GEOLOGICAL BASIS OF ANCIENT GREEK COLONIZATION

GEOLOŠKE OSNOVE STAROGRŠKE KOLONIZACIJE

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Crouch, Dora P.: Geološke osnove starogrške kolonizacije

Prispevek je predhodno poročilo o interdisciplinarnem preučevanju pomena fizične osnove urbanizacije v antičnem svetu. Z vidika geologije so medsebojno primerjana grško-rimska mesta. Ali fizične poteze kažejo na medsebojni vpliv med geološkimi procesi in človekovimi gradbenimi izražanji? Kakšne geološke spremembe so se dogodile v tem času? Počasne geološke procese je težko datirati, toda plazove, poplave in zamuljevanja je lahko določiti in primerjati s podatki o človekovih zgradbah. Geološka informacija lahko pomaga k podrobnejši opredelitvi mestne zasnove, zgodovine in arheologije posameznega mesta.

Ključne besede: interdisciplinarnost, inženirska geologija, grško-rimski čas, hidrogeologija, hidravlika, vpliv, morfologija, strukturna geologija, mestna zasnova, urbanizacija.

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Crouch, Dora P.: Geological basis of ancient Greek colonization

This is a preliminary report on a new collaborative study about the importance of the physical base for the process of urbanization in the ancient world. Greco-Roman cities are compared in terms of their geology. How do physical features show evidence of interaction between geological processes and human construction efforts? What geological changes took place during the period? Slow geological processess are difficult to date, but avalanches, floods and silting up can be bracketed and compared with the dates of human structures. Geological information can make more specific the urban design, history, and archaeology of each site.

Key words: collaborative, engineering geology, Greco-Roman, hydrogeology, hydraulic engineering, intervention, morphology, structural geology, urban design, urbanization

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INTRODUCTION

This is a preliminary report of a new study relating the geological base to the history of urbanization in the ancient Greco-Roman world. The study is based on preliminary work done by each of the investigators, such as Water Management in Ancient Greek Cities by Dora Crouch, leader of the team. She is an urban and architectural historian. Other team captains are Prof. Dr. Paul G. Marinos, an engineering geologist at the Technical University in Athens; Prof. Dr. Ünal Özis, an hydraulic engineer at Dokuz Eylül University in Izmir; Dr. Laura Ercoli, a structural geologist at the University of Palermo; and Dr. Giovanni Bruno, an applied geologist at the Technical University in Bari. Our junior collegues are hydraulic engineers, geologists, and speleologists, and we also have the cooperation of Italian, German and French archaeologists who have been working on our selected sites.

This pioneering study will be the first to compare groups of cities in terms of their geology. Of course, there are existing studies of groups of cities, such as Rorig's of German trading cities of the Hanseatic league (Medieval Towns), Andrews' of the urban design history of Maya Cities, and Hohenberg and Lee's of the economic history of European cities (The Making of Urban Europe, 1000-1950)[1].Yet to compare cities in terms of their geological base, analyzing both form and function in terms of that base, has not been done.

In the Mediterranean region, karst is the major type of geology, and is related strongly to urban location and form, as I know from my preliminary study. Indeed, Vit Klemes (then president of the International Association of Hydrological Sciences) told me that there was no Greek city that was not built on or next to karst terrane, citing as proof the Greek cities of Asia Minor. From the twenty-five Greco-Roman sites studied in my first volume, we have selected eleven which exemplify differing geological situations for further study:

in Sicily: Agrigento, Morgantina, Selinus, Syracuse
in Greece: Argos, Corinth, Delphi, Delos
in Turkey: Miletus, Perge, Priene.

The chosen sites will be analyzed in terms of their structural geology, hydrogeology, morphology, and engineering geology. We are particularly interested in how their physical features were ammenable to hydraulic engineering and urban design. For instance, we will examine the relationships between siting and foundations, consider building materials in

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[1] Rorig Medieval Towns. G. F. Andrews Maya Cities. 1975. University of Oklahoma Press. P. M. Hohenberg and L. H. Lee, The Making of Urban Europe, 1000-1950. 1985. Harvard University Press.

terms of what was available on or next to the site and what the aesthetic characteristics of such materials were, and analyze the utilization of water for baths, public fountains, drainage channels, etc.

QUESTIONS

In studying the ecology of human settlement as set of practical constraints on human needs, desires, imagination - not as a set of theories - we will be asking the following questions:

1. What is the underlying geology and hydrogeology of the site?

As an illustration our integrative work, the person who did a recent dissertation on the morphology of Argos will restudy that site with us, integrating new hydrogeological and archaeological information into her previous understanding of the site and giving us the benefit of her morphological understanding. Maps of hydrogeological and geological features will be made if they do not already exist, and correlated with archaeological maps.

2. What geological changes took place at the site during the period studied? How much and what kind of correlation can be determined with datable changes in urban form during the same period?

Slow geological processess are difficult to date, but rapid events such as avalanches, floods and silting up, can be bracketed and compared with the dates of human structuress and pottery, to some extent. I will supply historical dates known from previous studies, and the geologists will ascertain the probable chronology of the geological events. It is likely that the Turkish sites will be most amenable to our attempts at dating, as the geological processes along the Ionian and Aegean coasts have been very rapid during the last 2500 years, and are not too difficult to correlate with human constructions in the area.

3. How does the local geology provide construction materials, water, and building sites? How was water managed at the site?

Construction materials and building sites can be determined by surface reconaisance by a historian/archaeologist plus reference to the archaeological literature, but investigation of water supply will take the collaboration of geologist, hydraulic engineer, and urban historian. It is likely that our Morgantina and Perge studies will be the most fully developed for the question of water supply, as we have hydraulic engineers working specifically on these sites. Without the input of geologists, however, many of the nuances of of the sites hydrogeology would be overlooked.

4. How does this geology affect agriculture or port facilities here?

In the period studied, the choice between farming and herding was largely determined by geology, in the sense of suitable land for the activity adjacent to the settlement. At Selinus and Agrigento, settlements were sited to dominate the rich agricultural land which was the basis of the wealth of each city. We are already speculating that the silting up of the rivers at Selinus with concommitant scourge of malaria was a geological change that caused the abandonment of the settlement in the second century BC. Soil types and conditions further determined what crops could be grown. In addition to having a food-producing hinterland, five of the cities to be studied were ports, for which we hope to determine the interaction of geological base and human construction. Syracuse is perhaps the most noted port, but we will also examine Miletus and Priene in terms of the silting up of their ports.

5. Which features of the urban form were determined by specific geological materials, factors, and events?

At Priene, for example, the Stadium Bath was located in order to utilize a karst spring, recently cleared but not reported in the literature. This spring is now dry, but when when the dewatering occurred is an interesting question for urban form. Was the later Roman bath near the theater built merely for the convenience of the population, or was its new location necessary because the lower spring had gone dry?

6. How do visual features of the city acknowledge the geological base?

The grottoes above the theater at Syracuse, serving as fountains and reservoirs, were visible evidence of the termination of natural and man-made water lines. Their location in such a public place not only provided an amenity but also drew attention to the cooperation of nature and government in supplying water to the people. More abstractly, we may ask how are sight lines organized, such as the gap between the Erechtheum and the Parthenon as seen from the Propylaea, at Athens - a gap that draws the visitor's attention to Mt. Lykabettos. Such site organization is well-known since Doxiados[2], and we will look for similar features at our sites.

7. What features of the geology were altered or affected by human intervention?

We are thinking particularly of karst channels, shafts, and springs being altered for use by humans. Quarrying, port development, and irrigation systems have also altered the landscape. Some examples: At Delos, an inn was built around a natural karst shaft that alternately filled and emptied. At Priene, drainage from the western part of the city was poured into a karst shaft. At Corinth, karst channels were utilized in the agora and the Askelepion either for water supply or drainage, or as reservoirs. We will inspect all of our sites for such features.

We will know that we have completed the field work we set out to do when we have on hand:

1. Maps of the geology and hydrogeology of each site, correlated with maps of Greco-Roman buildings, streets, ramparts, etc. For each site, a new map will be created correlating the two kinds of information, geological and archeological.
2. For each site, a list of geological events during the period studied (800 BC to 400 AD).

[2] C. A. Doxiadis, Architectural Space in Ancient Greece. Cambridge, Mass.: M.I.T. Press, 1972.

Correlation of these events with human building at the site, to the extent possible. Explanation of what kind of correlation was found (if any), how this correlation was arrived at, and the degree of certitude of these findings.

3. A brief catalog for each site of major buildings, houses, etc., and the sources of materials for each[3]. An account of the geological basis for the agriculture or grazing at each site, and for port facilities. For some of the sites, a detailed account of the karst geology that produced water year round and made settlement possible here.
4. Description of the features of the urban form that were determined by the local geology in materials, placement, events or all three. An example could be the theater at Morgantina, made from limestone blocks of the hill against which it leaned; it was buttressed against the movement of the layer of clay on which it stood; eventually the theater was partially destroyed by that movement. Discussion of the ways that the urban form referred to and exploited the geological base.
5. Lists of geological features at each site that were altered by humans, and description of how they were used. An example is the use of the caves called "latomia" at Syracuse, which are the outfalls of the karst system, as prisons (after the late fifth century war with Athens) and as ropewalks.

My team will be looking for evidence of interaction between geological processes and human construction efforts. We hope that this infusion of specific geological information will make more exact, specific, and plausible the urban history and archaeology of each site. Although we realize that more than one study will be needed to define the correlation of geological and human timescales, we expect our efforts to illuminate this question for the sites examined and germinate further research by others.

Our study brings together the broadest concepts of how human society relates to its physical environment, with the most exacting attention to underlying geological structure and processes, as well as to visible features such as hills and valleys, perennial springs, and quarries for building stone. Previously, only limited, site-specific, building-type studies of our sites have been done[4]. We are looking for the link between historical developments and geological change during the period from the eighth century BC to the fifth AD - a long time by historical standards, but a moment by geological standards. By correlating these entities which had not previously been thought to have much connection, we will achieve keener insights into how the sites functioned as loci of human development both tangible and intangible. Through this new way of seeing, our team's research could lead other scholars to apply geological insights to other groups of cities, such as those that ring the Swiss alps or the group of Caribbean ports.

Our study will demonstrate the importance of the physical base for the process of urbanization in the ancient world. At one site (Argos, for example) we will study the hydrogeology and correlate it with the long distance water lines and with water distribution within the city. At Miletus and Priene, the quite different forms of karst at the two sites

[3] R. E. Wycherly, The Stones of Athens. 1978. Princeton University Press.

[4] e. g., B. H. Hill. 1965. American School of Classical Studies.

resulted in quite different water potential, since existing karst features became elements in Priene's water and drainage system but the "older karst" with fewer on-site springs at Miletus required development of long-distance water supply lines as early as the sixth century BC. In Sicily, if we can determine for Selinus where it obtained its water supply, that will give new insight into the relation of colony to hinterland on the frontier of Greek territory in the seventh through fifth century BC.

Another result will be the placement of science and technology firmly within the subject matter of history and other humanistic disciplines. It is common, at least in the United States, to assume that "the general educated reader" is concerned with literature, history, psychology, and art but not with science and technology. Yet if our survival depended on the invention of cities, and cities depended on careful resource management, and this in turn depended on profound understanding of the geography of urban location, we see that science and technology which learn about and control the environment are squarely at the center of human history, nor peripheral. Human culture includes water management and farming practices as well as religion, language, and marriage customs.

Anticipated results of our study will be first, understanding the geological constraints on social activity (such as colonization) in the Greco-Roman period. Second, correlation between geological features and details of urban form in these cities. Third, development of parallel chronologies of human construction and destruction with events of nature as revealed in the geological record during the period studied, by utilizing the documentary and archaeological record.

CASE STUDY

By checking the comparability of the geological situations of a mother city and a colony, this study will also make a contribution to the growing literature on colonization. Here as in other aspects of the geology of ancient cities, we will make no attempt to be study every possible example. Corinth and its eighth century BC colony Syracuse are ideal subjects for comparison, partly because each is well documented and partly because team members are thoroughly familiar with each of them.

After listing team members and their qualifications, this paper will cover the geology of the two cities as is known at the beginning of our study, a list and description of water technology available in the 8-7th century, the urban history clues for geological dating at these sites, and an analysis of each city's urban design in geological terms. Most unusually for Greco-Roman cities, Greek and Roman Corinth do not form a continuity. The Greek settlement was destroyed and left deserted for a century. Then the Roman city was built anew and populated by immigrants from Italy. This fact should prove useful in our attempts to correlate geological and architectural change.

To compare the geology of the mother-city Corinth with the daughter-city Syracuse will probably require not only numerous details about the geology of both cities, but also an intellectual leap to some level of abstraction. For instance, the karst or karst-like behavior of water in stone may have abstract similarities while being different in operational details.

We must ask whether any similarities we notice are intrinsic to the local geology in each case, or are merely artefacts of our modern mental construct.

TEAM

Investigatiors for Corinth are the author and Dr. Paul G. Marinos, who has already done studies of the water potential of the Corinth area and of the sea coast changes at the ports of Corinth. The cooperation of Dr. David Romano of the University of Pennsylvania Museum, who has been working on a topographical study of the area, will be valuable to our work, as will the accumulated knowledge of the present excavator, Dr. Charles K. Williams. For Syracuse, besides the author, the team consists of Dr. Laura Ercoli; Dr. Marina de Maio (a former student of Dr. Aurelio Aureli, foremost expert on the geology of Syracuse); Francesco Fanciulli, an hydraulic engineer and speleologist who has already investigated the water lines of the island of Ortygia, the original Greek settlement at Syracuse; and Dr. Rosario Ruggieri, another caver who does speleo-hydrogeological research; plus the collaboration of Dr. Deiter Mertens of the German Archaeological Inst. at Rome who is studying the Euryalus Fortress. We are hoping that Dr. Giovanni Bruno, who has already studied the springs of the harbor at Tarranto, will be able to join us for the study of the springs at Syracuse.

GEOLOGY OF CORINTH

The geology of Corinth as now known may be sumarized in a quotation from Donald Engels, Roman Corinth[5]:

The soil occupying the area of the ancient city is neogenic, that is, derived from the decomposition and weathering of underlying sandstones, limestones, marl, and conglomerate. It is not composed of alluvium washed in from elsewhere. Except near the steep north slope of Acrocorinth, most of the area of the ancient city was level, and there would be little probability of debris washing downwards for long distances within the city. Indeed, debris was found far up the northern slope of Acrocorinth and along the city's eastern edge, which slopes gradually to the west. This fact indicates that even after thousands of years, considerable debris has not yet washed down even from steep slopes, and that the area occupied by ancient buildings as revealed by surface debris has not been significantly distorted through time.

This general description may be supplemented by Hill's description of the geology at the location of the Peirene spring (Figure 1) immediately north of the Roman forum[6]:

The ledge... is formed of geologically recent sedimentary rock - conglomerate, sandstone, and poros - resting upon a deposit of clay of great but unknown depth, which doubt-

[5] D. Engels, Roman Corinth. 1990. University of Chicago Press.

[6] The Springs (Corinth), p. 16.

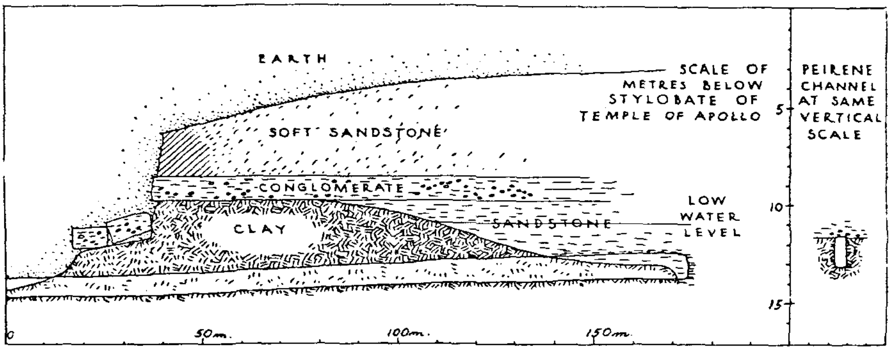

Fig. 1: Geological section at the location of the Peirene Spring, Corinth. Reprinted from Hill, The Springs, by permission of the American School of Classical Studies.
Sl. 1: Geološki prerez Peirene Spring, Corinth. Ponatisnjeno iz Hill, The Springs, z dovoljenjem American School of Classical Studies.

less underlies the whole terrace. The conglomerate and a fine hard sandstone are found immediately above the clay. Over them is a very soft reddish sandstone, perhaps more accurately described as extremely hard earth (known specifically as "stereo" in local excavation parlance. It is here called sandstone very loosely, as it contains little true sand, its principal constituent being decomposed limestone), which reaches up to within 3 to 6 m. of the modern surface and constitutes the chief material of the entire terrace. Along much of the north side of the terrace this sandstone becomes more compact and changes into actual rock - the soft limestone of calcerous tufa known as poros which constitutes most of Temple Hill, the rock-cut foundation of Glauke, and part of the seats and substructure of the Odion... The clay underneath this mass of porous material is very hard and uniform and quite impervious to water. It thus forms the floor of a great reservoir which holds the water that percolates from the surface through the upper strata of the terrace.

It is impossible to be satisfied with these descriptions since modern geologist have different ways of classifying and understanding the evidence. For example, Dr. Marinos interprets the so-called clay of the side walls of the Peirene reservoirs as marl. Certainly the marl would function like impermeable clay in trapping the percolating waters and making them available for human use, but because of its greater hardness, it would present difficulties in the creation of reservoir chambers. It is known from excavation that during late Greek and early Roman times the previous valley between the three springs and the race course was deliberately filled in to produce the large level area on which the Roman forum was built; this enormous fill was made of clay? sandy earth? decomposed limestone? skree from Acrocorinth? all possibly cemented now by 2000 years of inundation and seepage by calcium-carbonate laden water.

The geology of Syracuse as now known has layers (top to bottom) of clay and conglomerate, limestone, basalt, tufa, blue marble, and alluvial silt. Just from this list, we can see that clay, conglomerate, and limestone are found at both cities. The details of similarities and differences between the two are to be found in the kinds and clusters of the stone, clay, etc. and in the patterns of hydrogeological potential. We can get a sense of those details in the description of Syracuse by Burns[7]:

The plateau, its slopes, and its southernmost spur - the island of Ortygia - are parts of a calcerous massif that rests on a base of basalt and compacted sedimentary marine clays that form a continuous permeable stratum. This base has essentially the shape of a shallow bowl, slightly tilted, with the northwestern rim higher that the southeastern one. The bowl receives a great amount of water at its western end, where the Crimiti mountain range makes the prevailing winds shed their moisture. Because of the southward tilt of the bowl, the water trapped in certain sandy layers and pockets under the limestone is under considerable pressure, causing it to well up in copious springs wherever the edges of the impermeable strata reach the surface at lower elevations. Such springs are Arethusa near the southern tip of Ortygia, Ciane in the Anapo plain, and the so-called Occhio della Zillica, where sweet water wells up from the sea bottom in the Great Harbor. Mauceri experimentally confirmed these facts by drilling through the various strata into the aquiferous sands and bringing in artesian wells in selected places.

In the eighth century when Syracuse was founded from Corinth, the traditional knowledge of water management already included:

- collection and use of water from springs and rivers (since the prehistoric period)
- cisterns (since the third to second millennium)
- dams (since the third millenium)
- wells (since the third millemnium)
- reuse of excrement as fertilizer (since an unknown early date);
- gravity flow pipes, channels, and drains (no later than second millenium)
- long-distance water supply lines with tunnels and bridges (at least by the 8th century BC)
- intervention in and harnessing of karst water systems (at least by the 8th century)[8].

Not all of these techniques would necessarily have been in use at any one site. Pressure pipes had been used at Minoan sites during the second millenium, but their use seems to have been forgotten and not reinvented until the sixth century. Underground long-distance water supply lines were developed first in Armenia in the eighth century, thence to Persia, and thence westward no later than the sixth century. However, since the natural behaviour of karst channels seems to have served as the model for these aqueducts[9], it is certainly possible that the "invention" was made simultaneously in several areas, like the practice of intervention in karst channels for human purposes. Further, since the dating of water system elements is rather loose, especially for the eighth and seventh centuries BC, it is difficult to

[7] A. Burns, "Ancient Greek Water Supply and City Planning: A Study of Syracuse and Acragas". 1974. Technology and Culture, Vol. 15 #3, drawing on F. S. Cavallari and A. Holm, Topografia archaeologica di Siracusa. Palermo, 1883-91, pp. 95-142, and L. Mauceri, La fonte Aretusa nella storia e nell'idrologia. Siracusa, 1924, pp. 15-30.

[8] This chronology is explained in D. P. Crouch. 1993. Oxford University Press, pp. 338, and "Avoiding water Shortages - Some Ancient Greek Solutions", Diachronic Climatic Impact on Water Resources, forthcoming proceedings of NATO-sponsored conference in Heraklion, Crete, Oct. 1993.

[9] Crouch, Water Management, Chapter 10, "Natural Models for Water Elements", pp. 115-120.

ascertain whether any specific water element known at Corinth belongs certainly to this early period. If it does, then it could be a model for similar elements at Syracuse.

At Syracuse, the points of investigation of the present study include the latomie and the catacombs, both studied in terms of karst, earthquakes, and human intervention. Shoreline changes since antiquity, and the question of fresh-water springs in the sea. Springs supplying water to the site. Tunnels of the water system as old karst channels and as later catacombs (human intervention). Correlation of geological features with urban form, namely in the locations of public open space, locations of water supply elements and buildings, and the changing city limits during the period studied.

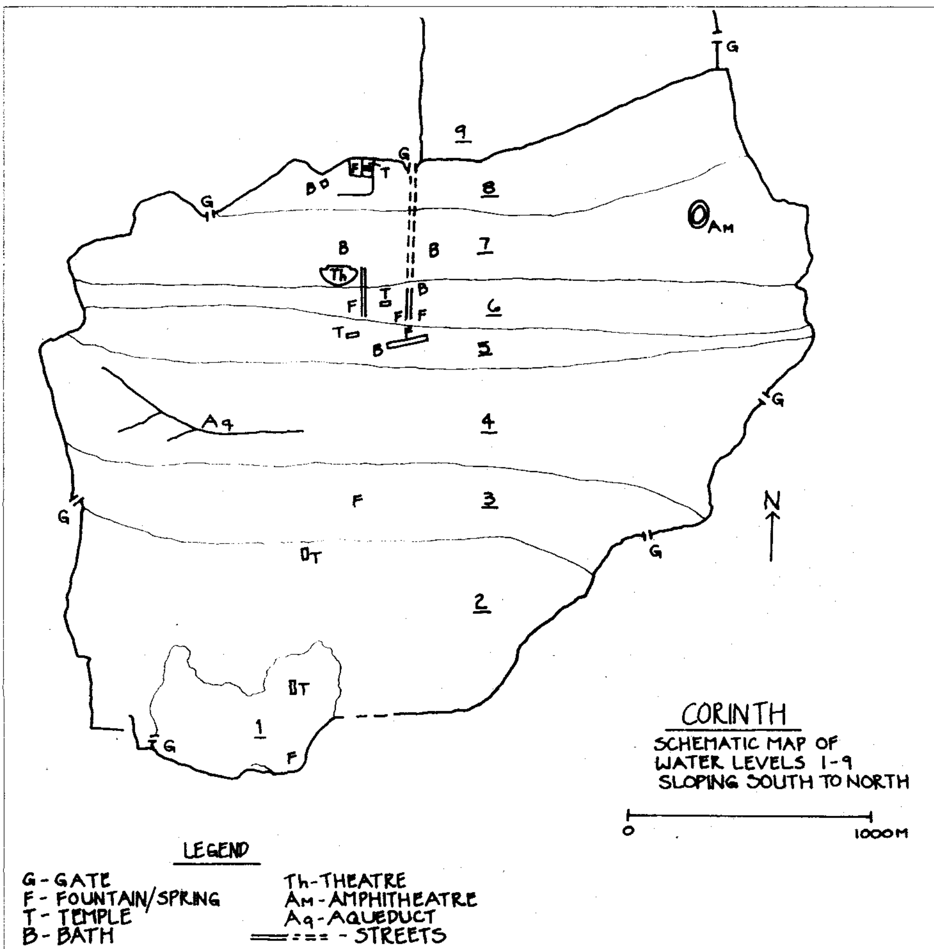

Fig. 2: Terraces of Corinth.
Sl. 2: Korintske terase.

Other aspects of the transfer of Corinthian water technology to Syracuse are less tangible and therefore more difficult to discover in the physical record. That is the mind-set that enabled the Greek engineers to integrate new data into their tradition and to continue to develope their water technology during the following centuries. I consider this aspect of their tradition just as important as knowledge of how to preserve the purity of spring water. Since water management is not discussed at length in the ancient authors[10], we are left to examine the physical evidence and then infer the thought processes that led to the evidence we are evaluating.

In Figure 2, the geological relief of Corinth, the terraces are numbered 1 to 9 as they descend from south at the bottom of the map. The ramparts of the city form the outline of its shape, with the long walls extending to the coast suggested by the north-south lines at the top of the map. The relief in terraces 1 and 2 is extreme, as they are the peak of Acrocorinth and its south slopes; the northern slopess, not shown, are even steeper. Note the spring at F just below the top of the peak. The placement of the temple (of Demeter and Kore) at the lower edge of terrace 2 is likely to have taken advantage of a source of water at this point. Another fountain in 3 is the still-flowing one with the Turkish name of Hadji Mustapha. In the fourth terrace, an extensive aqueduct has been discovered that served the Potters' Quarter west of the city center. Dating to no later than the 6th century, it was adapted to the changing needs of the people, part of it being walled off as a reservoir at a later period. In terraces 5 and 6, both fountains of the archaic period and a bath of the fifth century are known, testifying to the grouping of water sources that made this an ideal location for the earliest agora, continuing to serve the residents of all periods including today. Two more baths in terrace 7 were possible because of abundant water here, and the extensive complex of Asklepion, Lerna Fountain, bath, and gynnasium at the south edge of terrace 8 would not have been possible without still another outpouring of water. Just to the southeast of the numeral 9, a copious flow ("Baths of Aphrodite") supplied a palace of the Turkish era. This map does not extend all the way to the coast, but if it did we would see still further resurgences at the port of Lechaion (a 3rd century AD villa, etc.).

Figure 3 is a closer look at terraces 5 and 6 in the central area. At lower left at CB is the fifth century bath, which is seen to overlie some (probably karstic) channels running from the south. Immediately to its east is a former channel which later was used as a reservoir having a capacity of 100-245.000 liters. The south stoa along the southern edge of the agora/forum was built to take advantage of another channel running underground in this area; all but two of its shops had wells supplied by water from this channel.

A very early fountain (F) was placed at the north edge of the race course, and was abandoned when the agora became the forum of the Roman period. But one of the three fountains that ringed the original lower agora (the Sacred Spring, Periene Fountain, and the Cyclopean Fountain) persisted in use from the Geometric era until today. The Peirene fountain was remodeled and refurbished every few centuries and is still flowing. The Sacred Spring, in contrast, went out of use in the fourth century, suggesting that it may have been

[10] See Water Management, Chapter 6, "Greek Urbanization - Theoretical Issues" and R. Tölle-Kastenbein, Antike Wasserkulter. 1990. Munich: Verlag D. H. Beck, passim.

dewatered when the South Stoa was built. And the Cyclopean Fountain was abandoned to be used as a building site, then re-opened as a spring in Byzantine times. At the far left of the plan, the Glauke Fountain is shown at the edge of a scarp. The original topography of the upper part of this detail was a long east-west ridge on which the Temple of Apollo was built at the east end. Material for the temple (and probably other buildings) was quarried from the hill, so that eventually a valley was formed thorough which the "early road" ran. Only a single large block of the original surface was left, which became the fountain of Glauke. The grooves from which building stone was extracted became the reservoirs for this fountain. In spite of the indication here of a scarped edge, the fountain seems never to have been supplied by a resurgence at this place, but rather always to have had a pipeline from near the Hadji Mustapha fountain, with the pipes replaced from time to time as needed.

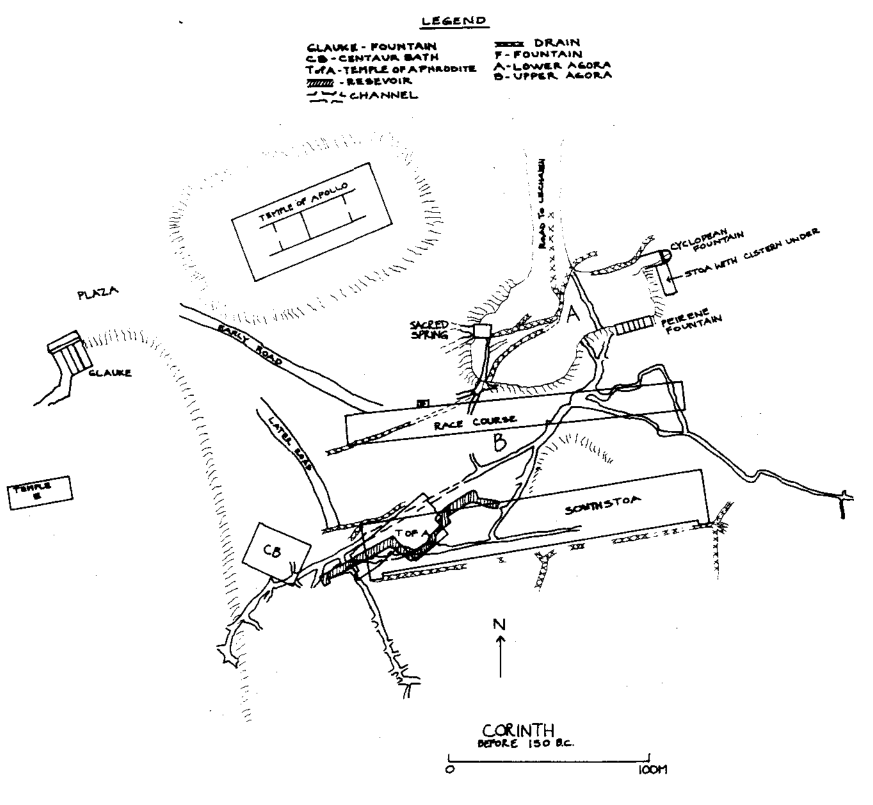

Fig. 3: Terraces 5 and 6 at Corinth, in the central area.
Sl. 3: Korintski terasi 5 in 6, v srenjem delu.

Placement of the original race course in Greek times was at a more acute angle that shown here, with its west end pointing toward the Centuar Bath. Already in the Hellenistic era, a second version of the race course was placed as we seen here, which had necessitated importing some of the fill to level the area, as mentioned above. It would be interesting to look under the Roman steps from the lower to the upper agora/forum (just about at A on the plan) to see whether earlier Greek steps bridged from level to another. I anticipate that such steps were necessary if the fourth century in-filling extended as far north as the north edge of the Sacred Spring, which went out of use at this time.

GEOLOGY OF SYRACUSE

Now let's see what we can determine from similar plans of Corinth's colony, Syracuse. Figure 4 is a map and profiles of the hydrogeology of Syracuse. The profiles are at upper right. From profile B-B, we get an idea of the dish-shaped result of the uplifting of the plateau and submergence of the isthmus between Ortygia and the mainland. On the map, the major water lines (dots along black lines) are laid out on a representation of the geology. As at Corinth, the upper layer of clay and conglomerate rests on limestone. The small crosses indicate catacombs and latomia, both to be construed as ancient karst channels pressed into later human uses. Note that the coastline shown is that of the ancient period, not modern, with major changes in the size and relationship of the Great and Small Harbors.

A closer look at the main settlement area of Syracuse is show in Figure 5. From bottom to top of the map we see first the island-peninsula of Ortygia with the Arethusa Spring at A and another fountain at F. Three large temples bracket what was probably the original agora area. From there, a major street led north to the second agora on the mainland, placed midway between the two harbors; some of this open space is preserved in the modern park called Foro Siracusana. The third agora at the left would have been convenient for trade in agricultural products from the plain to the west. An earlier and then a later wall were built to enclose the built-up area, the outer wall serving also to protect essential sources of water for the expanding city. Streets and large buildings on the map are known from excavation. Towards the top of the map, a scarped edge is the locus of a series of karst caverns. Three aqueducts entered from upper left, and supplied the grottoes above the theater (Figure 6) and a reservoir in the next cavern, called Paradiso. This last aqueduct also supplied a bath located just to the north of the Paradiso cavern. Aqueduct 1, the Galermi aqueduct, brought water from the Crimiti Mountains to the west, for at least 25 kilometers. This aqueduct, built in the fifth century BC, utilized siphons and pressure pipes to bring the water over hills and through valleys to the expanding city. (Such technology was not yet known in the eighth century when Syracuse was founded, but is known to have been used already in the sixth century at Olynthus, a modest agricultural town in northeast Greece.) the cavern farthest right on the map is that in the Santa Lucia area, a node of settlement from the second quarter of the fifth century BC until now.

Not visible on these plans was the equally important drainage system of Syracuse. We have seen some of the drains of Corinth in Figure 2. Drainage and waste disposal were important concerns as soon as ten or more families and their lifestock were living in close proximity. With the use of cisterns went the necessity for drainage pipes or channels under the streets or alleys. Sometimes these drain lines were made of pipes small enough to be handled by individuals, as in Figure 7, but often they were constructed of large blocks of stone. For these, community cooperation - and funding - was essential. So commonplace

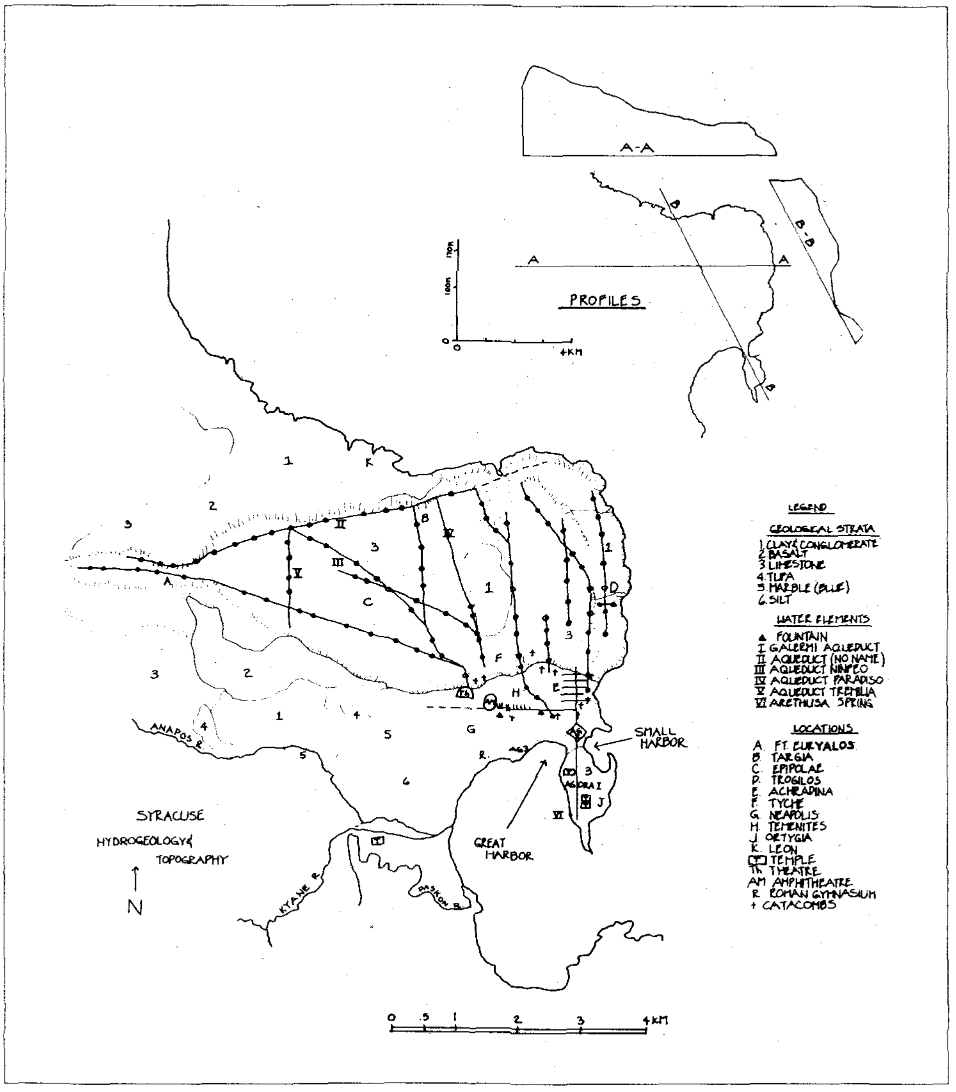

Fig. 4: Map and profiles of the hydrogeology of Syracuse.
Sl. 4: Hidrogeološka karta Sirakuz, s prerezi.

were such stone drains that we find them not only in capitals like Athens - where the Great Drain of the agora was built no later than the sixth century - but also in the mid-fifth century plan of Morgantina (later a colony of Syracuse) when that settlement was a very small town, a mere outpost of Greek culture (Figure 8).

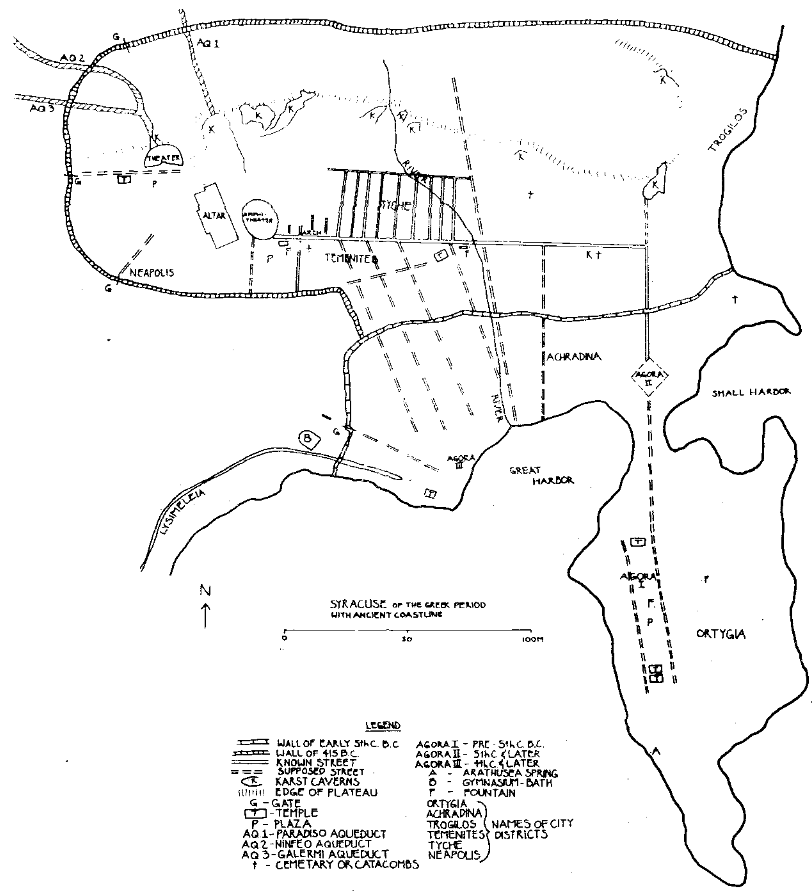

Fig. 5: Main settlement area of Syracuse. Note the three aqueducts entering from upper left, and the row of karst caverns along the scarp.
Sl. 5: Glavni poselitveni del Sirakuz. Vidni so trije akvedukti, vodeči z zgornje leve strani, in vrsta kraških jam vzdolž strmine.

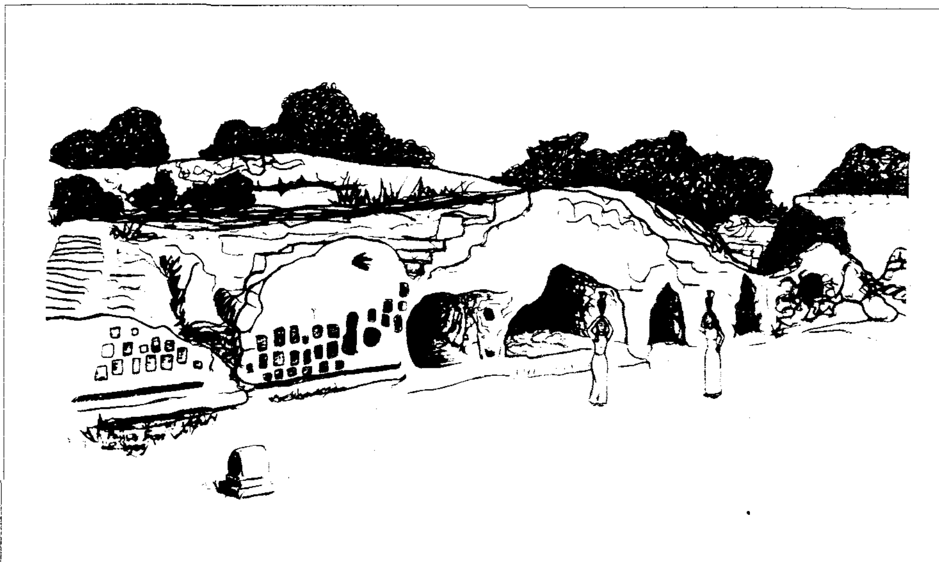

Fig. 6: Grottoes above the theater at Syracuse.
Sl. 6: Jame nad sirakuškim gledališčem.

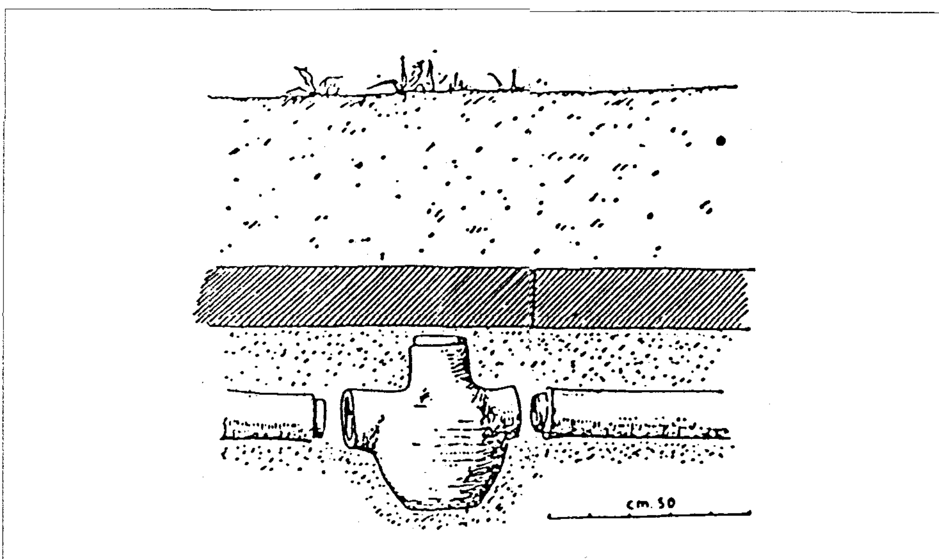

Fig. 7: Drain pipes and settling basin at Syracuse, as reported by B. Pace, Arte e civilita della Sicilia antica (4 vol.) Milan: Ed. Dante Alighiere, 1935-38.
Sl. 7: Dovodne cevi in usedalni bazen v Sirakuzah, po B. Pace, Arte e civilita della Sicilia antica (4 vol.) Milan: Ed. Dante Alighiere, 1935-38.

Thus, without even completing our current study, we can already indicate some of the correspondence between geological base and urban form. As yet, however, we cannot show much of the one-to-one correspondence between geological events and the events of architectural and urban history. We have scattered clues to the water management of each site,

Fig. 8: Stone drains of Morgantina, next to the House of the Official.
Sl. 8: Kamnite cevi v Morgantini, poleg Uradnikove hiše.
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but not the detailed accounts we are working toward. We find it easier to discuss the provision of building materials and the utilization of the topography by ancient urban designers than to analyze the geological base for agriculture or port facilities. Our investigation of the way geological features were altered by humans is just beginning.

CONCLUSION

From this exposition, preliminary as it is, you can begin to see the implications for geology of its integration with many kinds of studies. With new consciousness of the earth as our mother, we turn to the twin sciences of geology and geography for the best information on the nature and behavior of our planet. The earlier studies of Kraft, Rapp, Bintliff, Davidson and Shackley[11], and others related geology to archaeology. More bridges are needed between geology and history, geology and the social sciences, geology and the history of architecture, geology and ecology, and so on. From my own training, I see that geology and the history of art are markedly similar disciplines that rely on chronology and visual nuance - though the chronologies are of vastly different scales. In this new study, I hope to callibrate the scales and promote cross fertilization between these adjacent disciplines.

GEOLOŠKE OSNOVE STAROGRŠKE KOLONIZACIJE

Povzetek

Prva naloga pričujoče študije je primerjava skupin mest z vidika geologije. Izmed 25 mest, prvotno zajetih v preučevanje, jih ta prispevek obravnava 11: na Siciliji Agrigent, Morgantino, Selinus in Sirakuze, v Grčiji Argos, Korint, Delfe in Delos ter v Turčiji Milet, Pergamon in Priene. Za vsak kraj posebej morajo raziskovalci odgovoriti na naslednja vprašanja:

1. Kakšne so geološke in hidrogeološke osnove mesta?

2. Kakšne geološke spremembe so nastale na posameznem mestu v preučevanem času? Kolikšne in kakšne so mogoče korelacije z datiranimi spremembami mestnih oblik v istem času?

3. Kako so od lokalnih geoloških razmer odvisni gradbeni material, voda in gradbene parcele? Kakšna je bila oskrba z vodo?

4. Kako geološke razmere vplivajo na tamkajšnje kmetijstvo ali pristaniške možnosti?

[11] J. C. Kraft and G. R. Rapp, Jr., "late Holocene Paleogeography of the Coastal Plain of the Gulf of Messenia, Greece..." Geological society of America Bulletin 86 (1975): 1191-1298; J. L. Bintliff, Natural Environment and Human Settlement in Prehistoric Greece, Oxford: BAR Supplement Series 28 (i & ii) 1977; D. A. Davidson and M. L. Shackley, (eds.) Geoarchaeology. Boulder, Colo.: Westview Press, 1976.

5. Kateri urbani elementi so neposredno odvisni od geološke osnove, faktorjev in dogodkov?
6. Kako vizualne oblike mest odražajo geološko osnovo?
7. Katere geološke oblike je spremenil oziroma je nanje vplival človek?

Za vzorčno študijo je zelo ugodna primerjava Korinta z njegovo kolonijo Sirakuze (8. stol. pr. n. št.). Posebno zanimiva je primerjava oskrbe z vodo, saj je bila do takrat razvita že vrsta ustreznih tehnik. Čeprav preučevanje še ni končano, že lahko pokaže na določeno ujemanje geološke osnove in mestnih zasnov. Iz tega je že mogoče videti pomen geologije in njenega vključevanja v najrazličnejša preučevanja. Prva preučevanja Krafta, Rappa, Bintliffa, Davidsona in Shackleya so povezala geologijo z arheologijo. Več povezav pa je potrebnih med geologijo in zgodovino, med geologijo in družbenimi vedami, med geologijo in zgodovino arhitekture, med geologijo in ekologijo, itd. Iz mojih osebnih izkušenj vidim, da sta geologija in zgodovina umetnosti močno podobni vedi, ki se opirata na kronologijo in na vizuelno niansiranje - čeprav sta kronologiji v zelo različnih merilih.