of part of the Schlern Dolomite, comprising a gradual transition from a typical Stuoress-Cassian fauna to the 'Travenanzes' Raibl fauna of the Falzarego district.

(2) The Wengen and Stuoress-Cassian fossiliferous tufaceous series are present throughout the district of Enneberg and Ampezzo in complete zonal development. These palæontological zones are therefore *not*, as has been said, the tufaceous facies of the dolomitic rock composing the massives in these areas. On the other hand, the Upper Cassian zone and the higher Raibl zones are developed in varying degree *within* Enneberg and Ampezzo as local facies of local dolomitic sediments. 'Cipit Limestones' (the true coral-reefs of the district) occur both in the tufaceous and in the dolomitic facies at all horizons as occasional local beds of comparatively small thickness (loc. cit., GEOL. MAG., 1894).

(3) The Wengen and Stuoress-Cassian tufaceous and calcareous series of Enneberg and Ampezzo represent time-equivalents of part of the calcareo-dolomitic series south of the Buchenstein-Mahlknecht passage-area of facies, that area having been one of the chief localities of contemporaneous eruptive fracture-planes.

(4) In many cases the passage-areas between facies of different lithological character, as well as the passage-bands between sub-jacent rock-groups of different lithological character, have been the seat of subsequent differential movement or distortion. So that the complex local developments of passage-areas and passage-bands in the Upper Trias of South Tyrol have induced many local effects of cross-movement which now complicate the stratigraphy of that district.

(5) The more general movements associated with Cretaceous-Tertiary upheaval in the Eastern Alps have called forth an east-west strike, which must be regarded as fundamental in the district, and also a cross-compression from east and west or slightly oblique directions. The complex resultant system of folds, faults, and overthrusts has been cut by subsequent faults associated with local subsidences.

II.—THE GEOLOGY OF BAD NAUHEIM AND ITS THERMAL SALT-SPRINGS.

By A. VAUGHAN JENNINGS, F.L.S., F.G.S.

- I. Introduction.
- II. General Physiography.
- III. The Rock-Formations present.
- IV. The Springs, Borings, and 'Salines.'
- V. The Geological Problems involved.

I. INTRODUCTION.

THE eastern extremity of the wooded range of the Taunus, where its last spurs slope down to the Wetterau Plain and the streams from its valleys give up hurrying and wander lazily across the fertile flats towards the Main, has been a spot rich in interest since at least pre-Germanic times. The ancient Kelts, when

overwhelmed by their Germanic foes, left behind them, now deep in the detritus at the foot of the Johannisberg, their hearths, chisels, and millstones, mixed up with shells and bones. In addition to these typical relics of the race, there have also been found special forms of earthen vessels, used evidently for evaporating the waters of the saline springs. The tribes described by Tacitus as being in possession at the end of the first century do not seem to have been similarly enterprising, but it is known the victorious Romans of the third century resorted thither for medicinal baths.

FIG. 1.—BAD NAUHEIM. View looking west. In the foreground the Grosser Sprudel and Friedrich-Wilhelm's Quelle [Borings 7 and 12]. The Johannisberg in the distance.

The place was, in fact, a Roman sanatorium sixteen centuries before the modern Teuton evolved the 'Kur' to music, or the somewhat over-subtle phonendoscope whispered in the doctor's ear of fell diseases that are at work below, and perhaps, occasionally, of some that are not. In mediæval times and throughout the later centuries its ancient reputation was sustained and increased. The nineteenth has seen the opening of a system of baths in 1835, which has so advanced in public estimation that the number of visitors has risen in 60 years from 189 to 17,760, and of baths from some 112,000 in 1890 to over 227,000 in 1897.

It is not, however, the object of this paper to give statistics or to advertise a health resort. The above figures are quoted only to indicate the growth of the place as a justification for giving some account of its geological features in English. Several thousands of the visitors annually are British, and I have found that there really is a small percentage, even of these, who would be glad to know something of the structure of the country which produces the waters they seek to benefit by.

It is a matter of great difficulty to obtain information on the spot, as the geological map and its description are old and out of print; while the excellent guide, written in 1888 by Herr Bergrath Otto Weiss¹ and Dr. Groedel, contains in its geological chapter some views as to the order of succession of strata which later research has corrected, and is insufficiently illustrated to give a clear idea of structural features. This is my excuse for attempting to give some sort of account of the district, though an imperfect one. For many of the details I am of course indebted to the older works mentioned at the end, but on the other hand a considerable part of the following notes are from personal observation, though made only on short excursions under conditions of a necessarily limited activity.

FIG. 2.—Geological Sketch-map of country around Bad Nauheim.

B. Blätersandstein.	O. Orthoceras-schiefer.
D. Devonian series.	Sp. Spiriferen-sandstein.
T. Taunus-quarzit.	

II. GENERAL PHYSIOGRAPHY.

The old village of Bad Nauheim, and the new town which has grown up beside it round the springs, lie at the foot of the Johannsburg. The hill, rising 858 feet above the sea and about 390 feet above the plain, is wooded at the top and on the northern slopes;

¹ Herr Weiss has been identified with the history of the locality from the earliest days of organized baths, and knows more than anyone else as to the various borings. He was most courteously willing to give all information, but unfortunately his illness prevented my profiting by his store of knowledge, except in a few minutes interview when I was on the point of leaving.

vine-clad on its steeper southern aspect, but scarred here and there by reddish rock patches where the iron-stained quartzites of which it consists have been quarried for building material or for road-metal. From the summit there is a drop on the south and west to the saddle at Hasselheck, and then a steady rise to the Winterstein and the general mass of the Taunus. Towards other points of the compass one looks over a wide valley-country with rich fields and scattered villages and trees, so that our hill of observation constitutes as it were a promontory running out from the high ground into the plain.

On the south the plain stretches away twenty miles to Frankfurt, merging into the broad valley of the Main. The plain is not, however, a monotonous level, as in the foreground rises the low hill on which stands the old town of Friedberg, with its picturesque turreted tower rising above the ancient fortress. Northward the low country extends past Weisel and Butzbach to the blue distance round the Vogelsberg. To the east the landscape is similarly varied by the low rises behind the railway and the more distant Münzenberg with its double-towered castle.

Taking thus a comprehensive view of the whole district, the geologist will note that there are three distinct scenic elements to be considered. First, the Taunus range which stretches south and west from his point of observation; secondly, the relatively low land on the south, east, and north-east; and lastly, the detached and separated elevations which rise from the plain. To understand the meaning of these three features it becomes necessary to examine the rocks of which they are composed.

A superficial examination of specimens in the immediate neighbourhood shows that the rock is a white or reddish 'quartzite,' using the term in its widest sense; more accurately, a series of compact sandstones and grits which have suffered greater or less alteration.

There is in many places a well-defined flaggy structure, indicating the sedimentary character of the formation. It has a distinctly Palæozoic aspect, and in many places recalls some of the British Devonian strata to the mind. Such is, in fact, the age ascribed to it, as it belongs to the 'Taunus-quarzit,' which, though here devoid of fossils, is now known, by observations elsewhere, to belong to the Lower Devonian series.¹

The dip of the beds is here a very steep one to the south and east, but many variations will be found in the districts lying to the west. In fact, the whole range is much contorted and the strata doubled up in sharp folds, as has been shown by Koch, Kayser, and others.

Leaving for future consideration the question of the presence of other strata than the 'quartzite' in this Palæozoic ridge, and descending to the lower ground, one meets with a marked change in the character of the rocks, though the wooded condition of the ground and the accumulation of detritus and Post-Tertiary deposits have to a great extent obliterated the abruptness of the transition.

¹ The suggestion of Gosselet (*Ann. Soc. Geol. Nord*, xvii, p. 300) that the base of the series is Archæan does not seem to be accepted by English or Continental geologists.

In the quarries south of Bad Nauheim or round the village of Ockstadt there is a series of sands, sandstones, pebble-beds, and loosely cemented conglomerates, which are horizontally stratified and evidently of far later date than the rocks of the hill. They are, in fact, Tertiary beds representing the infilling of a great lake which once occupied the whole of the western district.

If one crosses the broad zone of fertile fields covering these later strata, the hill at Friedberg shows another abrupt change. Here, though the outer slopes of the hill are green and gradual, there are rough black crags under the castle of distinctly basaltic appearance. Round Schwalheim and Wisselsheim there are less prominent exposures, but it is easy to ascertain that these eastern elevations are of the same lithological nature.

III. THE ROCK-FORMATIONS PRESENT.

It is therefore evident that the three scenic features above referred to have a definite geological meaning, and that the component parts of the whole area may be classed under three corresponding headings—

- A. The Palæozoic Ridge.
- B. The Tertiary Strata.
- C. The Igneous (basaltic) Series.¹

Before proceeding to a study of the position of the salt springs and borings it will be well to notice in somewhat greater detail the characteristics of these different formations.

A. *The Palæozoic Ridge.*

As has been already observed, the Palæozoic rocks are of Devonian age; a series of flaggy, more or less ferruginous, altered sandstones, grits, and 'quartzite.' They are evidently of sedimentary origin and belong to the 'Taunus-quarzit' group; overlying the 'Sericit-schiefer,' but stratigraphically below the other members of the Devonian system. Fossils are apparently absent, though some obscure plant remains are said to have been found near the Winterstein. The strike is N.E.-S.W., and the dip varies from 28° S.E. to 72° or more in the same direction. It is not probable that the student will meet with any other form of Palæozoic rock in the neighbourhood, but if he has an opportunity of consulting the geological map he will find certain other formations recorded. Thus the 'Stringocephalen-kalk' is mapped as occurring near Hasselheck. I have been unable to find it there, and in suggesting a doubt as to its presence I am glad to find I have the support of Professor Wittich. The 'Orthoceras-schiefer' are similarly marked as cropping out by the Teich and north of Nieder Mörlen, but I have not been able to identify them in either locality. The

¹ Throughout this paper the Post-Miocene deposits are left out of consideration. There is doubtless much interesting matter awaiting study in this direction, and Herr Professor E. Wittich (see list of references at end) has studied what he regards as Pliocene and Glacial beds in the neighbourhood.

'Spiriferen-sandstein' is recorded from the borings, but has not been mapped as appearing at the surface in the immediate neighbourhood.¹ In the concluding section of this paper the relationship of these formations will be again referred to, and a possible explanation of their position in the borings suggested. Even if, however, there have been errors of observation in the field, it is probable that the evidence of the borings may be trusted in showing the existence of these formations below the surface. Comparison with other districts would lead one to expect them here, as the usual succession for North Germany is as follows:—

(A) Upper Devonian	{ Cypridinen-schiefer
Goniatiten-kalk }	Absent.
¹ (B) Middle Devonian	{ Stringocephalen-kalk.
Calc-schiefer = 'Orthoceras-schiefer.'	
² (C) Lower Devonian	{ Koblenzer Grauwacken
Hunrückschiefer
Taunus-quarzit.
Taunus-phyllite = 'Sericit-schiefer.'	= 'Spiriferen-sandstein.'

B. The Tertiary Strata.

The softer, almost horizontally stratified, beds which form the fertile fields of the Wetterau belong, as already stated, to Oligocene times. In the south-west the whole series of strata is well seen, but at Bad Nauheim itself it is only the upper part that is represented at the surface. In the quarries south of the town and round Ockstadt this portion, however, is typically developed and easily observed. In places there are loosely compacted sands, beautifully colour-banded, and reminding one of those at Alum Bay. Other beds consist of coarse quartz-sand with some ferruginous cement, but infiltrated with calcite, the shining cleavage faces of which often extend over considerable areas. Selenite and chalybite are also commonly present. In the coarser beds the pebbles of older rocks are frequently coated with concentric pellicles of yellow, brown, or brilliantly red iron oxides, and a remarkable ferruginous conglomerate results.

In spite of their varied character these strata appear to belong all to the 'Blättersandstein.' Though unfossiliferous here, they contain at Münzenberg such mollusca as *Litorinella*, *Cyrena*, *Unio*, *Cyclas*, and *Helix*, as well as leaves of plants such as *Cassia*, *Rosa*, *Acer*, *Ficus*, *Cinnamomum*, *Sapindus*, *Amygdalus*, and *Cratægus*.

Below the Blättersandstein comes the 'Litorinellen-kalk,' a yellowish limestone with fossils; again partly of fresh and partly of brackish water habit. *Succinea*, *Pupa*, *Helix*, and *Neritina* occur

¹ The nearest is a little west of Ober Mörlen, where it is said to occur with a dip of 40°-50° S.E. in the same strike line as the Oppershofen-Krausberg outcrop, where characteristic fossils occur. A patch of schiefer, believed to be equivalent to those of Pfaffenwiesbach containing *Orthoceras*, is mapped as occurring immediately south of the sandstone.

² All these strata are unfossiliferous at Bad Nauheim, but in the Koblenz district contain characteristic types, such as *Rensseleria*, *Megantieris*, *Pentamerus*, and *Ctenocrinus*. In other parts there occur *Stromatopora*, *Calamopora*, *Fenestella*, and *Chonetes sarcinulata*.

together with *Cyrena* and *Mytilus*. A specially interesting feature is the occurrence at Bönstadt of porous limestones, evidently formed by incrustation of Algæ such as *Vaucheria* and *Chara*, with shells bearing a fibrous overgrowth, apparently due to incrustation of *Chatophora*.

Under this lies the 'Cerithienkalk,' with *Nerita*, *Mytilus*, and *Litorina* in association with familiar friends of the Hampshire Basin, such as *Cerithium plicatum*, Lam., and *Cytherea incrassata*, Sow.; passing gradually below into the 'Cerithiensand and Sandstein.' In this case also there are beds with typical land or fresh-water shells—*Helix*, *Bulimus*, *Pupa*, and *Planorbis*—but these occur in narrow and unimportant bands, while the associated strata contain not only the brackish-water genera but also such marine forms as *Perna*, *Fusus*, and *Bulla*.

At the base of the series lies the 'Cyrenenmergel,' a blue or yellow, clayey or sandy deposit, in which the proportion of marine shells is still greater, and includes, in addition to those above mentioned, *Nucula*, *Buccinum*, and *Murex*.

C. The Igneous Series.

The hills formed by the third group of rocks in the Nauheim neighbourhood have been spoken of as interrupting the continuity of the Tertiary plain, but they do not rise with the striking abruptness of, for instance, the phonolitic Hohentwiel and neighbouring basaltic hills in Southern Baden. They are low, rounded elevations, except at the north end of the Friedberg outcrop, evidently parts of lava flows rather than denuded volcanic necks.

The rock itself appears to be a typical dark basalt; often compact and without crystals distinguishable by the eye, but at times with distinct clear green olivines. It is rarely slightly vesicular,¹ but shows a slight tendency to columnar jointing in places. Weathering results in the usual pale-brown crust, and often a rough spheroidal structure is revealed in the process.

Surface accumulations seem everywhere to mask its actual contact with the Tertiary beds, but I have been unable to observe any phenomena of metamorphism in the latter. This at first sight gives one the impression that the basalts are older than the Oligocene strata, but there is evidence elsewhere to show that such is not the case. At Wickstadt, for example, the Litorinellen-kalk is overlaid by basalt.

IV. THE SPRINGS, BORINGS, AND 'SALINES.'

Having thus obtained some insight into the nature of the strata of the district, one is led to consider what is the relationship between the character of these rocks and the presence of the thermal and saline springs to which the locality owes its fame. With this in view it will be necessary to note in some detail the position and

¹ There is a brownish-grey scoriaceous rock, which is used in Nauheim for kerbstones, etc., but which I could not find *in situ*. Closer observation showed the presence in it of clear blue Hauyn crystals, and it probably comes from the well-known quarries of Niedermendig.

depths of the various borings and some of their characteristic phenomena. As, however, a good deal of statistical information is obtainable from the guidebooks published on the spot, an attempt is here made to direct attention only to such facts as bear on the geological questions involved.

FIG. 3.—Ground-plan of Bad Nauheim showing site of Old Town and New Baths and Park, with Springs and Borings.

The various borings which have been made during the present century in order to obtain a larger supply than that yielded by the small natural springs, have been numbered from 1 to 12.

That known as No. 1 (ignoring an attempt made in 1816) was made in 1823; it was carried down 18 metres, and gave a spring

yielding 284,500 litres a day, with $2\frac{1}{2}$ per cent. of salt and a temperature of 25° R. The second, made in 1824, was 153 metres in depth; it gave water of similar composition at 21° R. Nos. 3 and 4 were stopped at 31 and 22 metres respectively.

These four¹ were bored near together in a N.E.-S.W. line on the south-east side of the circular 'platz' which now occupies the centre of the park. No. 5 seems to have been a little north-west of these, and was undertaken in 1838. At 32 metres it gave a supply of 397 cubic metres per day, with 3.55 per cent. of solid matter and with a temperature of 26° R. The 'Alte Kurbrunnen,' known as No. 6, was situated about 100 yards further east, and at 19 metres produced a similar spring with temperature 18° R.

The great boring made in 1839, No. 7, going down to a depth of 159 metres, shares with the last of all (12) the responsibility of supplying the great system of baths. It had been carried down to a depth of 159 metres when, as there was no result, the works were abandoned. In December, 1846, after violent thunderstorms and heavy rains lasting for some days, there was a sudden rush of water up the deserted shaft, and the supply has never stopped since. The water contains a large quantity of carbon dioxide, and solids to the extent of 3.5 per cent., with a temperature of $26-29^{\circ}$ R.

Numbers 8 and 9 were experimental borings made a short distance to the northward (between the 'Waitz' tower and the Teich); but the temperature of the water was much lower and the general result unsatisfactory.

The tenth attempt, made a mile south by the third 'gradirwerk,' could only be carried to 65 metres, when it gave an effervescent water with much bicarbonate of soda. It is much used as a medicinal drinking water, and is known as the Ludwig's Quelle (Ludwigsbrunnen).

The eleventh was a small boring 29 metres deep, which subsequently ceased to give any supply.

Lastly, the twelfth, now the Friedrich-Wilhelm's Quelle, was bored in 1855 to a depth of 180 metres, with an 18 cm. diameter. The water did not rise spontaneously at first, and two hand-pumps were employed. In about half an hour a column of water charged with carbon dioxide rose suddenly in the boring, blowing up the pumping apparatus and rising 16 metres above the ground. It was found to give 1,214 cubic metres in the 24 hours, with a temperature of 30° R. and 4.3 per cent. of dissolved solids. The boring is situated only 4 metres east of No. 7, and the two together supply practically the whole bath system. The ordinary thermal brine baths are derived mainly from 12, but there are underground pipes from both sources to supply the effervescent baths, or 'sprudel-bäder,' in the bath-houses 1 and 5.

¹ In the plan (Fig. 3) I have unfortunately numbered these four from west to east, instead of in the reverse order, as correctly shown in the sections (Figs. 4 and 5), but their close proximity and the fact that 2 is the only deep one renders the error of no importance.

Such is a brief summary of the history and nature of the Nauheim borings. From the geologist's point of view the features of interest fall into two series: first, the strata traversed by the borings; and second, the temperature and contents of the waters themselves.

The former question may be more conveniently dealt with in the concluding section of this paper, but it may be noted, in passing, that those borings which are likely to give most help in explaining the subterranean structure are Nos. 1-7, 11, and 12. An almost straight line can be drawn through these, approximately at right angles to the general strike of the rocks.

The results of chemical analysis of the contents of the different springs are given in many of the books of local and medical information published on the spot, and there is no necessity to investigate the numerous variations here. With a view to geological considerations, however, it may be well to reproduce the details of one typical analysis, that of the Friedrich-Wilhelm's Quelle (No. 12).

AMOUNT PER 1,000 GRAMMES OF WATER.¹

Sodium chloride	29.29
Lithium chloride	.05
Potassium chloride	1.11
Ammonium chloride	.07
Calcium chloride	2.32
Magnesium chloride	.52
Calcium sulphate	.03
Strontium sulphate	.04
Calcium carbonate	2.60
Iron carbonate	.04
Silica	.02

At the risk of seeming to break the promise given above to keep entirely to such matters of detailed description as bear on the geology of the district, I am tempted to insert here a note on the process by which the concentrated brine, and subsequently the dry salts, are obtained. It is distinctly difficult at first for the enquiring visitor to understand the meaning of the curious structures round the town; and the process is not only interesting from the commercial, chemical, and mechanical points of view, but in some of its features is very suggestive to the biologist and geologist as well.

About the middle of the century the old method of simple evaporation in troughs was discarded and a more elaborate system adopted. A short distance south of the town a number of long tanks across the plain of the Usa were constructed, and above each an immense erection of heavy timber frameworks. The interspaces of these massive structures are entirely filled in with what may in general be termed 'brushwood,' but which consists almost entirely of close-packed bushes of blackthorn. Along the top of each of these 'gradirwerke,' as they are termed, runs a trough containing the water from the springs with nearly all its lime, iron, and salts; and this is allowed to percolate down through the brushwood

¹ These are the chief constituents of the dissolved solids. There are traces of various other substances, but those given here are such as can be recorded in the second decimal place.

masses below. As the water trickles over the twigs the lime and remaining iron oxides are deposited as a stalagmitic crust upon the wood; but the more soluble salts remain, and the water which drips into the underlying tank is a more or less concentrated brine.

Such is the principle of the process, but it takes one a little time on the spot to discover how the mechanical difficulties are overcome. The method seems to be this. The saline waters from the two great 'sprudels' are directed into an open trench, which empties them into a large round tank situated in the fields south of the town. To raise this water to the top of the 'gradirwerke' would appear a difficult task; and yet, in spite of the flat country, the very small quantity of water in the Usa, and the almost imperceptible current, it is performed by means of two water-wheels. The three western 'works' are supplied by a large double pump by the Ludwig's Quelle. There is not sufficient force of water to turn the wheel directly, but having been once started it is able to pump up sufficient water to resupply itself as well as to pass on the remainder up two great pipes to the top of the framework. The eastern 'works' are similarly supplied, but in this case the wheel is as far away as the village of Schwalheim beyond the railway on the east. The 'connecting-rod,' if such it can be called, between the wheel and the nearest of the Gradirwerke is a long series of hollowed tree trunks placed end to end. These are supported at intervals on the axles of pairs of iron wheels, which run on rails laid on the top of low stone walls. The whole row moves backward and forward some eighteen inches with the turning of the wheel. A mechanical system distinctly cumbersome, but as there is no haste necessary in the process it is probably as effective as any other and more economical.

The first of the solid contents of the spring water to separate are the iron oxides, with which the basin of the Great Sprudel is coated. In the trench leading off the waters to the Gradirwerke there is a similar deposit of a powdery red oxide on twigs, leaves, etc., that have fallen in. With the exception of a few diatoms and filaments of cyanophyceous algæ there seems little life here. I had expected to find *Leptothrix ochracea*, but was unsuccessful. Further on, when the lime begins to precipitate, a red porous 'travertine' is produced. Almost all the remaining iron seems removed after passing the tank, as the stalagmite on the brushwood is very rarely tinged with red.

At the present time there is little evident incrustation of the brushwood, owing to its having been comparatively recently renewed,¹ but the lately removed material often shows a crust nearly two inches in thickness, and blocks of it are used all over the neighbourhood as ornamental rockwork for gardens.

In the western salines the brine, freed from lime and iron, undergoes some evaporation, and at times very delicate, hollow, salt stalactites are formed, as well as imperfect or hollow salt crystals like the 'hopper-shaped' crystals, seen by evaporation

¹ I understand that the period of renewal is about every ten years.

of salt solution under the microscope. The brine in the tank at this point is clear, and contains but little life. A few floating patches of a green alga (*Rhizoclonium*?) are, however, generally present.

In the last or most westerly tank the appearance is very different. The water has a stagnant and turbid aspect, and is often covered with bacterial scum. Dense masses of *Vaucheria* form rounded cushion-like growths at the bottom, and the filaments become completely incrustated except at the growing tips. If these had been formed under natural conditions, and subsequent infiltration by lime had occurred, a formation would be produced which can be paralleled by the oblique limestones already referred to as found at Bönstadt in the Northern Wetterau.

The algal masses are crowded in the spring by larval cases of a dipterous insect, some half an inch long, and later in the year the surface of the water swarms with small black flies. As the cases become similarly incrustated they would contribute to rock formation and produce a rich 'indusial' limestone deposit. As the water here contains a high percentage of salts the luxuriant growth of these two organisms is remarkable; and doubtless microscopic study, which I was unable to undertake, will reveal other forms of interest.

V. GEOLOGICAL PROBLEMS INVOLVED.

Leaving here this brief description of the distribution of the various formations and of the general character of the springs

FIG. 4.—Geological explanation of the data furnished by the borings as given by Dieffenbach (Desc. of Geol. Map of Hesse, Darmstadt, 1856).

B. Blättersandstein.

L. Litorinellen-kalk.

T. Taunus-quarzit.

S. Spiriferen-sandstein.

O. Orthoceras-schiefer.

S.k. Stringocephalen-kalk.

and borings, we may turn, in conclusion, to some consideration of the geological problems involved. The chief of these may be enumerated as follows:—(a) the underground structure as indicated

by the data given by the borings; (b) the extent and character of the ancient lake; (c) the reasons for the chemical and physical characteristics of the springs; and (d) the connection between the eruptive rocks and the general phenomena of the district.

In discussing these points it is scarcely possible in any case to make dogmatic statements, and the following remarks must be regarded only as a statement of the case for investigation.

(a) When one examines the published details of the different borings one cannot fail to be struck by the wide differences which exist, in so small an area, between the depths at which the Palæozoic rocks were encountered.

FIG. 5.—Geological explanation of the data furnished by the borings here suggested.

B. Blätersandstein.	L. Litorinellen-kalk.
T. Taunus-quarzit.	S. Spiriferen-sandstein.
O. Orthoceras-schiefer.	S.k. Stringocephalen-kalk.

Although the Devonian rocks of the Johannisberg are dipping south-east at a high angle where they disappear below the Tertiary beds, and are met with at 120 m. in boring 4, yet they are not touched at all in borings 5 and 11. The deep boring 2, on the other hand, while it meets Palæozoic rock at 130 m., does not touch the Taunus-quarzit, but traverses some 165 m. of 'Orthoceras-schiefer' and terminates in 'Spiriferen-sandstein.' Borings 7 and 12, on the other hand, strike the 'Stringocephalen-kalk' immediately below the Tertiaries, and terminate in that formation.

These facts appear to show that in the first place the old land-surface on which the Tertiary beds were deposited has a distinctly irregular contour, and secondly, that by some agency, either folding or faulting, the members of the Middle Devonian series are present under Nauheim at no great depth, but with very limited horizontal extension.

The explanatory section published in connection with the old geological map, a copy of part of which is given on p. 351, looks

fairly satisfactory at first sight, but on study is found to contain serious difficulties. The 'Stringocephalen-kalk' on the right can hardly be accounted for without any corresponding mass on the left; and the theory requires that the dip of the 'Taunus-quarzit' on the east slope of the Johannisberg should be represented in exactly the reverse direction to what is actually the case. More serious still is the difficulty that it places the 'Taunus-quarzit' above the other members of the Devonian, whereas it really underlies all but the 'Sericit-schiefer.'

Under these circumstances I thought one might try to make a hypothetical section which would better fit in with the known data; and it seems to me that some such structure as is shown in Fig. 5 would meet the requirements of the case. It is not necessarily true, as there may be considerable faulting, but until there is evidence of the presence of faults it is as well to try to explain matters without their help.

An infolding such as this is just what might be expected from the structure of the Taunus range as a whole. The peculiarities of the boring records are easily accounted for on this supposition, and several other isolated facts fall readily into place. Thus, if it is true that boring 10 in the plain on the east passed through 'Sericit-schiefer' and then touched the 'Taunus-quarzit,' such is what might have been expected, as is shown in Fig. 5. Similarly, the reported outcrop of 'Orthoceras-schiefer' near the Teich-haus is by no means impossible; while the patches of the same rock and of 'Spiriferen-sandstein' mapped to the west of Ober Mörlen can also be accounted for as an infold similar to that below Nauheim.

(b) Passing on from the question of these contorted Devonians to the simply and conformably stratified Tertiary beds of the Wetterau plains, one expects a simplification of the task of explanation. Such there is to a certain extent; but, on the other hand, there are new questions of a totally different character which crop up in the endeavour to follow out the history of the country.

While there can be no doubt that the area over which these deposits extend was in Middle Tertiary times an enclosed lake, yet the stages which preceded the isolation of this extent of water are not so easily recognizable.

The fact that mollusca characteristic of brackish water—such as *Cyrena*, *Cerithium*, and *Litorinella*—are found in beds as high as the Blättersandstein, is somewhat remarkable in itself. When we find, moreover, that in the deeper layers there is a much larger percentage of such types, and finally in the lowest strata we have to deal with typically marine genera, it is evident that the succession of beds records a series of great physiographic changes. It seems almost certain that in Oligocene times these districts were covered by sea-waters from the south; and the contours of Central and Northern Europe suggest a similar communication with the ocean on the north.

It seems probable that the district was a dry land area, while the Cretaceous rocks of other parts of Germany were being deposited; that an Eocene or post-Eocene subsidence let in the sea-water from

a long northward extension of the Mediterranean reaching from the Marseilles neighbourhood up the Rhône and Rhine valleys, perhaps establishing communication with the North Sea; and that the earth-movements which subsequently completed the upheaval of the Alpine chain separated the northern gulf from the sea to which it had formerly belonged.

The process of severance was doubtless gradual, and allowed of a transition period in which the marine *Murex* and *Perna* were slowly displaced by the brackish-water *Cerithium* and *Cyrena*. In the upper strata there are narrow bands in which the fossils indicate the prevalence of purely fresh-water conditions, but the brackish-water types continued to exist apparently through Miocene times.

(c) As to the chemical and physical questions connected with the Nauheim springs, anything like a complete discussion is beyond the scope of this paper. Those who wish to know how far the consideration of the amount of soluble salts in springs, rivers, and seas may lead them in the discussion of the geological age of our planet, should read Professor Joly's interesting paper in the Transactions of the Royal Dublin Society for 1899.

So far as the local questions are concerned we can only make a note or two on, firstly, the chemical contents, and secondly, the physical conditions.

In the first case it is evident that we are not dealing with 'special' types of springs—saline, chalybeate, or calcareous—but with a combination of all. It would be interesting to know the sources of the different contents, but it is difficult to make anything but the vaguest suggestions.

As to the iron, it is evident that a certain amount may come from denudation of the Devonian rocks on the west, and more from the breaking up of the basalts. The extraordinary amount of iron oxides in some beds of the 'Blätersandstein' suggests that they may have contributed large quantities to the underground supply from which the springs now rise, but they, in turn, must have derived it from neighbouring Palæozoic or igneous rocks in Tertiary times.

With respect, again, to the calcareous contents, there seems a much larger proportion than the geological features of the surrounding country would lead one to expect. The limestone strata are of small extent, and anything contributed by the decomposition of the felspars in the basalt would be insignificant. There is, on the other hand, a great quantity of calcareous matter in the Tertiary beds, derived at that date, most likely, from a greater distance and from a larger extent of since denuded limestone in the district. Much of this has been and is still being gradually carried down through fissures to the subterranean reservoirs which the borings have 'tapped.' The lime was doubtless largely separated through the agency of organisms, but in beds of this character the shells would almost certainly be to a large extent redissolved.

It is possible, however, that we have not here sufficient to account for the surface phenomena, especially when we also take into consideration the enormous amount of carbon dioxide in the waters of the Sprudel. Probably there are deep-seated calcareous strata,

beyond the reach of the borings, where a high temperature prevails and intense chemical reaction is still in progress.

The soluble saline constituents again offer us much the same problem. The physiographic changes of Tertiary times must have been slow, gradual, and constantly varying, and the alternations of marine, brackish, and fresh-water conditions probably resulted in a large residue of salt in the strata then being deposited. The minerals present in such formations as the Blättersandstein certainly suggest this; but whether or not such a residue is still present, a vast amount has probably been washed down into the subjacent rocks.

If this be considered insufficient as a source of the present regular supply, one is obliged to fall back again on the supposition that there exist below the deepest borings either great salt beds or a stratum of immense chemical activity.

Turning from the question of chemical contents to that of physical conditions, one meets again with questions more easily asked than answered. The most obvious are the cause of the high temperature of the waters, and the reason for their expulsion. As to the former one might suggest a very great depth of origin, but we have no evidence that these springs rise from a stratum deep-seated enough to account alone for their heat. Mechanical pressure, added to such strong chemical activity as may exist at a relatively high level in the earth's crust, even locally, might also account for it in part. In addition to such conditions, however, we have to remember the proximity of great basaltic masses which were themselves in a state of fusion at a period not, geologically speaking, so very remote. As the presence of thermal springs is so commonly correlated all the world over with the existence of comparatively recent volcanic action, it is probable that we are safe in here regarding the present temperature of the brine-springs as residual from volcanic times.

With respect to the cause of the expulsive force with which the waters of the two great 'sprudels' are thrown up, it seems that the German geologists, as a rule, are inclined to follow their great leader Bunsen, who studied the district early in the century and ascribed the effects entirely to the freeing of the carbon dioxide.

That the sudden liberation of gas, with the diminishing pressure as the water rises in the tube, must have a very great effect in producing the violence of the final escape, cannot be denied; but this does not necessarily justify a neglect of hydraulic pressure altogether. The great drainage area of the Taunus, its large rainfall, and the fissures and cavities it contains all seem to suggest the probability of a very efficient hydraulic system at work; and the history of the Great Sprudel, where the first outburst only occurred some years after the construction of the boring, as a consequence of heavy rains, would appear to support this view.

Also, as Professor Cole has pointed out to me, why neglect 'residual pressure'? Just as we may attribute high temperature to the survival, *in extremis*, of volcanic conditions, so the tectonic 'Alpine' movements are not to be regarded as entirely dead, but the remaining strains and pressures in the earth's crust may still be factors in the ejection of these heated waters.

(d) With regard, lastly, to the agency of the basaltic eruptions, the considerations involved have been already referred to, and my own observations have been too limited to permit of a definite opinion. A superficial study of the country would lead one to the

conclusion that the basaltic masses had been consolidated before the Oligocene seas or lakes deposited sediments round their bases, and that they formed islands in the waters of Middle Tertiary times.

There is, however, I understand, evidence elsewhere for the Miocene age¹ of the eruptions, and of a still later date for part of

¹ See note on p. 355.

those of the Vogelsgebirge. One can only conclude that the patches in the immediate neighbourhood of Bad Nauheim represent lava-flows at a considerable distance from the active centres, and that they forced their way through the sedimentary rock, with comparatively little disturbance or metamorphism.

The fact that there are reappearances of basalt between Homburg and Ober Erlenburg and on towards Wiesbaden, suggests the existence of a very wide zone which may have a far greater subterranean extent than the minor surface exposures lead one to expect.

In conclusion, I have to express my thanks for assistance to Professor Kinkelin, of Frankfurt; Professor Brauns, of Giessen; Professor Wittich, of Darmstadt; and Professor Denckmann, of Berlin; to Herr Bergrath Otto Weiss, of Nauheim; and lastly, and very gratefully, to Herr Sanitätsrath Dr. Ferdinand Credner, who, in the interests of geology, treated with a generous leniency a somewhat disobedient patient.

The works mentioned below cannot, of course, be regarded as a complete bibliography. I have only recorded such as were brought to my notice during a brief visit as a starting-point for the next student who has the good or bad luck to find himself at Nauheim.

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