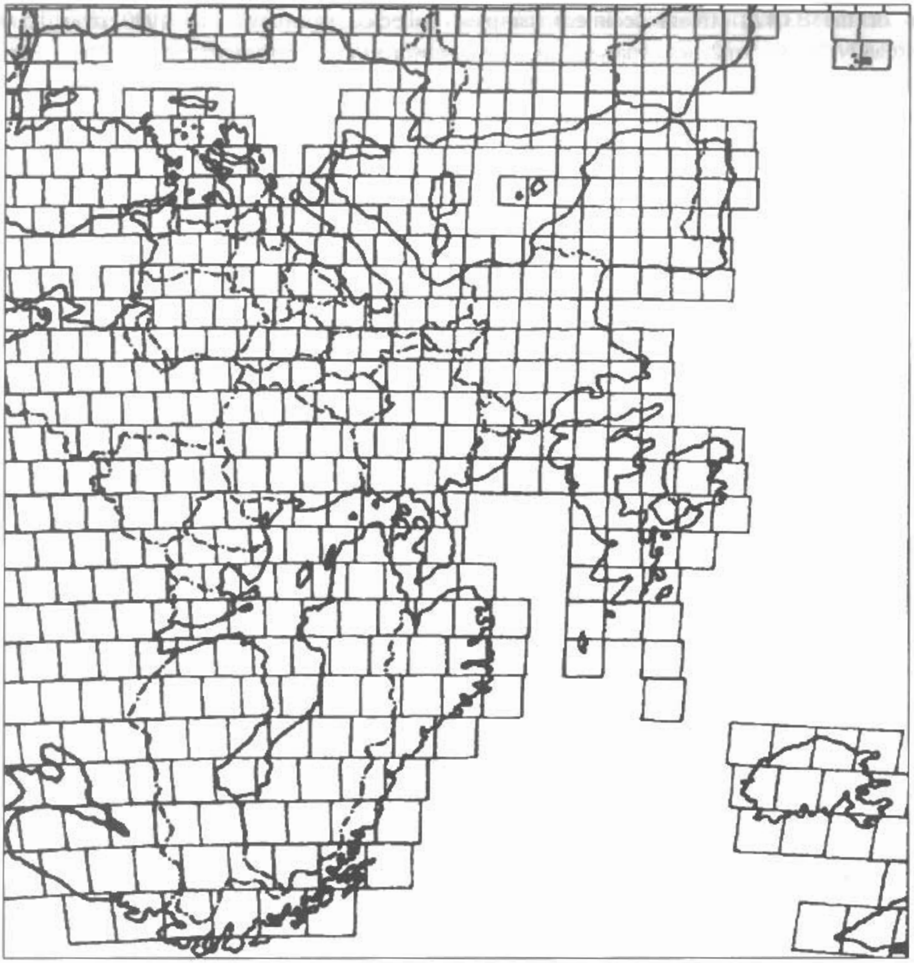

**Fig. 1:** Geochemical terrestrial network of Europe; nominal 160 x 160 km cells defined by two parallels of latitude 1.5° apart, and two meridians. In order to retain a constant area, the cells are systematically displaced in longitude E and W in successive latitudinal bands.

The Geochemical Terrestrial Network (GTN) sample sites will be randomly selected in each quarter of the 160 km grid cell. Composite samples of each material, from at least five sites in each cell, will be created for the purposes of the Global GTN. Atlas-scale geochemical maps will be produced by the collection of representative samples in smaller cells of 80x80 km, 40x40 km or 20x20 km, according to the spatial definition that can be afforded. Closer space sampling will either be carried out at the time the GTN samples are collected, or subsequently. Sample materials include active stream sediment, floodplain sediment, overbank sediment, soil, surface humus, water, till and lake sediment. All sample types will be prepared and analysed for 78 elements under strict quality control and assurance procedures (Darnley et al., 1995).

## 5. REGIONAL GEOCHEMICAL SURVEYS IN GREECE

A systematic regional stream sediment survey, as part of an integrated "phase" mineral exploration programme at a density of 1-2 samples/km$^2$, was initiated in Greece in November 1971 by the then Uranium Exploration Department of the National Nuclear Research Centre "Democritos" and covered Central and Eastern Macedonia and Thrace (Smith et al., 1976) (Fig. 2). The minus 0.177 mm grain-size fraction of the 33,478 stream sediment samples, collected from 1971 to 1980 over an area of approximately 18,000 km2, was analysed by atomic absorption spectrometry (AAS) after a hot $HNO_3$-HCl leach for Ag, Co, Cu, Hg, Mn, Mo, Ni, Pb and Zn, and by fluorometry for U. The Institute of Geology and Mineral Exploration (IGME) continued the regional stream sediment programme, covering other parts of Greece with probable ore potential (Fig. 2). The minus 0.177 mm grain-size fraction of the 60,365 stream sediment samples, collected over an area of approximately 38,000 $km^2$, was analysed by AAS following an aqua regia digestion for Ag, Cd, Co, Cr, Cu, Mo, Mn, Ni, Pb, Sb, Sr, V and Zn, and element specific methods for Hg and U. Since, the project was proceeding slowly it was decided in 1986 to cover the whole of Greece (131,944 $km^2$) with a density of one sample/10 $km^2$ for the production of a multi-element and multi-purpose geochemical atlas. Stream sediment samples were selected from the archives and unsampled areas covered with this sampling density. The 15,000 samples, collected for this purpose, have not yet been analysed due to other priorities.

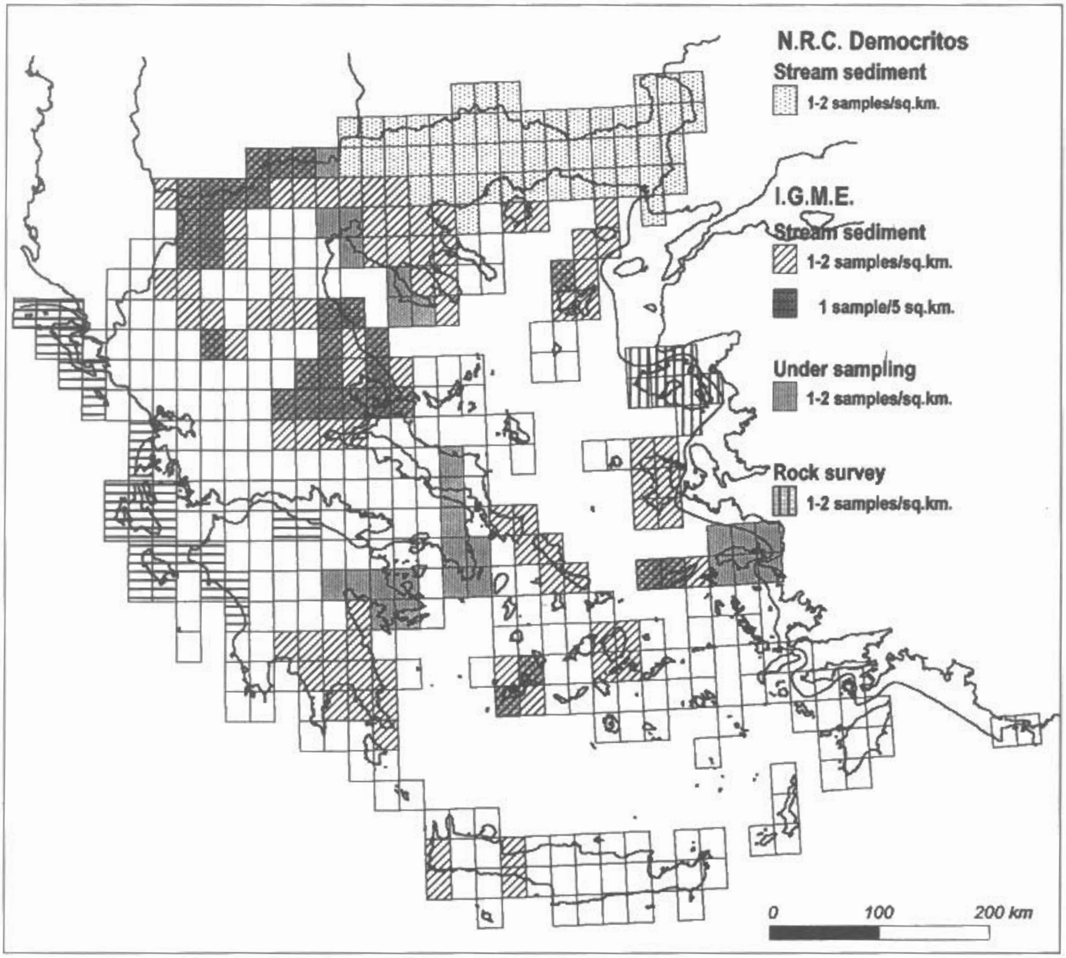

**Fig. 2:** Regional geochemical mapping coverage of Greece.

Regional geochemical data have been used till recently for the delineation of areas with mineral potential. Since, 1982 new interpretations were made for environmental contamination and element deficiency purposes (Demetriades and Constantinides, 1983; Demetriades and Hadjigeorgiou-Stavrakis, 1989, 1991).

Plans for the immediate future include the multi-element analysis of stream sediment samples, collected for the geochemical atlas project, and IGME's active participation in IGCP/IUGS/FOREGS projects for the production of significant geochemical baseline data. Long term plans encompass the complete coverage of Greece at a density of 1-2 samples/km$^2$, the multi-element analysis of all regional stream sediment samples, and the production of multi-purpose regional geochemical atlases at a scale of 1:250,000 and for some areas at 1:50,000.

All these projects require, however, generous State funding for the next ten years. Finally, the Hellenic regional geochemical databases will be linked to the Global Geochemical Database through the Geochemical Terrestrial Network.

## 6. ENVIRONMENTAL MANAGEMENT

Management of environmental issues is a difficult task, for most problems are international and not national. The 1992 Rio de Janeiro United Nations Conference on Environment and Development (Earth Summit'92) set up twenty-seven fundamental principles for the management of global and national environmental issues to achieve sustainable development (Quarrie, 1992). In order to fulfil the objectives towards sustainability, it is necessary to have reliable and comparable data on the state-of-the-environment. Sets of environmental indicators have, therefore, been put forward by international organisations to monitor environmental change. Essentially, these descriptive indicators place a minimum level of organisation of data collection needed to produce an environmental quality profile. Environmental indicators must be selected to help explain changes in the environment and their relationships with human activities. Three main groups of environmental indicators are distinguished for organisation of data collection (Stanners and Bourdeau, 1995):

1. state-of-the-environment indicators,
2. stress indicators, and
3. pressure indicators.

It is quite apparent that geochemical data are part of the state-of-the-environment indicators, and undoubtedly play a significant role in the other two groups (Demetriades, 1996). IUGS "Global Geochemical Baselines" will provide a high quality and compatible international data set about the chemical state-of-the-environment. Further, the GTN sample sites can be used for future monitoring of environmental change. This project will provide, therefore, the necessary data for sound decisions and better management of environmental issues by policy makers.

## 7. CONCLUDING REMARKS

The IUGS project "Global Geochemical Baselines" is now in its most difficult phase, for apart from producing detailed instructions on sampling and sample preparation procedures, it includes the task of finding the necessary funds. It is strongly believed that national Geological Surveys, mining companies, environmental institutions, the automobile industry, international organisations etc., should support this project for "geochemical maps represent the most urgent and important task within geology for today's human society" (Professor K. Kauranne, Finland, 1988). Darnley (1995, p.9) further states that "time is not on the side of mankind!", because of the population growth and the enormous future demands on the natural environment. The GTN and the global geochemical atlas can be completed by the year 2005 if funds are made available. International collaboration is, therefore, required to raise the necessary amount of money estimated to be in the order of US$300-400 million, about equal to the cost of launching one NASA Space Shuttle (Darnley et al., 1995). Undoubtedly, the future survival of humankind on earth is more important than other seemingly significant priorities of public policy makers.

The global geochemical mapping project will provide decision-makers with a high quality data set about the chemistry of the surface layer of the earth, which is significant to the well being of biota. Everybody concerned with sustainable development and quality of life on earth must, therefore, support this project for present and future generations.

## ACKNOWLEDGEMENTS

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