NATURAL ROCK ASPHALTS
AND BITUMENS

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THEIR GEOLOGY, HISTORY, PROPERTIES AND INDUSTRIAL APPLICATION

BY

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PREFACE

THE entire absence of a modern English work upon the materials that will be considered in the following pages is almost inexplicable. Beyond occasional articles in the technical journals and the necessarily biased pamphlets of the producer, manufacturer or seller, no English literature having reference to these most valuable products is to be found until we go back for a space of nearly twenty years, a period during which much advance has been made in the production and the use of these articles, fresh deposits have been uncovered and worked, many fallacies have been exposed and extensive chemical research has been made in them. This being so, it is hoped that the appearance of this volume may be regarded as opportune, particularly so since the past year (1912), although not actually celebrated as such, was the bi-centenary of the re-discovery of the use of rock asphalt for constructional and waterproofing work.

As one who is daily in touch with the various materials about to be mentioned, the writer is aware how much the want of such a work is felt by those who, whilst they are desirous of obtaining a deeper and clearer insight into the production, properties, and uses of these articles, find that such knowledge is inaccessible, owing to the lack of any recent English work dealing with them. The idea of the writer, therefore, is to fill this want in the following pages, and, bearing in mind the difficulties that he himself has had to overcome, as well as the problems that have been placed before him in his position as advisory expert on these materials, it has been his endeavour to keep all matters as clear and as lucid as possible. With this ever in mind, unnecessary technicalities have been rigidly avoided, tests have been kept as simple as possible, and if the matter which is dealt with in the introductory remarks is kept in mind, there should be no indecision at any time as to the particular material that may be referred to in any particular place, a difficulty not entirely overcome by some of the previous writers upon this subject, though it must be understood that the terms "asphalt" and "bitumen" are used here in their restricted commercial sense, and not as adopted in geology.

It has been his endeavour also to adopt a strictly impartial position in his remarks, recommending no particular mine above another, no particular bitumen in preference to another, unless practical experience has clearly proved such a superiority. In any case, each type can usually show some advantage over the others, so that it rests finally with the prospective user to decide upon what particularly desirable property he is requiring in the material to be employed in the work at the time under his control, and then to specify or to purchase accordingly. The rock asphalt, for instance, that makes the best wearing roadway is not, as will be seen in the following pages, the most suitable for roofing purposes, nor is a short fibred bitumen always the best to use in the manufacture of bituminous materials that are to be subject to any appreciable tension. In all cases it is a matter of a particular property for a particular purpose, and it is here that the services of an experienced independent consultant in asphalt and bitumen are of inestimable advantage.

It is the hope of the writer that the reader, having arrived at the end of this work, will be able to acknowledge that he has gained information of profit and advantage to him in his work or profession. No trouble has been spared by the writer to obtain suitable information and material for this work with which to complement his own personal knowledge, and the various foreign works which bear thereon have been carefully studied for that purpose. The matter having reference to the ancient uses and writings regarding these materials, too, has been furnished to him by a scholar specialising in ancient lore, to whom the writer is also greatly indebted for much of the general information which has also been embodied in the chapter bearing thereon. A further visit was paid by the writer to the Continent during the past year, in order that the matter and descriptions given in the chapter bearing on the Continental asphalt mines should be as accurate as possible.

It will be noticed that at times the subject-matter in the following pages is at variance with that of other writers, particularly American ones, on certain more or less technical points, but it should ever be borne in mind that each country has its own peculiar conditions, particularly as regards climate, with the result that what is a success in the one may turn out to be an absolute failure in another. An article in a recent issue of an American technical journal bears independent witness of this, as does also M. Barabant's reference to certain London roads inspected by him that had been made up with a rock asphalt which had given anything but satisfactory results when used in his own city, Paris. It is owing to this fact that the writer has preferred to refer principally to the European writers on this subject as his authorities, instead of American ones, except, of course, where their intimate knowledge of local material enables the latter to speak from first-hand acquaintanceship.

The writer takes this opportunity of acknowledging his intense appreciation of the unstinted permission afforded him by Professor Clifford Richardson, of New York, to make reference to the contents of his well-known work, "The Modern Asphalt Pavement" in those parts of this present volume devoted to American bitumens. Nor can he conclude without expressing his deep sense of gratitude to Mr. H. W. Brant, of Newcastle-on-Tyne, by whom the matter dealing with the practical application of rock asphalt mastic has been almost entirely written. As the outcome of many years of close attention to the practical side of this industry, his remarks can hardly be otherwise than of the greatest value to the practical user of this material.

In his position as an entirely independent consulting expert upon these materials, the writer will be pleased at all times to hear of any problems regarding their use which may be difficult of being surmounted by ordinary methods and to advise thereon. Should any of the matter found in the following pages appear to lay itself open to criticism—for, as has been mentioned above, it is at variance in certain portions with the statements of other writers—he will be glad to explain the reasons for his decisions in greater detail if the debatable ones are pointed out to him.

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INTRODUCTORY

Before commencing upon the subject proper, it is desirable, in fact it is most necessary, that a definite understanding shall be arrived at, as to the special material that will be spoken of when any particular word is employed.

To the average man in the street, the term "*asphalt*" has but a very vague yet withal an extremely elastic meaning. Under that heading he would place almost any jet black or dark brown amorphous substance which, although hard and brittle at the ordinary temperature, becomes soft and plastic when heated, until it finally fuses and melts into a liquid, the viscosity of which is more or less dependent upon the degree of heat that is employed. In this condition it is capable of ignition when it burns with a very smoky luminous flame, at the same time giving off a definite smell. To him, too, the terms "*pitch*," "*asphalt*," and "*bitumen*" are merely synonyms—and here, as we shall see later, he is to a certain extent correct—and they are therefore used at will and with delicious freedom to describe any substance that may have the foregoing characteristics. Even the daily papers are not above reproach in this particular matter, for it is no uncommon thing to see mention made in them of "roads made of asphalt and *other* coal tar products," whilst the definition of the word "*bitumen*" as found in a recently published dictionary is "a pitchy, inflammable substance," a definition palpably incorrect, since it fails to embrace the whole genus (including the liquid types), and at the same time it is extremely misleading, since it omits to mention that the inflammability is only existent under certain conditions such as when the flash point of the material has been reached, a point which is usually only attained after the material is in a fused state.

In another dictionary—"The Concise English Dictionary, Literary, Scientific and Technical," Dr. Annandale, 1910 —"*asphalt*" is defined as "the most common variety of bitumen, a black or brown substance which melts readily and has a strong, pitchy odor," whilst "*bitumen*" itself is stated to be the name of "a mineral substance of a resinous nature and highly inflammable, appearing in a variety of forms . . . asphalt being solid." Here again the definitions are not sufficiently wide. "*Asphalt*" is recognised as being merely the solid variety of bitumen, but against this it must be remembered that all solid bitumens do not melt readily, nor do they ever resemble pitch in smell. The strength of the odour given off by bitumen varies with the different types, some being almost odourless, but in any case the smell of bitumen, considered by some people as being healthy and pleasing, but by others as being offensive, is essentially peculiar to itself, so much so that, as will be seen later, it is sometimes possible to detect an artificial or an adulterated asphalt merely by heating a sample of it and noticing the smell that is given off. Again, mention is made in this same work of the verb "*to bituminise*—to convert (as wood) into a bituminous body." In his previous experience, the present writer has never met with this word used in such a way, for to use it in the manner mentioned would be to confuse pitch with bitumen, since the latter is never made by the conversion of wood.

The articles on "*asphalt*" and "*bitumen*" which are to be found in the latest (eleventh) edition of the "Encyclopædia Britannica," too, are very unsatisfactory. Referring to the former, we are told that this name was given by the Greeks—some of whose classical writers also employed the term "*pissasphaltum*" (*pissa*—

pitch)—to the solid or semi-solid kinds of bitumen, but practically the entire article is written around a very incomplete description of the bitumen " lake " found in the Island of Trinidad. As to " *bitumen*," the writer of this particular article informs us that this word was used by the Romans to describe the various descriptions of the natural hydrocarbons, and that " in its widest sense, it embraces the whole range of these substances, including natural gas, the more or less liquid descriptions of petroleum and the solid forms of asphalt, albertite, gilsonite, or uintahite, elaterite, ozokerite and hatchettite. To distinguish bitumen intermediate in consistency between asphalt and the more liquid kinds of crude petroleum, the term maltha is frequently employed. The bitumens of chief commercial importance may be grouped under the three headings of natural gas, petroleum, and asphalt." More definite and detailed expositions of each of these materials might be reasonably expected from such an authoritative work as this is supposed to be, instead of the meagre information actually given and the vague " it is said " method adopted.

Yet we must not be too critical with those unversed in the commercial difference between the three materials which we are considering, when we find in that estimable annual " Specification " the following definition :—

" Mastic asphalt is a composition material made of Trinidad bitumen or coal tar pitch and quartz sand, crushed stone or coke breeze *with or without the addition of natural rock asphalt.* It is claimed that the best results are secured when some of the natural rock asphalt is used in the mixture and Trinidad bitumen added."

How many architects or surveyors, specifying rock asphalt mastic for use in a structure and finding such a composition as the foregoing being used, would pass the work as being up to the specification ? The italics are the writer's.

The confusion, therefore, seems to be getting general, and it is becoming intensified by the haphazard use of the names when entirely different materials are referred to by each of them. Then, too, in a technical memorandum of the weights per cube foot of different materials "*asphalt*" is given as 100 lbs., whilst that for "*bitumen*" is only 87 lbs., thus clearly showing that two distinct articles are meant by these terms. This being so, it must be made quite clear what is meant by each word. In the trade circles themselves, as the foregoing extract shows, this looseness of expression is fast becoming habitual, thus rendering it more difficult each day that passes to define an exact line of demarcation. In his book published twenty years ago, Delano refers to the material extracted from the Trinidad "*lake*" as even then receiving all the three terms, whilst to-day we hear of it as "*pitch*," the material obtained in Asia Minor as Syrian "*asphalt*," and that from Cuba as Mexican "*bitumen*," although they are all avowedly and for practical purposes the same material, though in varying degrees of purity and of geological formation. In fact, for the materials which contain the Trinidad product, it is always claimed as a strong point by the manufacturers that they contain no "*pitch*." Delano even went so far as to affirm that the adjectival form of "*bituminous*" had at the time he wrote replaced the Saxon form of "*pitchy*," though in making this statement he must have been considerably exaggerating. The question, however, comes as to how such expressions shall be reconciled and how each class shall be separated and defined.

Different writers have different ideas upon this point. Some divide them in accordance with their physical properties, others according to their chemical properties, and yet others follow the different geological formation of each.

Thus, according to M. Thenard, the term "*bitumen*" applies only to liquids or solids which fuse at low temperatures, give off a strong smell and burn very readily in their liquid state, whether this state is natural or the result of the application of heat, and which leave but little carbonaceous residue, which last, however, is always very easily and readily reduced to an ash.

These conditions, though, do not exclude pitch, resin, and other similar manufactured or vegetable products, so that it is necessary to add to this definition that the bodies must have a natural and mineral origin. Again, the difficultly fusible "*wetherilite*" of Canada, the infusible "*walaite*" found in Moravia, and the "*wollongonite*" of New South Wales could not be included in the above, although other writers have admitted them to be bitumens.

By M. Gruner they are described under the term of the "*petrol series*" as distinct from the "*carbon series.*" He defines them as solid, liquid, or gaseous hydrocarbons which are rich in hydrogen, and he includes in them marsh gas, petroleum, ozokerite, maltha, and the bituminous rocks, with jet as a kind of link between the two series.

According to M. Descloizeaux, bitumens are liquid and solid bodies with a badly defined composition, formed usually of a mixture of various hydrocarbons in different proportions. He divides them into naphtha or liquid bitumen, maltha or viscous bitumen, asphalt or solid bitumen.

M. Jagnaux affirms that petroleum is composed of 88 per cent. of carbon and 12 per cent. of hydrogen, and that if into this composition be introduced oxygen as replacing the hydrogen, a series of bitumens are formed which are more and more viscous as the percentage of oxygen is increased. This, however, does not take into consideration the presence of sulphur and the absence of oxygen in various solid types.

In a chemical encyclopædia published some time ago under the direction of M. Fremy, "*bitumen*" is mentioned as a rock, at times solid but sometimes viscous. To the first is given the name of "*asphalt,*" and to the latter that of "*pissasphalt,*" which, however, is stated to be very often merely a mixture of asphalt and petroleum.

Other writers are not satisfied with a division that is merely dependent upon physical characteristics, but they have studied the action of different solvents upon bitumens. Thus M. Léon Malo considers solubility in ether, turpentine, and carbon bisulphide as being essential for a true bitumen, though this requirement has since been found to be subject to certain reservations. Holde, too, understands by this name natural products which are found either in a pure state or mixed with limestone, sandstone, and the like, and which in a pure condition are black and glossy, at the ordinary temperature are either pasty and viscous or else hard and brittle, have a melting point of not less than 35° C., and are easily soluble in carbon bisulphide, oil of turpentine, and chloroform, but only partially so in ether, petrol, and benzol, whilst they are almost quite insoluble in alcohol.

The present writer has always steered clear of such troubled waters by a rigid use of each term for such products as fulfil certain conditions, and for these only. As this line will be held to in the following pages, it is given here in full, especially so as, the limiting conditions being extremely finite and never overlapping, it can with advantage be adopted to replace the existing and present prevailing looseness and confusion of terms. There will be, we know, many who will deplore the somewhat arbitrary manner in using words to define materials to which the terms may not have been originally applied, but to these we would merely reply that in this essentially commercial age antiquity must give precedence to utility. Because "*asphaltos*" is the Greek synonym of the Latin "*pix tumens*," and because—to our present knowledge—naturally impregnated stone was then unknown, are we to continue to give the material referred to in this work as "*bitumen*" both these names, whilst the impregnated stone lacks a distinctive one of its own? As the word "*bitumen*" is to be found with but little change in at least four modern European languages as descriptive of the pure material, thus—

English	*bitumen*
French	*bitume*
Italian	*bitume*
Spanish	*betun*

it is proposed to continue to limit its use to that material only, the more so as this use of the word is apparently the custom on the Continent also.

The suggested manner of dividing for industrial purposes the materials over the names at our disposal is as follows :—

Bitumens :—All such substances which are found in nature and require no further treatment other than the extraction of the mineral and vegetable impurities that they may have mixed among them ; which are completely soluble in carbon bisulphide, but only partially so in ether, and almost completely insoluble in alcohol. Under this heading are ranged the bitumens obtained from Trinidad, Venezuela, Cuba, Mexico, etc., Barbadoan "*manjak*," glance pitch, grahamite, gilsonite, elaterite, wurtzilite, Syrian asphalt, maltha, goudron minéral, bergteer, the asphalt oils, and the viscous or solid bitumen that is found impregnating rock asphalt.

Also such substances which are derived from the distillation of any of the above or of the asphaltic petroleums.

Pitches :—All such substances which are derived from the destructive or fractional distillation of all other natural organic bodies or from the distillation of vegetable oils. This definition then includes the pitches obtained from coal tar, wood tar, lignite (brown coal), stearin, wool fat, cottonseed oil or the like, and the residues that are left upon the distillation of animal or vegetable fats, resins or balsams of any description.

Asphalts :—All such substances that are impregnated —as distinct from being merely mixed—with either bitumen, pitch, or a mixture of the two. The impregnation condition is necessary so as to clearly distinguish such bodies from impure bitumen, by which, as has just been mentioned, mixtures are designated. The minerals usually forming the base of asphalts are limestone or sandstone, though, in the artificial types, other pulverised materials are often used. It would, indeed, be preferable if only the naturally impregnated rock were alluded to under this name, but certain terms such as "British asphalt," which refer to essentially artificially formed products, have now such a definite technical meaning, that to exclude them from this heading would be at least undesirable, as causing that very looseness of expression and description that it is so necessary to avoid, even if such exclusion were not actually impossible. The foregoing is, of course, contrary to Delano's statement, wherein he defines asphalt as being "a natural product, a bituminous limestone in which carbonate of lime and pure mineral bitumen are most intimately combined by a natural agency," a description which in any case is too narrow and limiting.

Where possible, however, it is preferable to define the material that is made artificially from grit or crushed stone, whether bonded together with pitch or bitumen, as a "*macadam*," qualifying this term with the adjectives "*tar*" or "*bituminous*" as the case may be. Even the so-called "British asphalt" should be regarded merely as a "*tar macadam*" in which the mineral portion has been reduced to a granular state instead of being used in the much coarser grades customarily employed.

But even these headings can be, and are, divided into other sub-sections for the sake of clearness and in order to define the physical state of the body in question. Thus "*bitumens*" receive their sub-titles of "*bitumens proper*" for the solid types, and "*malthas*" for the viscous or semi-fluid types. "*Pitches*" receive their ordinary sub-headings of "*pitches proper*" for the solid types, and "*tars*" for the liquid ones. "*Asphalts*," however, being necessarily solid by reason of their mineral aggregate, are subdivided only as to whether they are of natural or of artificial origin, the words "*natural*" and "*artificial*" being used to distinguish between the two.

This method of division will be found to differ radically from that given by Professor Clifford Richardson in his work, "The Modern Asphalt Pavement," as the present writer cannot agree with certain of the conclusions which are drawn by him in that book. The term "*asphalt*" as used by him is unnecessarily general, and the term "*pyro-bitumen*" is confusing to the lay mind. Doubtless this difference of opinion arises from the fact that the "asphalt roads" referred to in that book are principally those formed of material which would come under the head of "*bituminous macadam*" in the foregoing summary, owing to the fact that naturally impregnated rock as we know it here in Europe is but rarely to be met with in the American geological formations, and even then the type of the rock is often different, being usually crystalline instead of sedimentary. The naturally impregnated rock that is found there is very often a sandstone in which the grains are merely held together with the bitumen which only forms a film around each individual grain without actually impregnating them as is the case with limestone. When the impregnated limestone rock is used in that continent, it is usually imported from one or other of the better-known mining companies in Europe, who have their representatives and hold stocks over there for that purpose. How different is the present division from the American one is clearly seen when it is pointed out that the latter includes as a "*bitumen*" the paraffin oils which, as the practical man in this country is aware, give anything but satisfactory results if substituted for proper bitumen in asphalt work. Again, following the purely geological idea, "asphalt" is included as a sub-division of "bitumen" and merely refers to the natural bitumen as found in Trinidad, Venezuela, Cuba, etc., whilst, although "*bitumens*" and "*pyro-bitumens*" are differentiated, it is nevertheless admitted that "there is no sharp dividing line between them, as the one is metamorphosed by time and exposure to varied environment into the other," and that the "*grahamites*," which are acknowledged to be bitumens, rapidly shade into pyro-bitumens. It had better here be mentioned that the definition given of pyro-bitumens is "those substances which upon destructive distillation give rise to products which are similar to natural bitumens." As showing also the difference between British and American nomenclature, it may be pointed out that whereas in England—and in Europe generally—the term "*sheet asphalt*" is given to those roofing and dampcoursing felts which consist of a woollen fibre saturated with a so-called coal tar "*asphalt*," it refers in America to rock asphalt mastic and also to a bitumen-sand composition when laid as a pavement.

The following definitions adopted by the American

Society for Testing Materials are given here for purposes of comparison.

"*Bitumens* are mixtures of native or pyrogenous hydrocarbons and their non-metallic derivatives, which may be gases, liquids or solids, and which are soluble in carbon bisulphide.

"*Bituminous:* containing bitumen or constituting a source of bitumen."

The summaries which are given by the different European writers are also open to similar objections as the American ones, but the subject opens up too vast a question to be adequately treated in a few lines, so that the reader who would go more fully into it is therefore referred to the works of the American and Continental authors direct.

All bituminous bodies, however, have the same quality of consisting of a combination of carbon and hydrogen, though in varying proportions. The liquid types are usually free or almost free from oxygen, sulphur, and nitrogen, whilst the semi-fluid and solid varieties contain more or less appreciable quantities of these latter. The smell of all of them is essentially "*bituminous*," whilst the colour varies from yellow to brown in the liquid forms, and from dark brown to black in the semi-liquid and solid ones. They possess a sharp line of demarcation from other organic matters to be found in nature which consist of the same elements (coal, lignite, etc.) by their conduct with various solvents. The rather loose expression of "*artificial asphalt*" given to the distillation products of these other organic matters has given rise to the assumption, though an erroneous one, that the natural types have been formed in a similar way by a distillation process occasioned by the intense heat of the earth. In the following chapter it will be shown that this idea has but little grounds upon which to be sustained.

CHAPTER I

GEOLOGY OF BITUMEN AND ROCK ASPHALT

THE story of the geological formation of bitumen is still receiving the attention of some of our greatest geologists. The intricacy of such research is, however, enormously increased by reason of the many and varied types of this material that are to be found, which range from a very thin liquid—Persian naphtha—to an extremely brittle and hard solid—gilsonite, glance pitch, etc.—and of its wide distribution in almost every part of the globe and throughout the entire range of geological strata from the Laurentian rocks to the most recent members of the quaternary period.

The question has been hotly discussed as to whether bitumen is not more or less intimately related to petroleum and the mineral oils, if it is not actually an offshoot from them. Professor Clifford Richardson, the well-known American expert upon bituminous matters, and to whose writings on the subject reference has already been made, unhesitatingly affirms his belief that such is the case; and this stand has also been taken by many other experts in America, Germany, and France, *i.e.*, those countries most interested in the production and use of the material. Even Delano, who, in common with Malo, his invariable authority, claims that bitumen is " only similar to itself," has to acknowledge this relationship.

In support of this hypothesis (for, like many other self-evident truths, it does not lay itself open to a direct proof, hence the controversy arising around it), it is pointed out that it is often to be found in Europe, Asia, and America in localities productive also of these oils, and that these oils, upon distillation, leave a residue which closely approximates to, even when it is not actually identical with, natural bitumen; hence the inclusion of their residues in this present work under the heading of bitumen.

In the "Encyclopædia Britannica" it is stated that "although the gaseous and liquid forms of bitumen may be regarded as having been formed in the strata in which they are found, or as having been received into such strata shortly after formation, the semi-solid and solid varieties may be considered to have been produced by the oxidation and evaporation of liquid petroleum escaping from the underlying or better preserved strata into other strata or into fissures where the atmospheric action and loss of the more volatile constituents can take place. It should, however, be stated that there is some difference of opinion as to the precise manner of production of some of the solid forms of bitumen." This statement, however, fails to explain the formation of such types of solid bitumen in which no oxygen is to be found, or of those deposits which are totally isolated from any other deposit of a more liquid bitumen from which it could have escaped in the way suggested.

Another theory of its formation is based upon volcanic action. As proving the possibility of such a surmise, it is shown that most types of solid bitumen contain an appreciable percentage of sulphur, a mineral usually discharged during volcanic activity; that the asphalt mines in Sicily and in Italy are not very distant from Mounts Etna and Vesuvius respectively; that the world-renowned bitumen *lake* in the island of Trinidad is now generally accepted as being contained in the crater of an extinct mud volcano; that at one of the oldest sources of supply of bitumen still in existence, the Dead Sea in Palestine, quantities of this material usually rise to the surface of the water after the surrounding district has been subject to volcanic disturbances. This last evidence is, however, unsatisfactory, since it must be acknowledged that semi-fluid bitumen oozes out of the nearby hot springs which drain into the sea, so that the probability is that the masses solidify below the surface of the water and adhere to the sides, from which they are only released by the earth tremors. The suggestion has been advanced by some writers, including Diderot in his Encyclopædia, that the fire which rained down from heaven upon Sodom and Gomorrah (Genesis xix. 24) consisted of burning bitumen which was thrown out by some adjacent volcano, but although the district is known to be more or less subject to earthquake shocks, trace cannot be found of any mention of any actual volcanic eruptions having taken place there, so that this supposition has very slight grounds upon which to be sustained. However, bitumen is to be found throughout the world and in many places where no sign of volcanic activity at the time of its formation can be recognised, so that the volcanic theory cannot hold good in every case.

In a departmental report on "The Production, Technology and Uses of Petroleum and its Products," issued by the United States Government, Professor Peckham, after supporting the theory of the relationship that exists between petroleum and bitumen, concludes that "all bitumens have, in their present condition, originally been derived from animal or vegetable remains, but that the manner of their derivation has not been uniform." It may be of interest to note here that, by suitable treatment of animal and vegetable remains *in vacuo*, chemists have actually been able to prepare substances which approximate, both physically and chemically, very closely to bitumen.

There is nothing really definite to oppose to any of these theories, though at the same time it is difficult to make a choice between them, or rather, to be more correct, to find a single one of them that will satisfy all the conditions necessary in order to be applicable to all deposits of every type of bitumen. In order to be convinced of this it is only necessary to consider a few of the more important deposits of that material.

At Pechelbronn, the strata of bituminous sand are found in contact with strata of lignite. The two are often found on the same level, and the lignite presents itself in greater quantity when the sand ceases to be rich in bitumen. This would suggest that the vegetable matter, the accumulation of which caused the formation of the lignite, also gave rise to the bitumen. It was the exploitation of the lignite deposits here, as a matter of fact, that occasioned the discovery in 1778 of the deposit of bituminous rock, though this latter was not, however, worked until 1828. A similar relationship between lignite and bitumen is to be found in the Hoering deposit in the Tyrol, whilst the stratum of bituminous rock near Alais also contains veins of this mineral.

According to P. G. Wall, bitumen is to be found in the island of Trinidad in certain schists which originally contained vegetable debris. This latter, it is suggested, was submitted to a special decomposition which resulted in the formation of bitumen instead of lignite. This theory has the advantage over that of the formation of bitumen by the distillation of organic matter by the internal heat of the earth, in that it allows of the existence in the bitumen of substances which, like "*asphaltene,*" could not have resulted from such a distillation. The fact, too, that bituminous solutions are not fluorescent, like those of oil residues or those of the pitches obtained by the distillation of pyroschists at high temperatures, seems to bear out this fact.

This author also affirms that this special decomposition is due simply to chemical action induced by the temperature customary with the climate of the Antilles. An inspection of the lignite found in the above-mentioned European deposits results in the recognising in them of traces of sub-tropical flora, so that the climate favourable to these changes in Trinidad might equally well have exercised the same influence in the case of the deposits in Alsace and the Tyrol. This hypothesis, however, does not allow of an appreciable content of sulphur in the bitumen, and it also overlooks the saccharoidal structure of the impregnated limestones at Lobsann and Hoering.

A more complete explanation of this phenomenon would be to include in it the intervention of hot sulphur springs acting either by themselves or in conjunction with the normal climatic decomposition caused by the high temperature and the chemical reactions resulting from it. The distribution of these springs follows the lines of dislocation of the globe, and this suggestion would imply a similar division of bituminous deposits. Following this idea, it might be taken that the bitumen is released from its place of origin, deep down in the bowels of the earth, and then rises to the surface either in conjunction with the hot springs that have a like origin, or by penetrating through the easily impregnated sedimentary strata lying above it. If, however, the water is cooled on its way to the surface, the temperature of the bitumen rising with it would likewise be lowered, with the result that the latter would solidify and coat the sides of these "*faults*" which form the great internal canals of this circulation. This idea is well supported by the degree of fusibility and the low density of many of the bitumens, whilst an actual example is perhaps to be found in the Trinidad "*lake*" deposit.

The idea, too, has been advanced that the formation of the sandy bitumen that is found in this Trinidad "*lake*" took place in the same manner as the volcanic mud of the numerous mud volcanoes in that district. At Turbaco, these volcanoes form a score or so of hillocks about ten feet high, having craters some two feet in diameter and which are filled with a muddy mass. The water in them is almost cold and no trace of the action of heat is to be seen. The gases they give off, however, are highly inflammable and are accompanied with bituminous compounds. It is therefore only necessary to imagine a fairly high temperature below, and that the water which these conduits convey to the particular volcano, the crater of which forms the basin of the "*lake*," is able to obtain the bitumen that it carries from the vegetable masses through which it passes, mixing it with the mud which the other volcanoes eject at a lower temperature without bitumen, and the intimate mixture of the two materials as found in the "*lake*" would appear to be explained.

There are mud volcanoes still in existence in the Caucasus, whilst in Auvergne the "*peperites*" or basaltic tufas, which are often rich in bitumen, probably owe their formation to a similar procedure by means of which they were placed upon the limestone shortly after the deposit of the latter, even if not actually at the same time.

The association of sulphur, pyrites, gypsum and various salts, bromides, etc., with bitumen is a necessary consequence of the theory of the intervention of hot sulphur waters, a theory which was first mooted by M. Daubrée, who, during his researches on metamorphism, was able to transform wood, by subjecting it to the combined influence of pressure and superheated steam, into lignite, oil, and anthracite successively, whilst from the last he also separated certain hydrocarbons which possessed the characteristic smell of the Pechelbronn bitumen.

But the question now comes as to the origin of the bitumens which are found in the primary formation and in the "*gneiss*" of Wermland in Sweden. In this epoch, geologists have not yet been able to find any other traces of organic life, so that it is partly on this account that the theory of the igneous formation of bitumen is based, a theory which becomes more probable when the bitumen to be found in granite, the "*ophites*," "*syenites*," etc., is taken into consideration.

However, there is one great objection to this theory, for the study of bitumen tends to show that usually this material is not a pyrogenous product and that some of the elements which it contains, such as the "asphaltenes," do not appear to be susceptible of taking a gaseous state, as would be necessary had it existed in the molten centre of the earth. This difficulty is usually got over by the further supposition that the material in being ejected from the centre of the earth is subjected to a transformation, in the same way that vegetable matter is changed into lignite and oil. Be it as it may, however, there are many geologists who are content to fix the origin of bitumen as being the result of these volcanic phenomena.

If none of the many theories that have been propounded, including those that are given above, appears to satisfy the origin of all the different types of bitumen, however, the reader will doubtless come to the reasonable conclusion that it is but a further proof of the infinite variety of methods which distinguish the working of nature, which, with absolutely different reactions, at times gives almost identical results. This idea, too, will appear the more forcible if, instead of considering only those exceptional cases in which bitumen, by the accumulation of large quantities, has formed, either of itself or by impregnating other rocks, deposits of considerable importance, we agree with M. Delesse that all sedimentary strata or igneous rocks contain, in very appreciable quantities, organic matter to which bitumen may be allied. Their presence in the igneous rocks was shown by Mr. G. Knox as far back as 1823, and his researches go to prove that they are in a greater proportion in the later rocks than in the earlier ones. As a result of all this, one is compelled to look upon bitumen no longer as an exceptional product and a mineralogical curiosity, but as a substance, the ubiquity of which can only be explained by the infinity of the procedures that have been employed by nature in its formation.

The geological formation of the rock asphalt is, however, more certain. In every case where this material is to be found, the impregnated rock is either a limestone or a sandstone, not, of course, necessarily pure, and in the former case the fossilised oolites are often clearly perceptible. The impregnated layer forms a distinct stratum sandwiched between unimpregnated layers of either the same rock or of marl, but with extreme rarity in "*pockets*," whilst very often several layers of the impregnated rock are superimposed, each being separated from the next by an unimpregnated layer of the rock. The Lobsann mine is a very good example of this, for here are to be found no fewer than five of these veins of bituminous rock, the one above the other. As is the case with coal, the thickness of the strata of rock asphalt varies considerably, ranging from a few inches to many feet, and when mined, the rock is obtained like coal, by driving galleries and shafts into the side of the slope. In some instances, as with certain of the German and Italian deposits, the rock is found almost exposed, and then the method adopted for the work is simply that of quarrying. A strange thing that is noticeable with this quarried rock is that the weathered surface has the appearance of practically pure limestone, and it is only when the face of the rock has been broken down that the well-known chocolate coloration is to be seen.

From the "smoky" appearance of the unimpregnated superimposed rock in certain mines, and the fact that in certain bituminous rocks "pockets" of pure bitumen are to be found filling up the cavities in the vein, some authors believe that at some distant period the bitumen must have penetrated the absorbent mass whilst it was in a gaseous or thinly liquid condition, impregnating it more or less richly according to the ease with which it made its way through the rock, and then, possibly still under the influence of that enormous pressure which first compelled it to seek such an exit, cooled. This would explain why, in the same mine, rock asphalt is found which shows a percentage content of bitumen ranging as wide as from over 30 per cent. down to practically nil.

The question of determining the age of the bituminous impregnation is rather difficult of solution, since the porous rock is capable of being impregnated a long time after its creation, but there are certain fairly frequent circumstances met with in rock asphalt which throw a little light on the subject. For instance, the fact cannot be overlooked that the greater part of the bituminous rocks segregate when they are submitted to the influence of heat, and the easiest explanation of this fact is to admit that their impregnation occurred whilst the rocks were still in a mobile state, or at least in a powdered condition. Although quartz, felspathic, and other similar sands are to be met with at all geological stages, it is much more rare for limestone and alumina to be thus found. Thus it must be concluded that the impregnation of rocks of this nature must either have accompanied or followed shortly after their deposit and preceded their cohesion.

An idea of this mode of impregnation may be found given in the formation of the Caucasian "kir," the supply of which is constantly being replenished with the fresh arrival of petroleum to the surface of the earth, the volatile portions of which evaporate out there, leaving the more solid portions to consolidate and form bituminous rock of the sand through which they percolate. In this example the impregnation takes place with an upward movement, but certain authors declare that the effusion of the bitumen has often taken place above the stratum of the rock that it has afterwards impregnated, the saturation in this case taking place with a downward motion. It is in this manner that the Trinidad "*lake*" bitumen impregnates the land upon which it overflows at a fracture in the side of its basin, though its content of sand is an obstacle to a thorough saturation of the soil.

It has often been affirmed that the impregnation by the bitumen could not have taken place at the same time as the sedimentation of the rocks, and in support of this the fact is pointed out that the bitumen, being insoluble in water, and being also lighter than it, would have remained upon the surface of the liquid mass when the pulverulent deposits were being formed. Mr. Hitchcock is, perhaps, the only writer who definitely declares an opinion to the contrary, which is inspired by the handling by him of various limestones in Syria, which contain as much as 25 per cent. of bitumen, a proportion which he considers is much in excess of what would have been retained by the rock had the impregnation of the rock been occasioned by saturation only.

The cause of the segregation of these bituminous rocks under the influence of heat is therefore explained by other writers in a different way. They propose to admit that the deposits were impregnated in their solid state and then reduced to powder, finally being reconstituted by the agglutination of this powder under the cementing action of the bitumen. It is evident, however, that, in common with all other rocks that have been reduced to powder by the action of nature, the crushing of these primitive rocks could not have been carried out without the formation of deposits intermediate between the original rock and the final powder, and made up of fragments increasing in size as the former is approached. In order, too, that the powdered bituminous rock could not be mixed with any foreign rock, it is further necessary to imagine the entire process of crushing and reformation as having taken place in a region which contains no other rock than it. The complication of these various geological requirements is of itself sufficient to demonstrate the impossibility of this hypothesis.

The deposits of rock asphalt which are worked at Acquafredda, and one or two other places in Italy, are totally different from the other European rocks that are impregnated with bitumen, in that they do not segregate when heated. These, therefore, must have received their bitumen whilst in their massive condition.

There are, however, certain deposits that have been formed from the remnants of other primitive deposits, in which small fragments, like balls or beans, are to be found which are impregnated with bitumen and enclosed in an unimpregnated rock, which, if placed in the presence of free bitumen, is susceptible itself of being impregnated.

The existence in the same region of two bituminous deposits belonging to different geological stages does not necessarily prove that the two impregnations took place simultaneously. The exudation of the bitumen, if it were formed on the spot in both instances, could have occurred at two very distinct dates. The vein at Bentheim gives a striking example of the renewal of an eruption of bitumen after an effusion of pyrites and a deposit of crystalline limestone had taken place upon the first one. *En passant*, too, it may be advisable to remark that the bitumens to be found in the same district are not necessarily identical.

CHAPTER II

APPEARANCE AND PHYSICAL STRUCTURE

The inspection of a sample of a rock asphalt—that is, of course, of the natural rock, not the mastic form—should always be made with the assistance of the microscope, and at a cut or fracture freshly made for the purpose. In his brochure upon his experiences with this material, which, as has been already mentioned, although published some twenty years ago, is apparently still the only English work obtainable upon the subject, W. H. Delano, a well-known expert in this material, states that "the rock should be of a chocolate color, fine in grain, evenly impregnated with bitumen, free from sulphur, pyrites, clay, sand or other extraneous matter."[1] In general, that is to say, as regards colour and formation, this still holds good, but the rigid exclusion of the other minerals that are mentioned is quite unnecessary and, in fact, undesirable, since the material that is obtained from certain of the well-known mines, as will be seen later, invariably does contain a small quantity of these alleged undesirables; yet practical experience covering several decades has proved that it gives quite as good results and shows equal lasting power as those few which do fulfil the foregoing requirements. It is undesirable, too, since our European sources of supply are not too plentiful, and such an elimination would entail their further limitation, from which it naturally follows that competition in supply being thus made less keen, and the demand for the material being capable of being met only by the fortunate owners of those few mines in which the rock fulfils these very stringent conditions, the price of

[1] "Twenty Years' Practical Experience of Natural Asphalt," 9.

the material would most certainly be raised and the cost of rock asphalt work would necessarily go up in consequence.

Then, too, in his composition of bitumen Delano is incorrect, as analyses made in later years have clearly shown. Professors Kayser and Richardson have both, though independently, clearly demonstrated the existence of sulphur in bitumen, which element is not mentioned by Delano at all, and in this respect, as in many others, he appears to closely follow the assertions of M. Léon Malo, and thus weakens his argument against the inclusion of this material in rock asphalt, since it must certainly be present there if the rock is to be impregnated with bitumen at all. In fact, it is further stated by the above mentioned authorities that the older the formation and the more solid the bitumen, the more sulphur it contains, which knowledge, it may be added, has been fully appreciated and extensively utilised in the manufacture of the artificial asphalts and other products. In all probability the idea that Delano had in mind in making this reservation was the exclusion of sulphur in a free condition in the rock; but even if this is the case, such an exclusion is clearly wrong, for, as shown by the analysis given on a later page, the rock asphalt as found at Lobsann (the second oldest worked deposit) contains it; yet it has been, and is still, most extensively used on the Continent, especially for government and municipal work, and, according to the statements made by the proprietors of this mine, it has actually been substituted by some municipal bodies in preference to the product as obtained in Val de Travers, which contains no free sulphur.

As regards sand, it need scarcely be pointed out that a large amount, the majority in fact, of the American material is essentially bitumen-impregnated sand, whilst even in Europe such a material is found and successfully used, though to a very limited extent. Besides this, however, when the impregnated limestone is being used, it is customary to add fine grit—which, of course, includes sand—of various descriptions and sizes to the mastic prior to use, in order to give to it the capacity of better resisting the traffic that is to pass over its surface. Then, too, Delano allows the use of Trinidad epure for the fluxing of the asphalt mastic, which bitumen is itself practically one half sandy matter. If, therefore, it is permitted to add artificially, sand or bitumen containing sand, what ground is there for condemning the material when that mineral is found naturally mixed with it?

The inspection for physical properties that is recommended is for colour, fracture, fineness of grain, and uniformity of texture and of impregnation.

The colour should be a deep chocolate, not black, as this usually shows a poorness of impregnation, *i.e.*, the grains of the rock are merely coated and not truly impregnated with the bitumen; nor should it be too light or grey (unless when obtained from an open quarry where, as has already been pointed out, the process of weathering tends to lighten the colour without, however, affecting the quality of the material in any way), as this shows a low percentage of bitumen.

The fracture should be earthy, that is, not having a sharp cleavage, but showing up rough and irregular as though it were a handful of earth thrown together. This shows a looseness of grain that is very essential for the successful formation of the powder for either compressed asphalt work, asphalt mastic, or the manufacture of compressed asphalt powder tiles. So loose should the grain be that it should fall to powder when heated on an iron plate.

The grain itself should be very fine and minute, of regular size and shape when examined under the microscope. In general, it may be taken that the finer the grain is, the more close will be the work done with it. As against this, however, it must be remembered that the finer the grain is, the softer is the material, which is therefore more easily worn and marked by traffic.

The impregnation of the sample should appear even, that is, the coloration should be practically the same deep chocolate; a light streak shows a bad piece of rock difficult of impregnation, and so liable to give rise to cracks and other weaknesses, whilst, on the other hand, streaks of a deeper coloration show a softer rock that will wear away more rapidly than the rest. These weaknesses are often eliminated by intimately blending the powder together immediately after the rock has been crushed.

The chemical tests for the quality and the constituents of the rock are given later in the chapter devoted to them, but it may be mentioned here that even if traces of foreign minerals other than limestone are found, provided, of course, that they are not present in any appreciable amount, they have no real prejudicial effect upon the material, since for gritted asphalt work, asphalt cement, etc., it is essential for foreign matter to be added to the original rock asphalt. The only exception to this is perhaps the material used for compressed asphalt work or in the manufacture of the tiles made from the compressed asphalt powder, as here it is essential that the powder to be used shall be absolutely free from such impurities which, if present, by preventing the adjacent grains from cohering, would be productive of cracks and similar weaknesses in the work when finished.

The quality of the rock as obtained from the different mines varies very considerably, thus enabling the architect or engineer to specify any particular material that may prove most suitable for his particular requirements at the time being. The finest and closest grained rock is perhaps that which is obtained from the Val de Travers mine in Neuchâtel, Switzerland, although the Lobsann product runs it very closely. Following these comes the rock obtained from the mines at Limmer and Vorwohle, then that mined at Seyssel, the series being completed as regards deposits still exploited for practical purposes or which are imported into the United Kingdom, by the coarser grained Sicilian, Italian and Spanish rocks. A fine, close grained rock does not necessarily mean a perfect material for all classes of work, however. As mentioned above, it has been found by experience (and this can be easily proved by cutting comparative samples with a knife), that the finer the grain is, the softer is the rock. Where therefore, there is much traffic, this class of material is not the most suitable. Again, the coarse rock is of advantage as offering more resistance to friction (traffic, that is to say), but not being so closely bound together, as in the case of the finer varieties, it is of little use on roofs, bridges, iron structures or any place where there is much vibration or alternate expansion and contraction. Under such conditions, unless very highly loaded with bitumen, it would most certainly crack and disintegrate. As, further, bitumen costs more than double the price of rock asphalt, the undesirability of such an excessive addition of bitumen from the economic point of view alone is at once apparent.

A method which is ever increasingly being adopted by well-known professional gentlemen, and one which practical experience proves can be thoroughly recommended, is to definitely and invariably specify the medium grained German rock asphalt for all purposes. When laid pure, it will withstand excessive vibration in as excellent a manner as the fine grained and much more expensive Val de Travers material. The Clifton Suspension Bridge, which was covered some years ago with the Limmer rock asphalt, clearly proves this. Then, too, when required for use where friction is considerable, it is capable of permitting a higher proportion (the writer has seen as much as 45 per cent.) of grit to be added and mixed with it and with more satisfactory results than with the coarse grained, equal priced Italian varieties.

Whilst making mention of the specifying of rock asphalt it may as well be advisable to remark here upon the apparent freedom permitted to builders and contractors in the choice of both the asphalt material and of the asphalting firms to spread the material. This cannot be too strongly deprecated. It is only natural that the builder is desirous of increasing his personal profit as much as possible (particularly if he has only secured the contract as the result of the keen cutting of prices) especially upon such items for which, should they prove faulty, he cannot be held responsible; and who can condemn him when the specification gives him such a wide scope as does the "*or equal*" clause usually to be found in conjunction with items for this work? The rule should be made—and rigidly kept—that the exact mine from which the material is to come shall be definitely stated without any "*or equal*" condition, and, if possible, the names of a limited number of asphalt contractors of repute, with the quality of whose work the architect or engineer is personally acquainted, and quotations from whom he would be prepared to consider for the work.

If only this were done, the trouble that is now found upon occasion with unsatisfactory asphalt work would at once be done away with, as all defects of this nature can be divided into those arising from bad material and those from bad workmanship. As it is, the builder is allowed usually to accept the lowest tender that is received, irrespective of the quality of either material or workmanship, and as an inevitable result the work is ofttimes scamped and rock asphalt as a material brought into disrepute.

It should be clearly understood that there is a price limit below which no firm of asphalt contractors can possibly go and yet put in the proper material and workmanship. If, however, the German material is specified, as has been most strongly recommended, the architect has some means of arriving at his decision, for the output of all the mines in that district is so controlled that the asphalt mastic must be sold at the same price in the United Kingdom to every purchaser, whether for 10, 100 or 1,000 tons, without any rebate or discount of any kind. This at once leaves the difference in the quotations that may be submitted for work in which it is to be used to be accounted for in the labour item only, so that if the difference is such that it shows that the lowest tenderer has not properly covered himself for this, it pretty well proves an intention to reimburse himself in either material or workmanship, either of which can only be scamped to the detriment of the work generally.

Yet it is well known that large numbers of contracts for rock asphalt work are given and carried out at rates much below those at which the work could be possibly done and still show a working profit to the contracting firm if it be done properly. Still, the firms who execute this cheap work continue to exist and even to prosper, so that they must be making a profit somewhere, and it should now be fairly apparent to the reader where and how. The objectionable feature of the case is that the firms who quote for high-class work are wrongly condemned as seeking to make too great a profit for themselves on the contract. It must be borne in mind that an architect cannot always be upon the building, nor can the clerk of works spend the whole of his time in watching the progress of one particular trade at work under his control, whilst the material itself can be greatly reduced in quality almost under their very eyes without their knowledge, so that preventive steps can only be taken at the outset if they are to be perfectly satisfactory, by a clear and definite specification of the material to be used and a limitation of the work to firms of high standing and repute.

A case is known to the writer where an architect was accustomed to invariably issue an open specification and to accept the lowest tender, which on every occasion without exception, was sent in by the same firm. As, however, this particular architect had a great deal of asphalting work continually passing through his hands, a second firm determined to make a bold bid for the next contract and, by dint of cutting their tender down to below cost, they secured it. The outcome was that the second firm did the work properly—though at a loss—and then left it to the architect to make a comparison of the two classes of workmanship. Needless to say, the first firm did no further work for this architect, whilst the second one was able to recover their temporary loss, in profit on the other work from this architect which this incident brought their way. The first firm had been making splendid profit, even at their cut figures, by cheapening the material and by cutting down the labour costs.

As with other things, however, sometimes the very caution that is now recommended causes the adoption of the other extreme, and in glancing over the various forms of tender for the supply of asphalt and bitumen as issued by different corporations, it is almost impossible to repress a certain amount of surprise at the specification of these materials which is embodied in them.

Thus, in the form of tender issued by the Borough of Camberwell, it is demanded that the material shall be "natural mineral rock mastic asphalt of the best Limmer quality. The mastic asphalt blocks should contain from 12 to 15 per cent. of pure natural refined bitumen, and not more than 20 per cent. of fine Bridport grit." Now let us inspect this specification in detail. At the outset, the name itself is misleading, as the material cannot be truly termed "*natural* Limmer asphalt mastic"—for that, the writer takes it, is the article implied—since it is permitted to have added to it no less than 35 per cent. of foreign matter, *i.e.*, refined bitumen and Bridport grit. Then, too, the material is an "asphalt mastic," that is to say, a mastic (or cement) made from asphalt, and not a "mastic asphalt," whilst, as will be seen later, "Limmer" is not a quality but a type, of which the quality varies according to the particular galleries and factories from which it is obtained and in which it is prepared. Again, the 12 to 15 per cent. of bitumen, being "refined," must necessarily be added during the "cooking" operation, and so does not include that which impregnates the rock naturally, since this is not refined. As this latter is, on an average, some 7 per cent., the total bitumen content required to truly fulfil this specification would be approximately 22 per cent., an amount which, as those who are intimate with this particular type of rock asphalt know well, it cannot carry. The most objectionable feature of all, however, is the demand for the inclusion of "20 per cent. of Bridport grit." To blend this with the mastic requires that the latter must be remelted and recooked here in England, when it follows that the brand of the mining company manufacturing the original mastic, and which is the only real safeguard of the architect or engineer, is lost. The work, too, is both inadvisable and useless; inadvisable since the further cooking tends to the loss of the necessary lighter elements of the bitumen, and useless since, once the material so prepared is again melted in the asphalt cauldrons upon the site of the work at which it is to be used, it requires the same amount of care and attention as if the grit were only then mixed with it; for, with the softening of the mastic, the heavier grit at once begins to settle to the bottom of the cauldron, unless the material is kept constantly stirred. Further, this requirement eliminates from tendering all those asphalting firms who do not chance to have a "cooking plant" installed in their works, and as this piece of machinery is both expensive and entirely unnecessary for ordinary work—so much so that the writer would be inclined to view with a certain amount of suspicion any small asphalt contracting firm who did chance to possess such an installation—many smaller but reputable firms are thus effectually debarred from entering into competition with their more fortunate fellow contractors.

The specification included in the tender form issued by the Metropolitan Borough of Bermondsey is slightly different. This reads, "The asphalt mastic used shall be a bona fide rock asphalt, and shall be mixed with a not larger proportion than 20 per cent. of clean washed Bridport grit; only sufficient bitumen as necessary shall be used, and shall be made from best Scotch shale oil and refined Trinidad pitch."

The ambiguity of the phrase "a bona fide rock asphalt" is almost too apparent to require to be more than pointed out. The objectionable remade rock asphalt mastic comes well under this heading, although it is one of the substitutes of the original product that should be most rigidly excluded. The unnecessary and disadvantageous inclusion of grit has already been referred to above, though the specification goes a step in the right direction when it does not insist upon a fixed percentage of added bitumen. A part that could be revised with advantage, however, is the constitution of the bitumen. By refined Trinidad "pitch"—and the misuse of the term "pitch" is to be deprecated—is implied, one would imagine, the Trinidad epure, and for this material shale oil or grease is most certainly not the best flux. True, its use has been extensively adopted in the past, when the use of rock asphalt, bitumen and bituminous products was more or less in its infancy, and when the existence, in practicable quantities, of suitable liquid bitumens for the fluxing of the solid types was unknown, but with the placing upon the market of the various malthas and bituminous oils, the necessity for an artificial product, as is shale oil, is dispensed with.

The rock asphalt mastic and bitumen that are to be supplied to the corporation of Dublin have, according to the official tender form, to fulfil the following specifications :—

> "The asphalt shall be composed of at least 95 per cent. of pure rock asphalt and shall have all volatile oils evaporated, and be perfectly free from all foreign substances, and shall be delivered in cakes as it comes from the mines without any adulteration or recasting.
>
> "The bitumen to be composed of Trinidad asphalt refined with not more than 20 per cent. of shale grease; it shall be perfectly free from clay and vegetable matter.
>
> "The materials to be supplied shall be fully equal in every particular to the specimens or samples exhibited, and when no specimens or samples shall be exhibited, they shall be of the very best brand and quality of their various and respective kinds."

It is gratifying to see that here, at least, the value of the brand of the mining company upon the original blocks of mastic is appreciated, and that the entirely unnecessary mixing in of a "filler" is not required. An impossible demand, however, is made when it is insisted that the mastic shall contain "at least 95 per cent. of pure natural rock asphalt" after the volatile elements have been evaporated, for, as already remarked, the average content of bitumen in the Limmer rock (which the writer is given to understand is the type used by this corporation) as drawn from the galleries, including the lighter oils entering into its composition, is on an average only 7 per cent. The lowest bitumen content to allow of the Limmer rock asphalt mastic being properly and satisfactorily worked, without any fear of charring occurring in the cauldron, is 14 per cent. Making no allowance, therefore, for the portion of the bitumen naturally present that will be evaporated out, a further 7 per cent. of added bitumen is thus necessary, yet the specification only permits of a maximum addition of 5 per cent. It is further omitted to mention to what temperature the bituminous rock is to be heated in order to extract the volatile oils, a matter which is of great importance, since these volatile oils are made up of a mixture of oils which distil out at different temperatures until only the brittle "asphaltene" of the original bitumen is left, a state that cannot be desired. The composition of the bitumen admits of the same criticism that has been given above, though, as will be seen by the chapter on American bitumens, if the Trinidad epure is referred to, it is an utter impossibility to obtain it absolutely free from vegetable matter and, if by the term is meant the very finely divided sand that it contains, clay.

Objection can be reasonably taken, too, to the mere visual inspection of the samples against which the prospective tenderer is to quote. Without physical and chemical tests, their qualities cannot be ascertained with any degree of exactitude. Since the material as supplied in bulk is to be tested by the city analyst, it is only reasonable that the contractors should in a like manner be in a position to test the material which is exhibited as a type sample. The analysis of the city analyst, whose certificate is to be final, whilst no doubt of great value as showing the comparative chemical properties of the sample and the bulk, can also be demurred to. As will be seen by the chapter upon analysis, a chemical test, or even a series of chemical tests, is totally insufficient to conclusively prove the fact of a rock asphalt mastic being pure or not. Artificial types can be, and are, now prepared so well that by none but an expert in the material—and even he at times can be led astray, as the writer once found when a friend of his prepared a sample which, when submitted to a German expert, was passed as being natural Limmer rock asphalt mastic although none of its ingredients had in reality seen the Continent—can their true character and formation be detected; the essential components are the same in both cases, and so both the natural and the artificial materials react and respond equally to chemical tests and reagents.

The above three specimens have merely been taken at random out of many, but they clearly show how neccssary it is that the present ambiguous and incorrect specifications shall be carefully revised and so worded that only the natural rock asphalt mastic and natural bitumen let down with a suitable natural bituminous flux, can possibly be used. To do this a long involved paragraph is not necessary, but one covering the essentials somewhat after the following :—

"The asphalt mastic to be natural Limmer (or Seyssel, Lobsann, Val de Travers, Ragusa etc., as preferred), mined and prepared by the . . . . Company, and shall be delivered on the site of the work where it is to be used, in the original blocks as shipped from the factory by that company, each block having clearly impressed upon its face the brand of the mining company mentioned.

"The bitumen to be Trinidad (or Selenitza, Bermudez etc., as the case may be) epure, cut down with Trinidad liquid bitumen (or Californian or other flux determined upon) so that when heated to a constant temperature of 165° C. (or the maximum degree of heat to which the material will be subjected when used) for seven hours it shall lose not more than 4 per cent. of its volume, whilst a No. 2 needle should in five seconds sink 3—9 mms. (according to the degree of softness required in the bitumen) into it when under a pressure of 100 grammes and at a temperature of 25° C."[1]

Any further addition to the specification for the rock asphalt mastic, as for example, the degree of heat necessary to fuse the material and the percentage content of bitumen, is rendered unnecessary, as the fact of the material being used as shipped from the mines, also implies that it is made to the definite and fixed standard that is adopted by that particular mining company for the material it manufactures.

In this way each firm which tenders for the supply is placed upon an equal footing with its competitors, so that, each having the same opportunities of securing the various materials requisite, none can complain of preferential treatment as is the case at present. The engineer will

[1] *See* Penetration Test in chapter on Analysis.

also be able to know exactly what material to expect, and knowing this he will also know how the finished work will—or rather should—act, so that should any fault arise, it can only be occasioned by faulty workmanship, and it is to prevent this that the names of reputable firms whose work can be accepted should be inserted. Only too often the workmen at present shelter their own shortcomings by blaming the material that they have been using.

It may be of interest to some readers to make mention here that the maximum period that is allowed by the Local Government Board for the repayment of loans issued by them for the paving of footpaths with rock asphalt mastic is ten years.

The following figures, which give the imports of rock asphalt into the United Kingdom, clearly show how much greater is the use of the German article than that obtained from any other rock asphalt producing country in Europe.

—	1910.		1911.	
	Tons.	£	Tons.	£
Germany .	24,960	58,092	24,330	53,784
France . .	11,985	25,301	13,716	32,272
Italy . .	10,308	18,604	12,200	19,943

CHAPTER III

HISTORY AND ANCIENT USE

To those who are at present dwelling under the belief that the present day uses of rock asphalt and bitumen are but modern innovations of no earlier date than the past century—and the writer has come across not a few—it will be of much interest to know that the employment of these materials and the knowledge of their properties may be referred to with safety as being nearly "as old as the hills," for mention can be found made of them even in writings which themselves take us back into the mists of antiquity.

The names of "*asphalt*" and "*bitumen*" at once carry us back to the civilised nations of former times. "*Asphalt*" is derived from the Greek word for mineral pitch, "ἄσφαλτος," by which this nation described this, to them, "*immovable*" body which was unaffected by the acids and alkalies then known. The Latin word "*bitumen*" is but a corruption of the phrase "*pix tumens*," signifying "bubbling or fervent pitch," by reason of the bitumen springs from which it exuded and from which it was obtained by them. The derivation of the expression "*pix tumens*" itself is very uncertain, as it is not really allowed to be Latin at all, but is said to come from the Hebrew, a surmise which would appear probable when it is borne in mind that one of the principal sources of supply at that time was the Dead Sea in Judea. Delano's statement, therefore, that "bitumen is in fact the Latin *equivalent* for pitch" is only very partially correct.

As rock asphalt must be accepted as a branch of bitumen in that it is a bitumen-impregnated rock, the ancient history of the one merges into that of the other, so that although bituminous stone or cement is referred to as being in use by the most ancient of builders of whom we can find any record, we cannot at this present age state definitely whether this stone was a natural product or one made artificially, except by unsatisfactory deduction, for, as will be seen later, about the Dead Sea, one of the oldest sources of supply, is to be found bitumen both in its pure state and impregnating limestone rocks.

One of the first instances in which we find this material mentioned in general literature is in that most ancient of writings in daily use, the Bible, where it is stated that in the construction of his ark, Noah gave it a protective coat of " pitch " within and without (Genesis, vi. 14), the material in this case being in all probability the mineral pitch, *i.e.*, bitumen. Following this we have an account of the kings of Sodom and Gomorrah after the fight against Chedorlaomer, the King of Elam (Genesis, xiv. 10), fleeing and falling in the Vale of Siddim, our modern Dead Sea, which was then full of " slimepits " or " bitumen " as the Vulgate more correctly translates the Hebrew word " *hemar*."

Other writers on this subject have been content to date the earliest use of bitumen for constructional work to the building of the Tower of Babel, but definite historical records have been found which assign its use for this purpose to a far earlier time even than this. Perhaps the first period in which it can be found playing a part in building is that during which Babylonia, *i.e.*, the country at the mouth of the Tigris—Euphrates delta—was inhabited by its, so far as we can judge, first occupants, the Sumerians. These ancient but highly civilised people have left us their inscriptions upon stones, some of which have been definitely fixed as dating so far back as the middle of the fifth millennium, whilst others by their script belong to still earlier times. One of the rulers of this race—or " *patesis* " as they were called—Gudea, we are told, had made for him some fancy pottery in which, in order to represent the eyes of animals, pieces of *lapis-lazuli* were used and held in position by means of bitumen. This pottery is still in existence, and is to be seen in the British Museum, though in the Louvre in Paris is exhibited a statue of Manishtusu, a still earlier "*patesi*," in which the eyes are formed of pieces of white limestone also fixed into position in a like manner. From their stone inscriptions, we find that these people were constantly making expeditions for building material, and frequent mention is made of the bitumen which they obtained from a place called by them Magda, which town, since one king who lived at Lagash, a place almost on the sea coast, says that he brought this substance many miles by river, is thought to be the modern Hit.

This nation was followed by the early Babylonians (2,500—1,900 B.C.), a Semitic race who had gradually mingled with and finally ousted their predecessors, and in the Biblical account of the building by them of the legendary Tower of Babel, we again find a reference made to the use of this material for building purposes.

Even at this early date it was extensively used for those very purposes, and owing to the same reasons that it is being employed at the present day, thus affording another splendid example of history repeating itself. It has been asserted with the utmost confidence that the roofs of the houses of that period were flat in formation and used in identically the same way as are the housetops of the Near East to-day. In order to make them watertight, it is stated that the clay or whatever substance was used to form the roof, had blended with it a quantity of bitumen. The inundations of the river Euphrates also necessitated the use of a permanent water-resisting dampcourse in every building, and as the city of Babylon, which was built in the form of a square, was some twelve miles in extent, the amount of bituminous dampcourse that was used in that city alone must have been very considerable. That this is really the case has been clearly proved by the modern excavations carried out in the valley of the Euphrates, as a result of which the investigators were able to definitely state also that the dwellers in Mesopotamia were further accustomed to use bitumen as mortar for building purposes. Thus the immense wall which, in conjunction with a deep moat connected with the Euphrates, defended the city of Babylon, was built in this way, for we learn from Herodotus that the bricks of which it was composed were formed of the clay dug out of the moat or brought in from the surrounding country, air-dried and burnt, after which they were laid in hot bitumen, whilst, as an additional binder, rows of reeds and palm leaves were inserted every thirtieth course.

The famous towers of Babylon (the one still in existence being now known to the inhabitants of that district as Birs Nimrod) were protected for no less than twelve storeys with a coating formed of a kind of concrete consisting of crushed brick cemented together with bitumen, so as to effectually retard the encroachments of both damp creeping up from the earth and of the waters of the Euphrates when that river was in flood. There is no doubt but that the sole reason why the one still in existence, as well as other very ancient buildings which are yet extant, has stood for such a great length of time is that the builders invariably used bitumen as an admixture, even if not actually by itself, in its construction.

The discovery of a method of forming tunnels below river beds is generally considered as being an English discovery dating only from the past century, but upon plunging into the history of the very earliest times we find that, according to the German writer Miesbach (1855), mention is made of a tunnel which is stated to have been constructed under the river Euphrates and built in with burnt brick, afterwards coated with bitumen, more than four thousand years ago by the mythical Queen Semiramis. This personage is said to have been the builder of Babylon, and the successor to Ninus, but as this latter is now affirmed to be merely a modified form of Ninua, as Nineveh was originally spelled, the whole legend in reality resolves itself into a fanciful allegory of the succession to power of Babylon after Nineveh.

The bitumen used in all the above mentioned buildings was in all probability obtained from the springs of Is. Herodotus (I. 79) refers to them thus: " The bitumen used in the work [the formation of the moat] was brought to Babylon from the Is, a small stream which flows into the Euphrates at a point where the city of the same name stands, eight days journey from Babylon; clumps of bitumen are found in great abundance in this river." At the present time there is a small town about 150 miles away from Babylon (now known as Hilla) which is called by the Arabs *Hit*, around which bitumen is still to be found in considerable quantities. Midway between Babylon and Hit there are the remains of an artificial canal joining the Tigris with the Euphrates, having Baghdad at the one end and Faluja at the other. This canal is called *Nahr Isa* (*Nahr* being the Arabic word for a small river), but as there is no bitumen to be found in this canal,[1] the Is of Herodotus must be the modern *Hit* and not the *Nahr Isa*, as some writers, confusing the two name places, have wrongly affirmed. The difficulty lies in the fact that the Greek language cannot reproduce the initial guttural sound of the Arabic *Hit*, whilst the replacement of " s " by " t " is quite a regular phonological change in Semitic languages.

The alluvial plains of Babylonia, however, may also have been drawn upon, for here are to be found both the clay for the bricks and the bitumen, which bubbles out of the ground in a semi-liquid condition, for the cement. The bitumen here is still collected by the nomadic Arabs and made use of for waterproofing their tents, and at Hit it is also employed by the natives for caulking their boats.

Though perhaps outside the scope of the present work, it may be interesting to know that the various Biblical accounts that have been referred to in the foregoing pages, *i.e.* the construction of the Ark by Noah, the erection of the towers of Babylon, as well as the formation of Moses' basket, which we are told was daubed with "*slime*," are all adaptations from the much earlier inscriptions of the Babylonians. Thus the first is practically a literal repetition of what is now known as the "Eleventh Tablet of the Gilgamesh Epic," which dates at least 4,000 B.C.

[1] My informant rather unkindly remarks, "not even as a waterproof lining for the banks."

In the original story, the Babylonian counterpart of Noah, Utnapishtim by name, relates that;

> "I provided a pole (*i.e.*, to paint with) and all that was necessary. Six sar (a liquid measure) of bitumen I smeared on the outside. Three sar of bitumen I smeared on the inside."

Apparently the outside received two coats of bitumen and the inside only one. The word that is used here for bitumen is interesting (ku-up-ri—Hebrew, *kopher*), since it is precisely the same one as is used in the Biblical account of the construction of Noah's Ark, and it is only found in the Bible in this one connection, so that since it is not Hebrew at all, it forms one of the possible proofs advanced by such theological students as refuse to acknowledge the divine inspiration of that book.

The Biblical account of the building of the so-called Tower of Babel (Genesis xi. 3) too, where we are informed that "'*slime*' had they for morter," cannot be said to aim at being historical. The writer clearly shows that his sole intention is to give an explanation of the "confusion" of the human languages. He had heard of the temple towers of Babylon and had heard the name of the town of Babylon (Bab-ili)—which was always rendered in Hebrew as "Babel"—and he wondered at the use of such a name. In Hebrew, "*babel*" means "confusion," and he finally decided that the word was used in this instance because God "confused" (*babal*) their language owing to their endeavour to raise their towers too high. Nobody has discovered the actual Tower of Babel for the simple reason that there must have been scores of them dotted all over Babylonia. Every temple here, it must be remembered, had its huge tapering tower called a "*zikkurat.*"

The hiding of Moses amongst the rushes on the banks of the Nile (Exodus ii. 3) finds its original in the Babylonian tradition of the infancy of Sargon I., who, like Romulus and Remus of the Romans, was supposed to have been of semi-divine origin. For safety's sake he was hidden by his mother by the waterside. Of this episode he relates upon the ancient historical tablets that:

> "She [his frightened mother] placed me in a basket of reeds,
> With bitumen [*kupri*] my lid she fastened."

The "*pitch*" mentioned in the Biblical narrative is probably a maltha or some other fluid form of bitumen, for in Isaiah xxxiv. 9, where the same Hebrew word "*zepeth*" is used, the context certainly implies a liquid as replacing the water of the rivers.

The inclusion of bitumen in all these hoary legends shows clearly how old is the knowledge of the use of bitumen for building and waterproofing purposes.

The next important nation of builders of whom we have any note are, of course, the ancient Egyptians, numbers of whose buildings are still extant despite the thousands of years that have passed since their erection. In their buildings we see it playing an important part in the mausoleums of the Pharaohs—the Pyramids—in the Sphinx and in the still existent temples, whilst it was also used by this people as a coating to the internal and external surfaces of the walls of the ground floors of their dwellings, as a lining to their tanks and cisterns, to their granaries, silos, etc., in fact in every building where the seepage of the Nile water was to be resisted. With this in mind, it is interesting to know that the same material is now being used in modern Egypt for exactly the same purposes, in the form of bituminous sheeting.

But its use with this nation did not stay here. In combination with cedar oil and other ingredients—the particular mixture apparently varying with the wealth and social position of the dead person or animal—it was employed by them in the embalming of their dead, the method of procedure being to take away all those organs of the body in which putrefaction could arise and then to fill up the cavities thus formed with a mixture able to resist the decomposition of the organic tissue left behind when hermetically sealed (by external bandages) from the influence of the air. The name "*mumiya*" (an Arabic term supposed to be ultimately derived from the ancient

Persian "*mum*"—wax) was given to the essential constituent of this mixture—believed now to have been either bitumen or an extract of that material—and the body so preserved became in the process of time to be referred to by the name of the preservative that was employed—a "mummy." How old is the knowledge of the preservative property of bitumen as applied to organic matter will be recognised from the fact that mummies are known which are nearly 5,000 years old, one of the oldest being perhaps that of King Mereure at present in the museum at Boulac, and who belonged to the Fourth Dynasty, ruling the country about 2,800 B.C.

It was apparently the custom of the ancients to build their defensive walls in bitumen, for, according to Diodorus Siculus, the walls of Nineveh were built in the same way as mentioned above for those of Babylon, as was also the Median Wall, as described by Xenophon in his "Anabasis," whilst Nebuchadnezzar states of his city that he "built it with burnt brick and bitumen."

One of the oldest sources of supply was, as has been already mentioned, the Dead Sea, so that it follows that the Jews were intimately acquainted with the substance, whilst to this day the bitumen obtained in Syria generally is often known as "Jewish pitch." Not only did this supply suffice for their own requirements, but they also sold it in the markets of Tyre and shipped it even so far as Egypt for embalming purposes. In Josephus' "Antiquities" (I. 43), Herodotus (I. 179) and Tacitus (Hist. Jud. V. 6) are to be found interesting accounts of the methods that were employed in their day to obtain the bitumen from the Dead Sea—the *Bahr Lut* of the Arabians, the *Lacus Asphaltites* (from which name some writers incorrectly declare that the term "*asphalt*" is derived) of the classics, the *Jam Hamelach* or *Jam Hacabarah* of the Hebrews—of which Strabo informs us that in his time it was filled with bitumen, whilst Diodorus the historian states that at the period at which he wrote, large masses comparable to small islands floated on the surface of the water, this of course being due to the high degree of salinity of the latter. We are informed by the writers mentioned that the collectors were wont to go with their boats to these floating masses and to pick up as much of the bitumen as they were able to carry. At first some trouble was experienced in drawing it into the boats owing to its semi-fluid condition. To harden it, therefore, vinegar was poured over a portion of the mass which thereupon congealed and could then be handled and pulled into the boat, the remainder of the soft material following by reason of its viscosity. A further difficulty had then to be contended with, for when sufficient bitumen had been stowed away into the bottom of the boat, it was discovered that the material could not be cut asunder with a knife having a blade of brass or steel, as these metals merely stuck into it without making any severance. Blood, therefore, was smeared over the point at which the bitumen was to be separated, when the latter could be broken with the utmost ease.

Other ancient writers besides those already mentioned, who refer to this material in their works are Homer (900 B.C.), Aristotle (355 B.C.) and Pliny (100 A.D.), of whom the last especially deals with the subject in a particularly exhaustive manner. He writes (Hist. Nat. II. 106): "Nihil in Asphaltite Iudaeae lacu, qui bitumen gignit, mergi potest," and that he was also quite conversant with maltha we see from the same work (II. 108), where he relates that "in Commagene urbe Samosata stagnum est, emittens limum (maltham vocant) flagrantem." In his thirty-fifth book he also mentions how multitudinous and varied were the uses of bitumen in the times of the ancients. Thus we learn that it was used by the poorer Romans to coat their household goods to protect them from decay. Herodotus informs us that the "bitumen liquidum," apparently petroleum, was imported from Babylon and Zakynthos, the most southerly of the Ionian islands, and used instead of oil in their lamps as an illuminant. As an unfailing remedy for many ills it was held in the highest esteem, and it was regarded as a certain preventative against boils, ringworm, gout, epilepsy, blindness, toothache and colic. Even on the toilet tables of the Roman ladies it was always to be met with, and it was used by them to colour and to beautify their eyebrows, whilst by the nervous and the hysterical it was also used in a similar way and for a similar purpose as the eau de cologne in the smelling bottles of the ladies of the present day.

It is further stated that bitumen was the principal ingredient in "Greek fire," the exact composition of which, however, being a state secret, is not now known. This material is said to have had the peculiar property of being capable of burning strongly even when under water.

From the Roman period onward, no attempt appears to have been made to discover the lost secret of the use of bitumen for constructional purposes,[1] although one would have thought that such knowledge would have been of inestimable value to the Romans in the building of their roads, bridges, viaducts, etc., especially so since the Italian deposits were so ready at their hand. Of the material itself it can be reasonably stated that, from the time of the ancient Sumerians down to the present age, it has not been lost sight of, but after its disappearance as a building material, perhaps the only practical use to which it has been put to any great extent was the caulking of boats.

In the writings of later times it is still to be met with. Valerius refers to it under the name of "bitumen solidum coagulatum"; Libarius, in 1601, looks upon it as belonging to that classification of compounds which included mineral oil, amber, sperm, etc. He was apparently acquainted with the deposits in Brunswick and Alsace, whilst he asserts that naphtha is merely the more volatile portion of mineral oil. In general, however, his writings on this subject are merely reviews of the mention made by Pliny, Discorides, Hippocrates, etc., as to the use of bitumen, though he also says that for the previous fifteen centuries,

[1] Since the foregoing was written, the writer has chanced upon a passage in Moxon's "Mech. Exerc.," p. 243, written in 1677, where mention is made of a "mortar used at Rome, called Maltha from a kind of bitumen dug there." The knowledge of the constructional value of bitumen must therefore have been lost after this period.

mineral oil—petroleum, that is—had been used for illuminating purposes by the civilised European nations and that this was also the fuel used in the famous "*igne Vestæ*," whilst, according to him, too, Hannibal used it in his military campaigns, possibly as an adaptation of the older "Greek fire." Kopp makes some interesting allusions as to its use in the Middle Ages, when it was employed to protect the vines and fruit trees from insects and blight, but more especially by the alchemists of that age. Many years of labour and numberless fortunes have been spent by these persons on this material in the fruitless attempt to extract from it the "*materia prima*," the substance from which the much sought after "*philosophers' stone*" was to be prepared.

But many references to this material under the alternate names of "*asphalt*" and "*bitumen*" are to be found in the literature of our own country from the very earliest times. Thus in an early alliterative work of about 1325 we find mention made of

> "The spumande *asphaltoun* that spyserez sellen."

At least two other allusions in the writings of the fourteenth century are Maundeville (IX. 100) who states that

> "It castethe out of the water a thing that men clepen *aspalt*,"

and Trevisa who, referring to this material, says that

> "*Asphaltis* glewe of Judea is erthe of blacke colour and is heuy and stynkynge."

In Copgrave's "Chronicles" (*ca.* 1460) we find mention is made of

> "A vessel of wykyris filled the joints with tow erde cleped *bitumen*,"

whilst it is interesting to note that even as early as the sixteenth century, the word "*bitumen*" is to be found incorrectly used to refer to an artificial product—wood tar—for in Turner's "Herbal" (*ca.* 1551) it is affirmed that

> "The Frenchmen seth out of it (*i.e.*, the birch tree) a certain iuce or suc otherwise called *bitumen*."

In that century, too, the knowledge of the application of the waterproofing properties of bitumen to building work must have existed, although we can find practically no mention of it in works on building subjects, for in Whitehorne's "Ord. Souldiours" he instructs his readers when forming certain military structures

"For every portion of such thinges (to take) five of aspalto."

But even in our classics it is also to be met with. Thus in Shakespeare we find the material (although with his usual poetic licence he uses the word as a verb and so has caused certain editors to incorrectly read it as "bottomed") mentioned in "Pericles" III. I. 72 and *ibid.* III. II. 56.

"We have a chest beneath the hatches, caulked and *bitumed* ready.
How close 'tis caulked and *bitumed*."

Milton, too, uses the two words "*bitumen*" and "*asphalt*," and in his "Paradise Lost" I. 729 (c.f I. 411) we read of

"Blazing cressets fed with naphtha and *asphaltus*,"

and in the same work, XII. 41, we also find mention made of

"The plain whereon a black *bituminous* gurge
Boils out from underground,—the mouth of Hell."

How vague an idea people then had of the exact type and formation of this material may be gathered from Blount's Glossary (1656), in which it is described as follows:

"*Bitume:* a kind of clay or slime naturally clammy, like pitch, *growing* in some countries of Asia."

This reference, however, is of value as showing that even at that time bitumen and pitch were regarded as two distinct substances although having certain physical properties in common.

Again, the use of bitumen as a toilet preparation did not end by any means with the Roman period. As late as 1752 we find that it is alluded to for this purpose in a publication on "Taste" (I. 1) written by Foote, a well-known "*beau*" of that time. In this he refers to

"The salutary application of the *asphaltum* pot."

Even the modern use of the compressed asphalt powder for the pavements of Paris can be found mentioned, and by no less an English poet than Robert Browning, who refers to them in his "Apparent Failure," stanza 4:

> "Who last night tenanted on earth
> Some arch, where twelve such slept abreast,
> Unless the plain *asphalt* seemed best."

Of the old uses of bitumen, that as a medicine seems to have died hard. Even in the sixteenth and seventeenth centuries a certain kind of bitumen was, under the name of "*mumia,*" recommended as an excellent dressing for flesh wounds and fractures, and was apparently very extensively used to this end; whilst it is worthy of note that it is not long ago that there was a patent in existence for the manufacture of a plastic dressing composed of bitumen which was recommended for use instead of the ordinary plaster of Paris type. Gradually, however, even the medicinal use of bitumen has disappeared with the advance of medical knowledge, and now, perhaps, the only use to which this material is put by that profession is in the formation of tinctures.

Thus this material, which was so highly appreciated and so extensively used by the ancient civilised nations, came to be entirely lost and, but for a very fortuitous discovery, might have been unknown even to this day. From this accidental find dates the modern application of rock asphalt, which has now grown to be an important trade in itself, the possibilities of which are ever increasing as requirements which can only be filled by the peculiar properties of this material in one or other of its various forms, arise.

CHAPTER IV

MODERN EXPLOITATION OF ROCK ASPHALT

The position of expert in some particular department in the administration of Berne, in Switzerland, was, about the year 1712, filled by a Greek doctor named Eyrinis. In his official capacity he visited in the year just mentioned the Val de Travers, the most important canton in the Swiss Jura, and situated at the lake of Neuchâtel. Whilst there, he either heard of, or came in contact personally with, a German workman called Jost, who had discovered that a rock was to be obtained from the cliffs which surround the lake which was capable of being burnt to a certain extent and which, by reason of its exceeding softness, could be easily worked to any desired shape with the most simple of tools. As fuel, however, the stone was found to be practically of no value, owing to the very large proportion of ash which was left behind in the grate, and Jost had tried in vain to find a suitable use to which the peculiar material which he had discovered might be put with advantage.

From his former studies of the ancient Greeks and Romans, Eyrinis in all probability must have learned of the use made by the great builders of old of asphalt, whilst no doubt his own knowledge of natural science also came to his assistance in making his discovery. Be it as it may, the discovery made by Jost interested him very greatly, so much so, in fact, that he himself prospected the district and found that the most important stratum of the rock was to be met with in the vicinity of Bois de Croix. From this place he obtained a number of specimens which he subjected to several careful analyses, as the result of which he discovered that the material contained in the rock was no other than that substance which had been known for a long time previously as bitumen. Being of an essentially practical turn of mind, he determined to find out if this strange stone could not be employed with advantage industrially, and in this he was more successful than the original discoverer Jost, since finally, by following the precedent of the ancients, he proved it to be of the greatest value for waterproofing structures. His method was practically identical with that adopted at the present day in the carrying out of "mastic" work. He first crushed the rock to a fine powder, of which he then made a cement or "mastic" by adding to it a suitable quantity of pitch. With the fusible mass thus obtained, he coated erections of both brick and wood, and found that by so doing they were then completely protected from the attacks of damp, wet or decay of any description, and so were rendered much more durable.

His petition to the King of Prussia—at that time the Protector of Neuchâtel—praying that a concession might be granted him of all the asphalt strata which might be discovered in that principality, was favorably replied to, and the concession thus obtained may reasonably be looked upon as the birth certificate of the modern employment of rock asphalt for building purposes.

In his work entitled "Dissertation sur l'asphalte ou ancien ciment naturel, découvert depuis quelques années au Val de Travers dans le comté de Neufchâtel par le Sieur E. d'Eyrinis, professeur grec et docteur en médicine, avec la manière de l'employer tant sur la pierre, que sur le bois," which appeared in 1721 and which was again published in 1784, he refers to the material and its use as follows :—

"As he has discovered by the help of God, in the municipality of Neuchâtel, a mountain which contains a true asphalt, which is from every point of view as good as the asphalt of Babylonia or of the Vale of Siddim, the which are so well known to scholars, and further, as a great quantity has already been extracted, he finds it advisable to acquaint the public provisionally of it by the mediary of these few lines, until such time as his work bearing the title 'Asphaltasphaltae sive invertibilis veritas ac securitas' is published. (This work, however, appears to have never been put on the market or else (which, however, is very improbable) all trace of it has been lost. Having in mind the hasty departure of Eyrinis from this district later, it may be possible that the volume referred to was never published. A.D.)

"As this asphalt consists of a mineral, earthy and non-conductive material, which is softer and more sticky than pitch, is less porous and is more solid than the latter, as is shown by its specific weight, it resists all attacks from the air, cold and water so well that it cannot be saturated by the latter, and is therefore more useful than any other substance known for cementing or coating every kind of constructional work, since it protects the woodwork against rot, against insects, and, above all, against the destructive action of time, and this to such a degree that, when continuously exposed to water, air, and all kinds of weather, instead of being destroyed thereby, the building is, so to speak, rendered indestructible by the coating. From this it is easy to conclude that this is a natural cement and one which is serviceable for bonding together wood, stone, and other materials with which bridges, wells, ships, and all other structures which must resist water or damp, are to be built.

"The method of using the cement is very simple. The stone is taken just as it comes from the mine and heated a little so that it can be ground to a coarse powder. A little pitch is added to it so that it will fuse the more readily and also cause the entire mass to become thinner, and then the whole is heated over a moderate coal fire.

"The wood or stone upon which the cement is to be spread must have been previously well dried and also heated a little. When using the cement upon stone, the present custom has been to add one part of pitch to ten parts of the asphalt. For use with wood rather more pitch must be added. When, however, marine work is being put in hand, it will be necessary to supervise the workmen with the greatest care in order that their work shall be as may be best suited for the particular purpose, though it will suffice for the present to add that the asphalt in question becomes softer and more liquid the more it is heated. In carrying out the fusing of the asphalt, however, it is always necessary to add a little pitch. This fusing should be carried out in a copper cauldron containing the exact quantity of asphalt that may be required for the work then being put in hand.

"The pitch must be melted first, then the asphalt added little by little, the mixture being continuously stirred throughout with a stick or shovel, until both materials have become intimately mixed together. Resin makes it harder and causes it to withstand the heat of the sun better. Dutch pitch, obtained from the roots of trees, makes it tougher. The mixture must consist of one part of pitch (*i.e.*, common pitch) and eight or nine parts of asphalt according as to whether it is desired to make it more or less liquid—depending upon the nature of the work to be done—and before it is quite cool, this cement can be levelled or brought to a smooth surface by means of a hot iron, such as is used by builders for cement work. Above everything else, the workman must take care that the stone or other material to be coated shall be thoroughly cleaned before the cement is laid upon it, and then if any weakness is found afterwards in the work, it cannot be occasioned by the material used but only by the kind of use and the method adopted in the spreading of it."

It will be seen from this that during the two centuries that have passed since the above was first written practically the only variation made from the instructions furnished by the discoverer is that of making two operations out of the one. Instead of using the mastic immediately it is prepared, or rather, instead of preparing, it on the site of the work at which it is to be used, it is now customary to make and "cook" the mastic at the mines and then to send it away in blocks which are afterwards broken up and remelted as required. Certain ideas embodied in Eyrinis' remarks, however, time has proved to be wrong. The use of "common pitch," instead of pure bitumen as the flux, caused his work to disintegrate with age, as did also the use of the other admixtures he mentions.

The results which he obtained by the use of this material received official confirmation. In a certificate issued in 1716 at Neuchâtel it was attested that a large number of cisterns and basins made of both wood and stone were lined in a most excellent and durable manner with his asphalt mastic and were thoroughly waterproofed thereby. A balcony and a warehouse roof were also coated in a like manner, to the entire satisfaction of their owners.

From this we see that Eyrinis had rightly judged the principal methods of using asphalt, for which even at the present time it is almost exclusively used, that is, as an insulation against cold and damp, as a water retainer, and as a paving. As, however, with many other benefactors of mankind, it was not permitted to him to enjoy the fruit of his discovery himself. By this time, too, he must have interested several high placed and influential people in this material, for we find that M. de la Sablonnière, the appraiser to the Confederation, after having first endeavoured to come to some arrangement with the original discoverer, himself succeeded in obtaining property in France in which he carried out various types of asphalt work of which he must be acknowledged to be the originator, a title to which he did not himself omit to lay claim.

For some reason, which is not now known with an degree of certainty, but which is believed by many to be directly traceable to the failure of his work as the result of his use of common pitch in the making up of his mastic, as referred to above, we find that Eyrinis had to leave Switzerland, and about the year 1735 we next hear of him in the Rhone Valley, in Alsace, where he lived in the mill at Merkweiler, between Sulz unterm Wald and Pechelbronn, and where he discovered and opened out the important rock asphalt mine at Lobsann, which has been continuously worked ever since its inauguration by him, right up to the present time. After his departure from Val de Travers that mine ran to ruin, the work being in the end limited to the distillation of the rock in order to extract the bitumen contained in it, the medicinal value of which had also been made known to the public there by Eyrinis. However, at the beginning of the past century, both the discoverer and his discovery had entirely sunk into oblivion there.

An undertaking which in 1797 attempted the working of the then discovered veins at Seyssel under a concession granted by a government decree dated the 9th Fructidor V. had a no better result, and for a long time even here the principal use of the rock was merely to extract the bitumen with which it was impregnated. It was discovered here, however, that an excellent mastic could be prepared by the addition of five to ten per cent. of the bitumen so obtained to the powder formed by crushing the broken bituminous rock, but as the great mistake was made of promiscuously recommending the use of such an asphalt mastic, even for such purposes for which it could not possibly be employed with success, it could not result otherwise than to throw discredit upon the possibilities of the material, so that it rapidly fell into disuse again, and the undertaking came to nothing, as in Switzerland.

If Dr. Eyrinis must be regarded as the re-introducer of rock asphalt for building purposes to modern civilisation, no less a share of the honour must be given to Count Sassenay, who first caused the mines to be worked with success and in a practical manner. The unsatisfactory methods adopted at Val de Travers and at Seyssel played no small part in the closing down of these mines, and it was only the appearance of this gentleman upon the scene at this juncture that caused more suitable and less crude means of extracting the rock and manufacturing the mastic to be employed, for prior to his arrival, the entire process was not carried out on a really business basis at all, but rather on more or less experimental and elementary lines.

In the year 1802, just ninety years after the first discovery of rock asphalt by Eyrinis, Count Sassenay secured the concession and territory of the Seyssel mine and at once introduced more rational methods of working, which he had, as the result of carefully investigating the properties of the bituminous rock, found to be more suitable and to be greatly preferred to the ones previously adopted. To this end, and so that the peculiar mineral could be studied with particular care, he had a special laboratory erected at the mine in which he also trained his workmen in the practical carrying out of rock asphalt work of all classes. In this way he was successful in quickly bringing the material back into the esteem which it formerly enjoyed. Its use was rapidly adopted in France, where the open squares, market places, bridges and roads were coated with a layer of this mastic, whilst casemates and other military constructions were protected from damp in the same way. To such an extent did its use spread in that country that even at the present time France can perhaps show more rock asphalt work than can any other country.

To Count Sassenay, too, belongs the credit of correcting the mistake made by Eyrinis of using pitch in the preparation of the mastic and also of discovering that, where the mastic is to be subjected to much traffic, the material can be made more durable by the addition of a certain percentage of dry pea gravel to it.

The success of the Seyssel working naturally gave an impetus to that at Lobsann, which, on the death of Eyrinis, who, in common with so many other inventors, died without any effects, passed into the hands of de la Sablonnière, whom we have already mentioned as having worked with him at Val de Travers. As near here, at Pechelbronn, there was in existence a well of mineral oil of which Eyrinis must have been aware, since he identified the oil from it as being the same material as that which saturated the rock asphalt found in his mine, it is possible that he, too, may have modified his method of preparing his mastic by substituting it for the common pitch which he had previously used with such disastrous results in Switzerland. If this be so, then he can claim priority to Count Sassenay for this discovery, but as there is no real proof to be found that he actually did so, the credit must needs be given to the latter.

Respecting this mineral oil well, we find that, according to Engler, there is a report by Wimpheling as early as 1498 which bears upon it, wherein it is stated that it was then known as the "Pechelbronnens," *i.e.*, "pitch spring," owing to a jet black, thick mineral oil that issued from it and which even in the sixteenth century was, according to Daubrée, collected by the peasants in the neighbourhood for use as an illuminant in their lamps and as a lubricant for their cart wheels.

In the year 1768 we find this mine (Lobsann) in the possession of the le Bel family, who also acquired an adjacent deposit discovered about the same time at Sulz unterm Wald by a M. Rosentritt, who was the owner of some salt pits there. From this family it passed into the hands of a firm styled Dournay Frères, who made use of the success of the Seyssel product in pushing their own, following which, at the time when the Seyssel material was the one principally used, the mine was owned and worked by another French company, with a working capital of close upon £50,000. After the Franco-Prussian War of

1870—1871, Alsace passed into the possession of Germany and the ownership of the mines was then handed to Count von Oppensdorp, and finally it devolved upon the "Lobsann Asphaltgesellschaft m.b.H.," by whom it is at present being worked.

The mine at Val de Travers had meanwhile sunk completely into oblivion, and it remained for the indefatigable Count Sassenay to resuscitate the rock asphalt production there until it reached its greatest height. He obtained the concession for the extraction of the rock here also, and after having formed an important company in Paris to carry on the work, he was also successful in securing the remission of all duty upon the importation of the products of this mine into France. The result of this was that at that period all the deposits of rock asphalt then being worked were in the hands of French proprietors or capitalists, but although this created a brisk competition between the various mining companies, as the result of which the prices of rock asphalt mastic were being constantly reduced, the heavy freight and transport charges involved effectually prevented the use of this material in other than the most important towns. For some considerable time, therefore, we find that the employment of rock asphalt mastic for roadways was limited to Paris, Lyons, and a few other towns situated near the mines. This material was introduced from France into London for foot pavements in the year 1836.

It was much later in the past century before the German mines were first exploited. The occurrence of bitumen here had been known for some centuries previously, the allusion to the mineral oil well at the Tagernsee being traceable back as far as 1430, whilst the Hannoverian deposits were referred to by Agricola in 1546. The village of Limmer in Hannover was known even in 1730 as a spot where bitumen-impregnated limestone was to be found, the discovery being made, according to some writers, by Eyrinis himself during his travels after his departure from Switzerland and before he settled down at Lobsann. It was in 1843, however, before the vein here was worked with any success, first by Hennig, but to-day there are several important firms, both English and German, who are busily engaged in the extraction of the bituminous rock from this and the near-by Vorwohler deposits. As is the case with the Val de Travers, Lobsann and Seyssel materials, to which this rock shows a great similarity, both as regards chemical composition and formation, the crude rock is principally ground up and fused together with the addition of a certain amount of bitumen in order to form a mastic, though a large amount is also sold as the crude powder or as the prepared powder for compressed work.

The Italian industry is of still more modern growth, although here, too, the extensive deposits of rock asphalt had been known for some considerable time prior to their actual working. The first mine from which it was extracted industrially on the mainland is apparently that in Abruzzi, where in the year 1868 a company was floated with the title of "Asphaltene" to work the vein which is found at Letto Manopello, in the province of Chieti. This firm, however, merely extracted the light oils that were contained in the bitumen which impregnated the rock. The very costly plant which was installed for this purpose did not extract more than 13 per cent. of bitumen even from the best class of rock, and of this bitumen there was never obtained more than 20 per cent. of oil lighter than 0·875. Even this oil when obtained was so very impure that it could not be used either for illuminating purposes or as a lubricant, whilst the fumes and vapors that were given off during the extraction of the bitumen and the distillation of the oil proved so objectionable and tainted the air to such a degree, that the inhabitants of the village of Grottamare near by were successful in obtaining an order for the closing down of the works.

At Rocca Morice, the asphalt vein was worked at a later date by an English company under the name of "The Anglo-Italian Mineral Oils and Bitumen Company," but there again the same mistake was made as at Letto Manopello of working the mines merely for the oils to be extracted from the bitumen in the impregnated rock. An extensive extracting and distilling plant was erected near San Valentino in which steam was used as the heating medium. The crude rock was drawn from the mine some five miles away by means of a light railway specially laid for the purpose, and though the bitumen which was extracted from the rock was small in quantity, averaging only some 5 per cent., yet the amount of oil which was distilled over was much greater, being about 65 per cent. Of this oil the lighter half could be used as an illuminant and the remainder as a lubricating oil. The illuminating oil, however, proved to be of an extremely low grade and the lubricating oil contained so much bituminous resin in it that, even after both had undergone a very extensive purification, they were only able to obtain a very slight demand, and that only in Italy. The company therefore finally stopped operations in 1882, though now the vein is again extensively worked by another company, but for its legitimate purpose, that of the extraction of the rock asphalt from which to form rock asphalt powder and rock asphalt mastic in the same manner that is adopted in the other European rock asphalt mines.

In Filettino and Colle San Magno, in the province of Caserta, rock asphalt deposits are also worked, but the vein being high up the mountain side, the crude rock is carried down into the valley where the factory is situated by women and made there into rock asphalt powder and mastic, in which latter, according to Köhler, as often as not, cheap coal tar pitch is substituted for the natural bitumen. This material is used principally in Rome and Naples, to which cities it is despatched by rail, for roofing and terrace work. The high freight involved in its transit, however, prevents this particular type from obtaining more than local employment. This last remark equally applies to the material that is obtained from the fairly extensive deposits in the Lariano district of the province of Salerno which have been mined by a Naples firm since 1878.

The best known Italian rock is without doubt that which is obtained in the island of Sicily. It has been worked here at Ragusa by two firms constantly ever since 1884, at first the crude rock itself being exported; but now, as in all the other mines mentioned, the preparation of the rock asphalt powder and mastic is also carried on fairly extensively. The material, whether crude or prepared, is sent to Mazarelli for shipment, at which port ships belonging to certain of the Mediterranean lines call regularly for cargo. In Sicily, too, the softness of the rock is taken advantage of in the manufacture of fancy articles both for use and ornament. Prior to 1840, however, it was only used locally as a building stone, for which purpose it was found to be particularly suited by reason of it being naturally waterproof, permitting of easy ornamentation and carving, and although chocolate in colour when first erected, it soon bleaches with constant exposure into a pleasing cream tint. It was first exported for compressed rock asphalt work about 1856, and then by foreign firms, but now the quantity exported annually in its various forms reaches six figures. The stone itself closely approximates Seyssel rock asphalt in its properties, is perfectly free from pyrites, contains but little clay and is insoluble in hydrochloric acid.

Up to the middle of the past century, although rock asphalt in its mastic form was very extensively employed in laying pavements and footpaths and as a dampcourse or a water retainer, as the purpose demanded, yet owing to the bad results obtained on experimental stretches, it was rarely, if at all, used for road work which was subject to heavy traffic. An accidental discovery made almost simultaneously, though independently, in the Swiss and the French mines about this time altered this state of affairs. At the mines at Val de Travers, Seyssel and Lobsann, it was noticed that the surface of the floors of the rooms, yards, and roads in which the bituminous rock was handled or over which it was drawn, in the process of time attained such a firm, resilient and watertight condition that better could not be wished for on the most perfect road. Professor Dietrich claims the discovery for the Lobsann mine, but Meyn Aates, when writing of a visit which he paid to the Val de Travers mine in 1856 remarks that "the road between the mine and the factory had a peculiar appearance and possessed a thoroughly close, firm and elastic surface, along which the horses were able to draw their loads with ease, yet without perceptibly wearing away the road." He regarded this road with the greatest esteem, but does not appear to have recognised the cause of the peculiar surface that had drawn his attention, or the very extensive use that could be made of the idea by adopting this system, so successfully demonstrated by nature, to the roads of large towns. M. Léon Malo has it that this discovery was made by M. Merian at Val de Travers in 1849, some seven years earlier, but if this is the case, it seems very strange that the above mentioned writer is apparently not aware of the fact. There is no doubt, however, that in 1858, three sides of the Palais Royal in Paris were laid in this way and with Val de Travers material. This was laid on a bed of concrete some 6 ins. thick, and was compressed to a thickness of approximately 2 ins.

Some years before the discovery of this practical application of the property of rock asphalt powder for road making, a French engineer, M. de Coulaine, had already made various experiments upon his roads with the material as the result of his observations upon it. He had a short stretch near Saumur, between Rouen and Bordeaux, laid, by making up the road in exactly the same way as for an ordinary macadam surface, except that, instead of finishing it with the customary road metal, he used rock asphalt which had been, previous to use, broken up into small pieces and heated. This surface coat, he found, rapidly became firm, as the rock, being plastic when in a warm state, was pressed into the interstices between the granite chippings which formed the first layer, and gave a quite dissimilar resultant finish to the road than was the case when ordinary broken stone was rolled in, since it became quite even and elastic. Other tests which he made upon the arches of bridges gave equally satisfactory results, since a surface was thus formed which was absolutely impervious to rain, a property which had not been previously obtained even when the surface had been most carefully coated with hydraulic cement. In addition to this, the new paving had the advantage of having no smell, of being perfectly clean, and, as it proved, of having very great durability since the variations of the weather conditions did not affect it in any way. Later, however, a trouble arose which caused this new method of road making which had given so much promise, to be abandoned for the time being. It was discovered that in the summer the heat of the day permitted the granite chippings to have a certain amount of play, since the bituminous covering and binder, which the heat caused to become plastic and soft, was unable to withstand their movement. The result of this was that cracks began to appear in the surface layer through which the rain filtered in the wet weather and which in the dry season became filled up with all kinds of dirt and detritus, which thus prevented the re-amalgamation of the bituminous rock with the advent of later heat. The necessary opening was thus given for the commencement of deterioration and the ultimate breaking up of the road. No attempt seems to have been made by this engineer to overcome this difficulty, and his idea of thus utilising the crude rock asphalt for road making fell through.

The idea was again experimented with later by M. Merian, of Bâle, who, as engineer to the asphalt mine at Val de Travers, had noticed, as we have already mentioned, that the road between the mine and the mastic factory was altering appreciably for the better, despite the fact that nothing was being done to it. Instead of becoming very dusty in dry weather, or extremely muddy in wet weather, or breaking up into holes and ruts with continuous use, the surface had become a dense solid mass which retained its even surface in all weathers. Upon investigating this interesting change he found that whilst the springless carts were passing over the road, part of their load was scattered over its surface. This rock was naturally crushed by the other carts which followed, and the iron tyres of their wheels, acting in a similar manner to the rollers and the rammers used for the present day compressed rock asphalt work, bonded the powder thus formed into a close, durable, dustless and waterproof skin.

Acting upon this idea, he had the road between Travers and Pontarlier laid in a similar manner, by first reducing the rock to a powder by suitably heating it and then, after spreading this evenly over the surface, having it well rolled. Notwithstanding the fact that the foundations upon which this work was carried out were not prepared in any way, and were therefore not too suitable, an excellent road was formed which gave no sign of the weakness developed by the road previously put down by de Coulaine. When this road was examined by M. Léon Malo some twelve years later he declared that, despite its very irregular maintenance, it was even then still in an excellent condition.

To M. Merian, therefore, must be given the credit of creating the modern compressed rock asphalt powder roads—for, although his methods, as can only be expected, have been brought more up-to-date, they have not, however, been appreciably altered fundamentally—even though the crude idea first presented itself to de Coulaine.

In England the first roadway to be laid in this manner was Threadneedle Street, London, where, near Finch Lane, a stretch of the compressed Val de Travers rock asphalt powder was put down in May, 1869, which was followed in October of the next year with further similar work in Cheapside and the Poultry.

With the extensive adoption of this method upon a large scale in the more important cities on the Continent, other suitable rock asphalt powder was looked for by those interested in its use, with the result that the rock asphalt previously mined in other districts exclusively for the manufacture of the rock asphalt mastic, or for the oil to be extracted from the bitumen that it contained, was now also employed for the preparation of the powder with equally satisfactory results. It may with truth be said that the rise of the Italian rock asphalt industry can be traced directly to this discovery, as the coarseness of its grain and the uniformity of its impregnation single it out as being of special advantage for this purpose. The coarseness of its grain, which, as already mentioned, makes it unsuitable for work subject to much vibration, enables it to successfully withstand such traffic that would rapidly wear away the softer varieties, whilst the uniformity of its impregnation renders unnecessary either the addition of further bitumen, or the intermixture with a more or less richly impregnated bituminous rock as is requisite with the other types of rock asphalt.

In America the use of rock asphalt, both as mastic and in its powdered form, has greatly advanced, particularly with the discovery of further beds of the impregnated rock in that continent, though it has now a very formidable competitor there in the bituminous concrete or macadam. The rock is now mined there to a large degree in many of the states, including Utah, Texas, Kentucky, California, etc., though in a great number of instances the rock thus found impregnated with bitumen is a sandstone and not a limestone, as is usual in Europe. Practical experience in that country goes to prove, however, that the substitution of the one for the other—it should be borne in mind that the customary asphalt work in that continent is compressed—is in no way prejudicial to the life or wearing capacity of the road surface that is formed with it, whilst the methods adopted in both cases are practically the same, the sandstone of course, not lending itself to reduction to so fine a powder as the limestone.

As there are but few deposits in Europe which furnish bitumen in a state of purity, it was endeavoured for a long time, before the wholesale importation of the American types, to extract this material from the various rocks which are most richly impregnated with it and which will surrender their bitumen content the most readily.

The method carried on at Pechelbronn was also applied to the "*molasses*" at Seyssel, to the "*faluns*" at Bastennes and the "*arkoses*" of Auvergne, and is based upon the fact that though water is less dense than the impregnated rock, it is denser than the bitumen which impregnates the latter, so that this bitumen, when made to liquefy by the boiling water, rises to the surface. With the exception of the Pechelbronn type, however, the bitumens referred to are denser than water when at the ordinary temperature, and though this density diminishes more readily than that of water as the temperature is raised, and finally becomes less than it at 100° C., yet the difference is not sufficiently great to give the bitumen the power to rise to the surface quickly. Again, the bitumen, whose fusing point is not always below 100° C., does not sufficiently release itself from the impregnated rock, which seems to be able to retain it by a kind of capillary attraction. In the case of the Bastennes bitumen, the salts contained in the bituminous sands dissolve in the water and so both increase its density and raise its boiling point, thus assisting the extraction of the bitumen.

Although this method is practicable, it has the inconvenience of (*a*) heating the entire mass of the rock together with a certain quantity of water, and (*b*) the evaporation of the water which remains mixed with the bitumen that has been freed from the rock. This bitumen, too, always retains a certain proportion of the rock, no matter how often it is refined—the refined Selenitza, for instance, shows a mineral content of 10 per cent.—in which feature it is similar to the Trinidad bitumen.

The method of extraction as carried on in the Abruzzi and the Tyrol always allows the bitumen to reach its melting point, but the heating of the rock with an open fire always gives rise to the risk of decomposing portions of the bitumen by overheating. The bitumen thus obtained has invariably to be again refined in order to reduce the percentage of the rock that it still retains after the preliminary heating.

A further method has been suggested which it is stated has been carried out successfully with other industries, that of dissolving out the bitumen in carbon bisulphide and then evaporating off the latter, when the bitumen in its pure state will be left. In the present state of the market, however, the cost of such a method of treating the rock would be too expensive for practical purposes.

CHAPTER V

SOURCES OF ROCK ASPHALT AND BITUMEN

So as to afford an opportunity for comparison between the sources of supply of bituminous compounds and of bitumen in ancient and modern times, we give here a list of such places in which these substances are now found. It is interesting to note how widely dispersed throughout the entire globe these spots are.

The requirements of the ancient civilised nations were, so far as we can at present discover, supplied from but three sources :—

The Dead Sea and the small bituminous springs on its shores.

The fountains of Is (the modern Hit).

The alluvial plains of Babylonia.

Our modern necessities are filled with difficulty, if we are to judge by the prices ruling at the present day for this material, even though it is now obtainable from, or found in, all the following countries :—

Argentina	France	S. Africa
Austria	Germany	Spain
Barbadoes	Honduras	Switzerland
Burma	Hungary	Syria
Canada	Italy	Trinidad
China	Japan	Turkey
Colombia	Mexico	United States
Cuba	Persia	Venezuela
Egypt	Peru	
Equador	Russia	

A large number of these deposits consist of more or less bitumen itself as distinct from the rock impregnated with it, though in varying qualities and consistencies, and in certain parts it is not in sufficient quantity as to make its extraction profitable for other than local use. With the soft or viscous bitumens, as will be readily gathered from their fluid consistency, it is very unusual to find them pure, but rather they are detected saturating some bed of a mineral which from its softness has permitted of such impregnation.

Pure bitumen, as distinct from that which is mingled with foreign matter, is found in nature in the cavities of the various rocks which are difficult of impregnation, such as the "*ophites*" of the Landes, the "*peperites*" of Auvergne, the "*syenites*" of Cuba, etc. In this condition they sometimes form veins of more or less importance.

These veins, without being immediately connected with the sedimentary deposits of bitumen, are usually to be found in the same districts, though at the same time it must also be acknowledged that they do exist in localities in which no bituminous beds are known. Thus in the Pays Bas to the south of the two ranges of hills around Bentheim a vein of solid bitumen averaging from 20 to 30 ins. thick is found in the middle of an argillaceous schist. Of this bitumen we are informed that its specific weight is 1·07, that it is unaffected by caustic potash or alcohol, although ether dissolves out a small and turpentine a large amount, whilst carbon bisulphide only extracts rather less than a quarter of it. When heated this material distils, but without fusing any further than to a wax-like mass. This semi-infusibility, and its partial insolubility in carbon bisulphide, place it on the extremes of bitumen, but its complete insolubility in either alcohol or caustic potash prevents it from being included as a "*retina asphalt,*" whilst its fairly appreciable solubility in turpentine excludes it from the "*pyroschists.*"

The deposits of bitumen occasioned by sedimentary formation are to be found in all geological epochs. The same district, and sometimes even the same mining concession, often possesses beds of bitumen belonging to the formation of different earths. In the following pages only those are referred to and described in detail which are in use daily in commerce.

Bitumen occurs in a solid state and in its purest condition in the Old World, in the Dead Sea. This is, as is well known, a large inland lake in the south-east of Palestine, lying some 1,300 ft. below the level of the Mediterranean Sea. It lies deep down between precipitous and bare cliffs and has been aptly described as a huge grave. It is about forty-seven miles long, its average width is about six miles, whilst its surface is some 22,000 acres in extent. The lake receives a considerable amount of water from the river Jordan and other streams and springs, but despite such additions its level is gradually lowering, as the entire amount of water thus received is evaporated from it by the tropical heat that prevails there. The whole district is absolutely barren, without the least vestige of vegetation, and gives one the impression of being completely burnt up. All nature seems to be dead, from which arises the name of the "Dead Sea," though the lake itself, according to recent visitors in the district, "lies at the gazers' feet, blue and smiling like the Bay of Naples."

Its origin has given cause for dispute. According to van de Bilde, it is to be attributed to volcanic activity which opened out a huge subterranean cavity, causing at the same time the occurrence of the bitumen, sulphur and pumice stone deposits which have been found in that district, the opening thus created in the earth forming the bed of the lake. The Biblical description of the destruction of Sodom and Gomorrah, which would imply a volcanic eruption, is held out in confirmation of this view. The district was carefully inspected in 1866, however, by Fraas who, on the other hand, states that no trace of volcanic formation could be discovered. On the contrary, he affirms that he found that the earth in the neighbourhood of the lake was composed of pure chalk through which the water forming the lake had worn its way. Instead, therefore, of the Biblical narrative just mentioned confirming the volcanic theory, it is now alleged that the latter is based upon it.

The water of the lake is clear but extremely saline; its specific gravity is approximately 1·21, but this figure varies according to the season of the year and also to the part of the lake from which the sample is taken. In the year 1778 Lavoisier determined it at 1·2403, in 1807 Marcet placed it at 1·211, whilst some years ago Mitchell gave the figure as 1·203. Ordinary sea water, it may be added, has a specific gravity of 1·027. Bitumen flows into the lake from several hot springs adjacent to it, together with water, and solidifies there in lumps which, owing to their lighter specific gravity (1·104), float to the surface, from which they are collected by being scooped up in suitable vessels. The quantity thus obtained is very variable, becoming much greater after local earthquake shocks, whilst, as we have already seen, in the ancient times, according to the Bible, to Strabo and Diodorus, it must have been very considerable. After the earthquake there of 1834, a mass rose to the surface at the southern extremity of the lake from which the Arabs carried off some twenty tons, whilst in 1837, after one of the greatest shocks to which that district has been subject in modern times, a mass was seen floating upon the surface of the lake from which fifteen tons were taken and sold in the bazaar in Jerusalem at £40 per ton.

Of these periodic appearances of "*islands*" of bitumen on the lake in the olden times we have a fairly detailed account left us by Strabo, who describes them as follows :

> "The lake is full of bitumen which at irregular intervals is thrown up from the depths of the lake. The bubbles burst on the surface of the water, which latter thus appears to be boiling. The mass of bitumen protrudes out of the water and has the appearance of a hill. At the same time it gives off smoky vapors which rust copper and silver and which tarnish the lustre of all polished metals generally, even gold, although these vapors are invisible. The natives can tell when the bitumen is about to come to the surface, as then their metal utensils begin to rust. Noticing this, they at once make their preparations for collecting the bitumen by means of rafts made up of a collection of rushes."

This writer mentions, too, that it is the weight of the water of the Dead Sea which causes the bitumen to rise to the surface.

According to M. Terreil, this water contains an organic material which furnishes the characteristic odour of the bitumen that is found here, and which is particularly in evidence in the neighbourhood of Ras-Mersed at a point where the fœtid emanations referred to by Strabo as accompanying the appearance of the bitumen can still be noticed.

Without attempting to explain the occurrence of the bitumen in the Dead Sea, it may be accepted that hot springs existing at the bottom of the lake cause the bitumen there to separate from the rock that it originally impregnated, in a similar way to the methods adopted on a smaller scale in many of the factories engaged in extracting bitumen from the rocks or sands impregnated with it by boiling them with water.

The bitumen obtained at the Dead Sea possesses a characteristic odour, is black in colour and forms a black powder when crushed. It begins to fuse at 135° C.; it is partially soluble in alcohol and ether, more so in benzine, and completely and quickly so in chloroform, carbon bisulphide, oil of turpentine, and the petroleum distillates. It is insoluble in the alkalies, whether concentrated or dilute, hot or cold. With concentrated sulphuric acid it evolves, upon heating, sulphurous acid, and forms a dirty brown solution. It is not attacked by nitric acid even when it is heated.

Regarding the deposits in the district of Palestine, the following extract from a consular report issued by the Foreign Office is of interest; and it might here be remarked that the concession for the working of the Hasbeya deposit, at present exploited by the civil list of the Sultan, was offered for tender by the Turkish government as recently as the beginning of the past year.

"The principal occurrence is in Syria. The bitumen is found principally at Hasbeya, south-east of Mount Hermon, where during the last eighty years it has been obtained with more or less interruption. Originally the estate and the mines were owned by the well-known Moslem family of Shehab, who worked it only when they were in need of money and stopped again when the temporary financial embarrassments were cleared off. Under the Egyptian administration the mine was confiscated and so remained idle for a long time. About 1856 some merchants belonging to Damascus received from the Turkish government permission to extract from the mine as much of the bitumen as they wanted. This concession was temporarily renewed conditional to the payment of an annual allowance, until finally the authorities determined to lease the mine properly and so put it up for tender. In consideration of a payment of 65·5 per cent. of the annual output, Ibrahim Abssi became the lessee. This lease was held about six years, until the death of Abssi, and since then it has not been renewed, as no lessee is to be found up to the present who will accept such terms."

The deposit at Hasbeya was worked at a place called Bir el Hummar, but, the demand being very limited, its yearly output was only a few hundred tons. Here a score or so of pits, rather more than a yard in diameter, have been dug into the ground, which open up a very rich deposit having the appearance of a "*fault,*" the numerous openings in which have been filled up with bitumen. M. Lartet, when he inspected these workings after they had been abandoned, found near their mouths, amongst heaps of waste debris, some flint strongly impregnated with bitumen and coloured a beautiful black with it. In the rock, too, he found numerous traces of petrified remains of fish. Dr. Anderson, who visited this mine during the time that it was being worked, analysed the bituminous rock to be found there and found it to be largely (77·36 per cent.) of limestone impregnated with, on an average, 10 per cent. of bitumen. The bitumen as obtained at Hasbeya is only slightly soluble in alcohol, more so in ether, and almost entirely so in oil of turpentine. It softens in hot water and fuses at 121° C. It burns with a yellow flame, leaving a grey cinder, which even a blowpipe does not reduce to an ash.

Near the source of the Jordan, amongst white chalky marls, is also to be found a marl which possesses a bluish tinge, so faint, however, that it could be easily passed by without being noticed. On breaking off a fragment from the surface of the rock though, a brown fracture is perceived, which loses its colour with a long exposure to the sun. The Khaliwet deposit between Rascheya and

Hasbeya is of this type, whilst similar deposits are also to be found to the north-east in the vicinity of Damascus.

Near the hot saline springs of Hamman, near Tiberiad, Father Hebard found a deposit of bituminous limestone, whilst these waters themselves, according to Dr. Anderson, contain bromine associated with an organic compound.

At Nebi Mousa, near the north-west extremity of the Dead Sea, is again to be found limestone which is rich in fossilised remains of marine life, which shows a beautiful black fracture and gives off a strong aromatic smell, though it only shows its presence by large bluish spots to be seen in the white cliffs, which spots correspond to the more highly impregnated parts. By reason of its great combustibility, it is used by the Arabs in that neighbourhood as fuel, besides in its customary employment as a paving for courtyards. It is known to these people as "the stone of Moses," and is now also made use of by the Christians in Bethlehem for the manufacture of pious articles. According to the analysis made by Dr. Anderson, it contains 69 to 82 per cent. of limestone and 14 to 25 per cent. of bitumen, the remainder consisting principally of earthy matter. It is the richness of the impregnation of this stone that occasioned the suggestion of the idea that it might have been formed by an emulsion of a liquid bitumen, or a bitumen in a liquid state, with a strong solution of lime in water, and this, it may be mentioned in passing, is held by some authorities to be the true theory of the formation of the bitumen-impregnated limestone, the fact of the material falling to powder when the binding agent is softened under the influence of heat being held forward as one of the sustaining proofs. Against this, however, is the uncontrovertable fact that the impregnated stone mined at Acquafredda in the Abruzzi does not segregate with heat.

According to the Arabs, bitumen is to be found in the red sand cliffs on the east shore of the Dead Sea opposite Ain Jidy on the slopes of Belkan, but European travellers have not been able to verify this statement. M. Lartet has, however, in his researches near Kerak, discovered bitumen on the shore between Ouadi el Draa and Ouadi

Kerak. The limestone and the beds of flint here appear to have been penetrated by a bituminous material which has coloured them a deep black. He believes, too, that in the vicinity of the west coast near Masada, he has discovered the rocks mentioned by Strabo as distilling pitch. The bed at Ouadi Sebbi which is enclosed in the middle of a dolomite limestone, in fact, shows numerous pieces of bitumen which have penetrated the rock in a fluid condition and gradually solidified there in the numerous cavities in it, filling them with a hard, black and brilliant bitumen in such a way as to lead one to imagine that there is a true bitumen "*fault*" there.

About a day's march from Ouadi Sebbi, near the salt deposit of Djebel Usdom, are to be found lying on the shore "*conglomerates*" formed of pebbles and flint gravel cemented together with bitumen and deposited there by the waters of the Ouadi Mahaouat on their way down to the lake. On making one's way up the Ouadi, the quantity of these remains is seen to increase, and at 300 metres from the shore an important deposit of bitumen is reached which has been explored by different travellers. Here the bitumen exudes out of cracks in the limestone, falling at times in the exact form of stalactites, and at certain points it cements together the sand and gravel which compose the old alluvial soil deposited on these limestones, and thus gives birth to the bituminous conglomerates that have been seen washed down the stream by the Ouadi Mahaouat.

On the west shore of the Dead Sea, and on the banks of the Lisan, the Arabs gather pieces of a hard and brittle bitumen which they offer to travellers. It is stated that ligneous fibres have been recognised in samples thus obtained, thus showing that this particular bitumen had a vegetable origin. It is affirmed, too, that there are springs of a semi-fluid bitumen opposite the town of Nasarieh in the province of Busreh. They are not, however, exploited, the use of the material there being apparently limited to that of a cement for building purposes locally and as a substitute for sealing wax.

In general the Syrian bitumen is so pure and so free from extraneous matter, that it can be used for the finest classes of work, such as for the best types of black varnish and for photography.

Of the lesser known European deposits, passing mention may be made of those found in Albania, worked principally by the Société Anonyme des Mines de Selenitza. This material is very similar to that obtained from the bitumen "*lake*" in Trinidad in many respects, and though it has not the tenacity of and is more brittle than the latter, it has a higher melting point, and is much more pure, as the analysis given later shows. This bitumen is now largely employed in both well-known German, French, and Austrian rock asphalt factories as well as by many of the large firms of rock asphalt contractors. In a large amount of the rock asphalt work carried out upon the world-famed Parisian boulevards, this bitumen is stated to have been exclusively used. On the coast of Albania, near Durazzo, is to be found the Apollinia of the ancient Greeks, the high hill upon which the priestess of the renowned Delphic oracle was wont to sit and inhale the fumes of the gases which were—and still are—emitted from it, until she became stupefied, a condition supposed to be necessary for the pronouncing of those inspired prophecies which have rendered that shrine so famous.

In Spain the "Compañia General de Asfaltos y Portland," whose territory lies near Pobla de Lillet, at the extreme north of Catalonia at the foot of the Pyrenees, are working important mineral deposits which bear bitumen in conjunction with lignite and petroleum.

Bitumen is also found in Russia, particularly in conjunction with the petroleum oil fields, a matter which is looked upon as tending to confirm the hypothesis of the close relationship supposed to exist between the two materials. It has been stated that the peculiar "*wurtzilite*" is obtainable in the Ural district, but up to the present the writer has not been able to ascertain whether it is present in such quantities as to enable it to be placed upon the market. Later advices, however, would show that it is found in Semirietschensk in Asiatic Russia some twenty kilometres from the Balchasch Sea and twenty kilometres from the river Ili which flows into it. This material is like bitumen, of a brown colour, has a specific gravity of 0·9 to 1·25, is easily cut and is elastic like rubber.

In the Caucasus the ground is saturated with a bitumen that has been formed by the evaporation of naphtha. It is known locally as "*kir*" and is found in large tracts near Goriatchevodsk. True bitumen deposits, however, are to be found situated near Mikailovsk and the mineral waters of Sleptzow. "*Kir*" is soluble in ether leaving behind it an earthy matter, and is heavier than water. A very impure variety of this material, known as "*katran*," is also to be met with which finds a very extensive use locally as fuel.

On the banks of the Volga there is to be found a small region of deposits belonging to the carboniferous formation amongst Permian, Jurassic and Cretacean rocks, which, however, belong to the geological stage earlier than that of the carboniferous limestone. They stop to the north at a bend of the river Volga known as the "Tumulus of the Tzar." These deposits are found still further east in the banks of the Sisranka, the Krunza, and the Oussa. When a forage pit was dug near Batraki, no oil was met with either above or below this formation.

To the south-east, carboniferous limestone is found in a succession of layers of ordinary limestone and of this rock impregnated with bitumen, which last material is also met with in a pure state in globular form. These globules are of but secondary importance, although the bituminous limestone is worked and employed in the manufacture of rock asphalt mastic. Particularly rich beds are found near the town of Sisran, along the banks of the Sisranka and its tributaries, along the Oussa and along the Volga between Kostyachi and Petcherskoie. In these last instances the carboniferous limestone shows a number of outcrops in the precipitous banks of the river, thus rendering their working more easy. Near the village of Petcherskoie the limestone beds dip below the level of the Volga, and are replaced with beds of Permian formation which, however, are very poor in bitumen.

To the north of the Samarskaia-Louka, in a wooded district known as Bahilova-Askoulska, is found a deposit of maltha. This deposit occupies an area some 400 metres long by 100 metres wide, and at the centre it is some 10 metres deep. It is in a layer of sand belonging probably to an alluvial soil and which contains 20 per cent. of a semi-fluid bitumen. It is only covered over with a thin layer of vegetable soil, and is surrounded by unimpregnated sand. It lies about three kilometres away from the river Volga.

The rocks containing bitumen in this district have been worked since 1874. They are extracted from open workings by quarrymen and used for the manufacture of rock asphalt mastic in three factories, of which the most important is perhaps that at Sisran, where the rock is especially rich in bitumen, as the following analysis made at the Technological Institute at St. Petersburg shows.

Bitumen	30·50
Limestone	66·23
Magnesium Carbonate	3·27

In Europe generally the occurrence of bitumen is fairly extensive, but it is usually found impregnating some mineral or rock, and not in really true deposits of a more or less impure type.

In Austria Hungary it is to be found scattered amongst lignites and clay in the bituminous sand of Tataros, which contains approximately 15 per cent. of bitumen. It forms here a black, soft and sticky rock which gives off a penetrating odour, and commences to fuse even when held in the hand for a short time. In the Tyrol, about the Inn, veins of impregnated rock are found which are called by the inhabitants of that district "*stinkstein*" or "*gallenstein*" according to the comparative richness or poorness in bitumen.

A little above Innsbruck the river Inn forms the natural boundary between the eruptive rocks and the Jurassic limestone which forms the left bank. The asphalt beds of the Seefeld district (some 5,000 to 6,000 ft. above the level of the sea) belong to this last formation. Their thickness varies from 6 ins. to 4 ft., and they are sandwiched between dolomite. There are, however, some beds of "*gallenstein*" which are rich in iron and copper silicates and show, especially low down the deposit, small veins of anthracite. "*Stinkstein*" has the following composition:—

Bitumen	26·41
Calcium and Magnesium Carbonates ..	38·22
Clay	6·67
Sand	19·03
Iron Oxide	5·95

The analysis of the bitumen reveals the presence in it of nitrogen as well as sulphur. This bitumen has been extracted from both "*stinkstein*" and "*gallenstein*" on a commercial scale in both vertical and horizontal retorts, the first allowing the escape of the more volatile parts, That obtained from "*gallenstein*" is the lighter of the two, the densities being 0·946 to 0·977 and 0·954 to 1·080 respectively, according as to whether horizontal or vertical retorts are employed. This bitumen is used in the manufacture of rock asphalt mastic.

Following the course of the Inn, a siliceous limestone is found a little above Kufstein, at Hoering, on the right bank of the river, which is also called "*stinkstein*" and which is similar to the bituminous limestone which is obtained at Lobsann. At Gratenbergl, near Hoering, the Jurassic limestone encloses a large amount of viscous bitumen accompanied by numerous veins of crystalline limestone. In Dalmatia a deposit of bituminous limestone has been known in the island of Brazza, opposite Spalatro, since 1839. This, however, only shows an average bitumen content of 7 to 8 per cent. It is found in conjunction with a dolomite of the Jurassic earth, having the chemical composition of $3CaCO_3 . 2MgCO_3$. The bitumen is obtained from it by a kind of liquation as a black pitch-like mass with a lustrous fracture, fusing at 90° C., and is completely soluble in oil of turpentine.

At Morroviuzza, near Sebenico, a similar bitumen is found filling up the cavities in a Jurassic limestone. In 1843 a bed of rock asphalt consisting of dolomite impregnated with bitumen and identical with that at Brazza was discovered at Porto Mandolo, near Trau, also in Jurassic limestone.

CHAPTER VI

SOURCES OF ROCK ASPHALT AND BITUMEN (*continued*)

In Germany, of course, are the well-known deposits of Limmer, Vorwohle and Alsace (Lobsann), near which latter are also found springs of the more fluid maltha, of which mention has already been made of that at Pechelbronn.

The deposits of Limmer and Vorwohle, as well as those of Ahlem and Velber, are in the neighbourhood of Hannover. The two former belong to the white Jurassic formation, whilst the latter are found in earths of the Cretacean epoch, and are of but little value owing to their low percentage of bitumen.

The Limmer mines are in the plains of Acker, in a slightly undulating earth. The asphalt beds are not very thick and extend only very slightly beyond their outcrop. The upper portion, which is $3\frac{1}{2}$ metres thick, consists of a very pure rock rich in fossil shells, and lies upon a deposit of clay of a similar thickness. Below this clay is found the principal layer of rock asphalt, which is some 6 to 7 metres thick and much richer in bitumen. Near the outcrops these beds are very dislocated and form thin layers which show a very variable bitumen content. They slope at an angle of 30 to 40 degrees from north to south, and are worked in the open by cutting a trench some 5 or 6 metres deep, though in those parts which are more distant from the outcrop the work is carried on by means of shafts and galleries in the ordinary way. According to certain authors, this rock asphalt increases in richness as the work advances, and variations have been noticed of from 8 to 20 per cent.

The following is an analysis made at the mines of a typical sample :—

Bitumen	14·30
Limestone	67·00
Clay, etc.	17·52
Loss	1·18

The Vorwohle mines are in a more mountainous district. The deposit here forms a succession of beds having a total thickness of 20 metres but with varying impregnation. They slope at an angle of 20 degrees towards the Hils mountains, and their bitumen content varies between 6 and 10 per cent. The following analysis was made by one of the mining companies here :—

Bitumen	8·50
Limestone	80·59
Clay, etc.	4·03
Insoluble in acid	4·77
Loss	2·11

Not far from the Hils mountains it is stated that between Creiensen and Holzminden, and near Wintjenberg, in Brunswick, important deposits of rock asphalt have been discovered in the white Jurassic formations below the limestone. There have also been noticed masses of gypsum impregnated with bitumen in the intermediary Jurassic formations and chalk. Further deposits in Germany of lesser note are in Westphalia, at Darfield, Buldern, Hangenau (Coesfeld) and Oppelhülfen (Münster), whilst in Alsace are found liquid, viscous and solid bitumens under very varied geological conditions. They are occasionally met with in the transition soil of the Upper Rhine in the metallic veins,

In Low Alsace, at Rothbach, Westerweiler, Rauschendberg and Molsheim, the "*faults*" which form the limits of the "*shell*" limestone show bitumen in both liquid and solid states.

In the Sulz unterm Wald district, the bitumen is found for a length of ten to twelve kilometres, impregnating the sedimentary layers at Sulz unterm Wald, Pechelbronn, Hatten, Schwabweiler, Oberkützhausen, Kinderloch and near Prentschdorft as a liquid, and in a more solid form at Lampertsloch, Lobsann, Walkmühle, Bulenbach, Drachenbronn and Lochmühle. According to M. Daubrée, these last deposits, although in strata-like masses, also appear to be connected with the dislocations of that district. They are crossed by numerous "*faults*" which run parallel with the terminal "*fault*" of the Vosges sandstones, which, whilst they were formed at the Tertiary epoch by outflows of iron ores, etc., were again opened at a contemporaneous epoch by the outflow of basalt at Gundershoffen, eight kilometres away from Lobsann. The deposits of salt, whose existence in the Tertiary earths has been proved by M. Daubrée, and which now feed the numerous saline and bromine springs there, have in all probability been formed in a similar manner. It may be mentioned that it was the working of one of these salt deposits that led to the discovery in 1771 of a bituminous deposit here, whilst it is said that the first petroleum wells that were worked in the United States, were discovered under the same circumstances.

The bituminous sand at Pechelbronn forms veins amongst the unimpregnated sand, and has a thickness of 0·8 to 2·0 metres, though at times it reaches to as much as 4 metres, and a width which varies from 30 to 60 metres. The general direction of these veins is almost parallel with the general direction of the stratum of which they form part, and of the limiting "*fault*" of the Vosges sandstone. A large amount of iron pyrites is found in them, whilst they also contain thin beds of lignite. At Schwabweiler and Pechelbronn gases are evolved, which in 1845 occasioned the death of five miners, whilst later, in 1849, the emission was so great in the St. Joseph workings that it caused the entire stoppage of the operations there for some time.

The bituminous limestone at Lobsann is in three layers, of which the thickness varies from 1 to 2½ metres, divided from each other by a soft friable limestone which itself possesses a bituminous smell. In it are found pyrites, calcium sulphate and masses of grey and red sandstone. The following is the composition of the bituminous limestone :—

Bitumen	11·90
Limestone	69·00
Sand and Clay	4·30
Sulphur	5·00
Iron oxide	4·45
Water, etc.	3·40

The Pechelbronn bitumen is black and viscous, with a density varying between 0·90 and 0·97. It is extracted for use in mixing with the bituminous limestone at Lobsann, for the fluxing of Trinidad and other hard and brittle bitumens, and also in order to obtain illuminating and lubricating oils from it. Where it is brought to the surface by natural springs or as the result of boring operations, it is merely collected from the surface of the water upon which it floats, and when found in the bituminous sands, it is extracted by means of boiling the mineral with water, as has already been mentioned.

When the stills used in the distillation of the bituminous limestone are taken to pieces, there is often to be observed lining the interior of the pipe through which the oil is discharged, a very solid and hard deposit, steel grey or black in colour, having a sharp metallic ring. This incrustation consists of almost pure arsenic, mixed only with traces of carbon, and often reaches $\frac{3}{4}$-in. in thickness. The arsenic thus deposited forms a millionth part of the weight of the distilled rock, though some limestones give much less. According to M. Daubrée, all the arsenic contained in the limestone is not condensed in this way, but an appreciable quantity passes over with the oils that are extracted. It has not been determined absolutely in what state the arsenic is associated with the rock, though by dissolving out the bitumen and the limestone successively, 2 per cent. of a residue is obtained, which gives the reactions of arsenious iron pyrites.

In Switzerland the Val de Travers deposit stands pre-eminent, although in 1900 another large deposit was discovered near Credo, on the frontier, between the Seyssel and the Val de Travers deposits, which consists of beds of sand impregnated with a readily flowing maltha. Of the first named, the beds at St. Aubin, Vallorbes, Charvenay and Orbe are too poor in bitumen to be worked with any degree of success, though that obtained at Epoissats has been used for the manufacture of the rock asphalt mastic.

The bituminous limestones which are to be found between the villages of Travers and Couvet are of varying but very appreciable thickness. They belong to the superior Urgonian (Cretacean epoch) and rest upon a pebbly limestone which is broken and faintly impregnated. They are covered with "*crappe*," which is itself nothing more than an asphaltic bed, but being less impregnated with bitumen it is much harder. Towards the hamlet of Presta the bed crops out parallel with the Reuse for a length of 800 metres. To the south-west, towards Couvet, the bitumen content diminishes and the bed disappears below the level of the valley. To the north-east it slopes sharply towards Travers.

Above this formation is a black asphaltic sandstone, separated from the bed of Urgonian asphalt by the entire thickness of the beds of the inferior Aptien.

The rock extracted from the Urgonian bed looks very much like soot and gives off a bituminous odour. Its content of bitumen varies between 10 and 20 per cent. An average sample shows the following composition :—

Bitumen	10·10
Limestone and Magnesium Carbonate	88·25
Clay and Iron oxide	0·25
Water	0·50

This rock asphalt is slightly attacked by dilute hydrochloric acid. Alcohol extracts but very little of the bitumen, though ether dissolves out almost all, leaving behind a residue of limestone which shows scarcely any coloration.

The principal mine is about a kilometre away from Travers, and is worked by an English company, both for the extraction of the rock, which is sent away in its crude condition, and for the manufacture of the rock asphalt powder and mastic. Operations are carried on some 15 metres below the level of the Reuse, the water of which oozes in and has to be kept down by powerful pumps which have been installed for that purpose.

In France the mines at Ain and Haut-Savoie (Seyssel) are also well known, though for practical purposes, compressed work especially, it is usually necessary to mix the products of these mines, owing to their low percentage of bitumen, with the richer products of other mines, according to some experts; for although the type of the limestone is such that it does not require the same percentage of bitumen as do the softer rocks when used for any purpose, yet the percentage naturally present is not sufficient in itself.

The first working of rock asphalt here dates back from the end of the eighteenth century. Very precise details on the subject are given in a letter from M. Secretan, the then lessee of the mines, addressed to the Minister of Mines, which is to be found in the Journal des Mines (Vol. 14), from which the following extract is taken :—

"Du Parc, le 22 Prairial II.

"We continue to meet with kidneys of pyrites in our galleries, from the cracks of which, as soon as an opening is made, there sometimes exudes a very pure bitumen.

"We have noticed that the rock asphalt surrounding these kidneys is several metres thick, being usually much greater than elsewhere, and contains more bitumen.

"Despite our constant study of the mine, we have not yet been able to obtain any definite knowledge regarding its formation. The bed we are now working is sometimes three to four metres thick, when it will end abruptly. Sometimes it reduces to ten centimetres thick and at other places it ends by splitting into two beds, each being from ten to twenty-five centimetres thick, separated by a layer of blue clay between which and the lower bed of asphalt is often to be found a narrow bed of very hard pyrites some three to four centimetres thick."

M. Léon Malo, in his work, "L'Asphalt," p. 31, mentions the existence of certain portions of the Seyssel deposit in which the impregnation is incomplete, that is to say, where portions only of the bed of limestone are bituminous.

The deposits at du Parc, Surjoux and Pyrimont are now exhausted and the work is being carried on in the Volant deposit by means of shafts and galleries, the bottom beds being some 35 metres below the level of the Rhone.

The rock obtained from these deposits shows a fine homogeneous grain without the interposition of particles of white limestone. The appearance of a fracture, whether made parallel or vertical to the direction of the bed, is the same, but sometimes the rock is dotted with spots which are not so deeply coloured, that is to say, which are less impregnated with bitumen. In other places it encloses numbers of shells 1 to 3 mms. in diameter, which are filled up with crystalline limestone and impregnated with bitumen like the rest. Often large rhomboidal crystals with planes of cleavage of 1 to 2 mms. are found which are similarly impregnated.

Under the microscope this rock has the appearance of a powder cemented together, each grain of which is enveloped in a thin film of bitumen by means of which it is stuck to the neighbouring grains. Another still finer powder, made up of small crystals of limestone and coloured brown by the bitumen, fills up the voids between the larger grains. In short, this limestone has a semi-crystalline structure and therefore is not capable of receiving more than a low impregnation of bitumen. This is verified by the following analysis made by the École des Ponts et Chaussées :—

	(*a*)	(*b*)
Bitumen	2·25	8·00
Limestone	97·00	89·55
Clay and Iron oxide	0·15	0·15
Magnesium Carbonate	0·20	0·10
Loss on heating to 90°	0·20	1·90

According to M. Berthier, this bitumen is readily and entirely dissolved by both ether and turpentine. If the rock is crushed and then treated with hot hydrochloric acid, it cakes together and then forms into brownish black clots which rise to the surface and adhere to the sides of the vessel. It is, however, necessary to heat it constantly for a long time, in order that the acid shall dissolve all the limestone.

Besides the impregnated limestone, sandy rocks of the "*molasse*" formation are also found in this district. They consist of grains of milky quartz, from the size of a millet seed to larger than a lentil, stuck together with a soft intensely black bitumen. Similarly rounded grains of white compact limestone can also be recognised amongst the quartz.

Alcohol but slightly attacks this rock asphalt, merely receiving a faint yellow colouration, whilst the residue does not apparently change except, perhaps, by becoming rather less fusible. Ether dissolves the bituminous matter almost completely, whilst oil of turpentine acts most energetically and dissolves it entirely. When treated with boiling water, as at Pechelbronn, only 3 per cent. of bitumen can be extracted.

At the commencement of the Tertiary era, Limagne formed a vast fresh-water lake, but to-day it is covered with important deposits of granite, "*arkoses*" and sandy clays, limestones, "*peperites*" and basalt. Bitumen impregnates the "*arkoses*" at Chamalières, near Royat, and the limestones at Pont du Château, Lempdes, etc. It has been found as veins in the granite, and it is also to be met with amongst the "*peperites*" (basalt cinders cemented together with a limestone slime). To this last category belongs the deposit at Puy de la Poix, described in 1759 by Guellard in the journals of the Académie des Sciences, from which the following is taken :—

"Le Puy de la Poix is divided in two levels, the higher of which is twelve to fifteen feet thick and the other a little less, though it furnishes more bitumen than does the first and also in it is found a quantity of a liquid bitumen in two or three spots. This hill faces towards the north and is formed of a more or less soft stone of a bluish colour dotted with black pockets of bitumen. The rock around these pockets is white or yellowish. Some of the rock is black without any pockets ; other parts are only partially speckled and partly black ; there are pieces of a reddish brown colour with round pockets of a deep iron grey ; some pieces are incrusted with a hard and lustrous bitumen, others are coated instead with a yellowish material which is spathic and almost crystalline. Many are dotted with pyritous spots showing the yellow colour that is peculiar to pyrites. At the side of the hill is a small mound about three feet in height and with a diameter of fifteen feet. It appears that this is formed solely of bitumen which apparently has solidified on the ground as it has emerged from below. The spring must be in the middle of the elevation, for no other sign of it is to be found although the ground around and below it has been dug up."

As a matter of fact, bitumen still exudes from the rock in conjunction with water. It seems to be expelled by certain gases which form bubbles in the bitumen and which can be ignited if a lighted match is put to them.

Le Puy de Crouelle shows similar phenomena. At Malintrat, the oozing out of the bitumen has given rise to the formation of underground workings which consist principally of a method of draining this material from the rock impregnated with it, the bitumen obtained being employed commercially in the same way as the Syrian bitumen.

Ebelmen has examined specimens of a bitumen found in this district which is solid at ordinary temperatures, but softens in the hand and fuses completely at a fairly low temperature. The following is an extract from the report he made upon this material as the result of his investigations :—

"The fracture is conchoidal and of a beautiful black colour. It can be reduced to a coarse powder, but it is not possible to pulverise it completely, as the powder which is formed coheres spontaneously. The colour of the pulverulent mass is a dark brown. At 12° C. its density is 1·068 ; it is only partly soluble in ether but almost completely so in turpentine. When thrown upon a bright fire it burns with a crackling noise, at the same time throwing out sparks in all directions. If it is heated carefully in a tube to 110 to 120° C., it swells up greatly, giving off a considerable amount of water which retains (probably owing to the light oils which evaporate with it), though to a faint degree, the odour which is peculiar to this bitumen. The faculty of decrepitating with the action of strong heat, possessed by this bitumen, is attributed to the giving off by it of this water. When submitted to a temperature of 160° C. for two hours, 1·885 grammes gave off 0·382 grammes of water, *i.e.*, 20·26 per cent. This water appears to be intimately mixed with the bitumen, from which it only separates out when the material is at a low temperature and coarsely ground."

The proportion of water mentioned by Ebelmen is, without doubt, greatly exaggerated, as the bitumen contains a certain quantity of oils which are volatile at less than 160° C.

The rocks impregnated with this bitumen differ amongst themselves, both by their special characteristics, like the "*arkoses*" of Chamalières, the quartz sand of Lussat, the limestones of Pont du Château, and also by their mode of impregnation. Amongst these deposits, some distance away from their outcrop, there exist beds where the diffusion of the bitumen is quite complete, so that the rock when fractured shows an even chocolate colour. Their thickness, though at times small, rapidly increases and often reaches 6 metres. They are worked by the Société des Mines du Centre, who are the concessionaires of Pont du Chateau, Cortal (Champ des Pois), Colombier des Roys (Dallet), Lempdes (Puy de la Bouriere), Lussat, Malintrat and Chamalières. The analyses of samples of the rock taken from (*a*) Champ des Pois, (*b*) Colombier des Roys, (*c*) Chamalières and made by the École des Ponts et Chaussées, are as follows :—

	(*a*)	(*b*)	(*c*)
Loss on boiling	0·20	0·25	0·10
Bitumen	19·75	22·40	8·20
Insoluble in acid	1·30	2·17	77·50
Clay and Iron oxide	0·52	0·93	0·92
Limestone and Magnesia ..	34·32	31·89	0·54
Sulphur	0·04	0·08	0·17
Carbonic acid, water, combustible matter and loss ..	43·87	42·28	12·57

Samples (*a*) and (*b*) are very rich in bitumen, but the evenly impregnated beds that have been studied by M. Bartet, engineer of the Ponts et Chaussées, only show a content of 11·59 to 12·56 per cent. of bitumen. It is the rock that is obtained from these last beds which is used in the making up of the roads with this type of rock asphalt, though M. Bartet also recommends the employment of the richer rock for the work.

The following are the terms in which he expresses himself with regard to this question :—

"The richness in bitumen is not corrective, for we have noticed that there are limestone beds in the galleries which are almost unimpregnated and yet which only differ from the bituminous rock of which use is made in the proportion of bitumen found in them. If they were mixed with the richer parts, a powder could be formed, the average bitumen content of which would be less than that of the latter, but whose chemical composition would otherwise be similar in every way. Whilst on this subject, we would remark that we entirely agree with those engineers who, in the manufacture of rock asphalt powder, reject all idea of mixing limestones, and who consider that the blending together of rocks obtained from different districts is never sufficiently intimate as to give the resultant layer of rock asphalt a sufficiently homogeneous character. But if this opinion is perfectly true, it does not follow that the result of the mixture of portions obtained from the same mine or quarry cannot be accepted."

To the south-east of the town of Dax is found, in la Chalosse, amongst Tertiary earths, an important outcrop of "*ophites*" ranging from east to west. Around these "*ophites*" are the bituminous deposits of Brassenpouey, Gaujac, Bastennes and Caupenne. The first named bitumen is so fluid that it is usually looked upon as a petroleum. A hill of partly earthy "*ophite*" rises amongst reddish and gypseous marls, and upon it is built the Château de Gaujac. From this rock are seen to proceed from three orifices, some 5 to 10 cms. in diameter, streams of water on the surface of which floats a pure bitumen. Five kilometres away to the north-west is the bituminous deposit of Bastennes. The bitumen here is mixed with a large proportion of micaceous quartz sand, which at times is of such a hard nature as to defy being worked. This deposit, which is not now worked, has a thickness of 2 metres, and enclosed in its lower part are found broken shells, bivalves, and the teeth of fish. It rests upon an "*ophite*" earth surrounded by beds of compact cretaceous limestone and of marls of different colours. It is covered with an arenaceous deposit of a micaceous quartz sand more or less thick and which, in certain places, principally towards the bottom, is mixed with clay. This arenaceous deposit, which seems to have been formed by the destruction of the sandstone rocks of the cretaceous earth upon which it rests, has a thickness of 5 metres above the bituminous layer. It can readily be imagined that the bitumen proceeded from the "*ophite*" rock in a pure condition, as at Gaujac, and in doing so mixed with an oolitic "*molasse*," but during the time that these deposits were worked, no orifices were met with by which the bitumen could have found an exit from the "*ophite*" rock in the way suggested.

According to M. Berthier, the rock is compact, of a dull brownish black colour and homogeneous appearance, although in reality it is very gritty. Although solid, it cannot be pulverised. When digested with boiling water it gradually releases the bitumen it contains, which rises to the surface of the water by reason of the latter dissolving the iron and aluminium sulphates out of the rock and by this means increasing its density. The density of this bitumen at 12° C. is 1·131, and when heated to 130° C. for an hour it only loses 0·002 per cent. of its weight. When strongly heated in a closed vessel, the bitumen fuses into a compact mass, decomposes without swelling up, and gives off thick oils, leaving behind it a slightly lustrous residue. When subjected to an open flame it fuses, burns for a long time with a long flame accompanied with a large amount of smoke, and leaves behind a white or slightly purple sand which is composed of small grains of white quartz sand mixed with a little clay. Ether and oil of turpentine extract almost the whole of the bitumen from this rock, but cold alcohol has no effect upon it, and even when it is heated to boiling point it only dissolves out a small quantity.

In Italy the Tertiary earths of the Appenines are very rich in bituminous deposits. Near Rome and Naples there are quite a number of them which are of fairly great importance, such as those at Chieti, Pepoli, Lanciano, Venotro, Ponte Corvo, etc. They are usually to be found cropping out in those places where the water of some stream has washed away the soil. The bitumen found in them is sometimes liquid and at times solid. A sample obtained by Ebelmen from the neighbourhood of Naples was found to be a very brittle solid with a lustrous conchoidal fracture. Ether has but little effect upon it, though oil of turpentine dissolves it to a very great extent. Its density at 13° C. is 1·175; it begins to soften at 100° C., and is completely fused at about 140° C., without any emission of steam being noticeable.

The deposits on the eastern slope are worked to a much greater extent than on the western one, in particular on the spur of the Maiella, where, by the side of the petroleum deposits of Tocco, an asphaltic zone stretches for sixty square kilometres along the Valle Romana (Manopello) to the valley of San Spirito (Caramanico) including Serramonesca.

Two types of rock are to be distinguished, the one formed of fragments cemented together with bitumen, to be found between sulphur and limestone formations, and the other composed of these last mentioned limestones impregnated more or less richly and having a depth which, at the rivulet of Acquafredda, exceeds 50 metres.

In Sicily, important rock asphalt beds have been worked for a very long time in the province of Syracuse, some kilometres to the south of Ragusa in the direction of the port of Mazarelli, itself some twenty kilometres or so further away. They appear upon a plateau known locally as Rinazzo or "*Contrada a pece.*"

The rock asphalt which is obtained here possesses all the shades between a light yellow to a deep chocolate, in which numerous glittering specks are noticeable which are identical with similar grains found in the surrounding unimpregnated rock. This latter is a limestone composed almost entirely of the debris of shells, amongst which have been found several "*clypeaster altus*" and a large "*siliquaria.*" This rock, which belongs to the Tertiary epoch, is usually classed in the Miocene. The asphalt deposit at Rinazza is not more than twenty kilometres away from the outcrop of basalts and basaltic tufas at Militello, Franco Conte, Bucheri, etc., and although split up by numerous "*faults*," it is not connected with an intruding vein of bitumen at any point.

The inspection of the cliffs that have been broken down with picks near Leperino reveals the succession of beds of which this plateau is composed. The rock asphalt occupies two distinct levels, the lower one being 5 metres thick. The upper layer is separated from this by about 25 metres of limestone, and it has the advantage over the lower one of not being entirely covered in. It slopes slightly to the north, and has a thickness which varies from 5 to 20 metres, from which, however, 2 or 3 metres should be deducted for the intruding limestone bands. Beside these important formations, large masses of rock asphalt which are not connected with the main ones in any way are found in the middle of the same limestone near Ragusa. The amount of the Sicilian rock asphalt that was exported in 1911 was approximately 120,000 tons, the greater portion of which was shipped to Germany, Great Britain, and the United States.

The following analysis of this rock was made by the laboratory of the École des Ponts et Chaussées :—

Water, etc., volatile at 100° C. ..	4·95
Bitumen	11·20
Limestone	83·79
Sand	0·06

The rock asphalt here has also been worked in order to obtain large blocks, which are afterwards cut up and used as paving stones, chimney pieces, door and window frames, stair treads and balcony bases. Being susceptible of being sawn, bored or carved with mouldings and sculptures, a very important opening was assured for this rock in the neighbouring towns. The dark colour that this material shows when freshly quarried disappears after a fairly brief exposure to the influence of the atmosphere, giving place to a bluish grey, a property common to all rock asphalt when so exposed. At a certain depth, however, the rock asphalt is so loaded with bitumen that the latter exudes of itself from the pores of the stone. It is then too soft for building purposes and clogs the teeth of the saw when any attempt is made to cut it. If used as a paving stone, it "sweats," *i.e.*, the bitumen works to the surface, and so it has to be heated prior to use, in order that this excess of bitumen shall be extracted, the fuel used for this purpose being the richer rock. The chief aim now, however, in working this rock is to use it in the manufacture of rock asphalt powder for compressed work, for which it is particularly suitable, and of rock asphalt mastic. The great value of this rock for the manufacture of the rock asphalt powder lies in the fact that the majority of the rock is ready for use with no further treatment than the necessary grinding. The usual bitumen content is from 9 to 11 per cent. and appears to depend upon the consistency of the bitumen.

In Spain an immense deposit of bituminous rock is found at Maestu, some fifteen kilometres from Vittoria. This rock is a sandstone, slightly argillaceous and impregnated with 8 to 9 per cent. of bitumen. The analysis made by the laboratory of the École des Ponts et Chaussées of a sample of this material is as follows :—

Water, etc., volatile at 100° C. ..	0·40
Bitumen	8·80
Sand	68·75
Clay and Iron oxide..	4·35
Chalk and Magnesium carbonate ..	17·25

In Africa bitumen has been discovered in the province of Oran, in Algeria, whilst a deposit of solid bitumen has also been found in the desert in Egypt between the Nile and the Red Sea which only fuses between 225° and 240° C. Its ash contains about 12 per cent. of mineral matters, principally the oxides of iron, calcium and magnesium. Mention, too, has been made of late of a deposit of bitumen which is stated to have been discovered to the north of Rhodesia, in South Africa, but at present fuller details and particulars are not forthcoming, though a company is at present being floated to exploit certain petroleum oil-bearing properties in the Transvaal, in conjunction with which it is hoped to discover deposits of bitumen.

In the north of India, and in Persia, extensive beds of minerals impregnated with a very fluid maltha are to be found, as well as springs of the pure material itself. They are not worked to any great extent, however, the rock asphalt that is used in the first mentioned country at present being imported from Europe. It is also claimed that bitumen is to be found in China, but details of the type and of the exact locality in which the deposits are supposed to lie are not given.

From the foregoing it will be recognised that the Old World is fairly well supplied with this particular material in some form or other, so that there need be little fear that the ever extending use of it will result in a shortage of supplies, at all events for some centuries yet.

CHAPTER VII

AMERICAN DEPOSITS OF BITUMEN

THE most important deposits of bitumen are those found in America, and of these the oldest and best known is that situated in the island of Trinidad in the West Indies.

This bitumen is much less pure than that obtained from certain European sources, such as that taken naturally from the Dead Sea or extracted from the different bituminous beds or rocks, but the almost inexhaustible quantity of it has rendered its use world wide. Sir Walter Raleigh touched here during his many voyages in these waters and "tarred" the hulls of his ships with this material, whilst we find that two shiploads of the crude material were forwarded to England about the year 1830 by Admiral Cochrane, from which year its extensive commercial use dates. Even in 1799 Kirwan, in his "Geological Essays," informs his readers that "a whole lake of asphalt is said to exist in the island of Trinidad."

The island in question lies at the mouth of the river Orinoco. The "*lake*" itself occupies a bowl-shaped depression in a truncated cone, situated some thirty-six miles south of Port of Spain. It is now considered that the hollow thus filled is the old crater of some extinct mud volcano, of which we unfortunately have reason to know that there are some still in existence in that district which have not by any means ceased to be active. In fact, the nearest volcano of this description in the vicinity of the "*lake*" is only forty miles away at Point du Cac. The position of the "*lake*" in the highest point of the island, known as Vessigny Hill, some 140 ft. above the sea level, tends to confirm this view.

It had better be explained here that, contrary to the idea which seems to be prevalent in the minds of many people, this "*lake*" is not an expanse of water. The writer has found innumerable instances where persons, being acquainted with the Dead Sea as a supply of bitumen, have come to the conclusion that all the other so-called bitumen "*lakes*" are of a like description, that is to say, a large tract of water upon the surface of which masses of bitumen are to be found floating about ready for collection. Quite contrary to this belief, all the American "*lakes*" of bitumen are merely deposits of a more or less solid bitumen which have certain well defined borders comparable to the shores of an ordinary lake of water.

The west end of this particular "*lake*" of bitumen lies about half a mile from the nearest point on the sea coast, and, as just mentioned, the deposit possesses well defined limits or shores. In area it is approximately 99·3 acres (Encyclopædia Britannica, 11th edition), though it is gradually shrinking by reason of the enormous demand that is being made upon its contents. The rate of this shrinkage may be judged by the fact that eighteen years ago the area of the "*lake*" was 127 acres. At one side the rim of the crater has broken down, so that practically the whole of the ground between this fissure and the sea is covered with bitumen, which thus gives it the appearance of a large stretch of black rock. This is the so-called "*land*" bitumen, of which mention will be made later.

The surface of the bitumen "*lake*" is split up into numerous small islands of bitumen, varying from 60 to 150 ft. in diameter, which are separated from each other by channels of water several feet wide and of varying depth, formed by the accumulation of rain water, in which are to be found small fresh-water fish and frogs, though the water during the dry season becomes slightly alkaline and contains considerable quantities of metallic sulphides. The water is drawn off through outlets cut in the rim, but owing to the continuous motion of the bitumen, which the Encyclopædia Britannica affirms is the cause of the interior of these islands rising and flowing centrifugally towards the edges, the position, size and shape of these channels are ever changing.

Though under ordinary conditions heavier than water, the bitumen here is enabled to float upon the surface owing to the large volume of gases contained in it, which have been estimated as being one third of its entire bulk.

The "*lake*" itself has the appearance of a flat field of bitumen, and is some 6 to 9 ins. higher in the centre than at the sides. It has been likened to "a vast asphalt pavement with many holes filled with inky water in which swim ugly fish and black beetles." R. T. Hill states that "anything more black or repulsive can hardly be imagined." It is roughly circular in shape, as would be expected of the crater of a volcano, and is about half a mile in diameter. Near the sides it is covered with a thin layer of earth which supports a luxuriant growth of tropical vegetation, and some of the islands in the "*lake*" itself are also covered with undergrowth of a similar description. The rim of the crater now rises above the surface of the "*lake*" for 3 to 8 ft., though prior to 1886 it was not noticeable.

The surface of the bitumen, with the exception of the centre of the "*lake*," where it is always soft and in a state of constant ebullition, is sufficiently firm in the cooler parts of the day to permit of being walked upon, and it will even support the weight of mules and laden trucks. It is necessary, however, to be constantly moving, otherwise the bitumen begins to give with the weight upon it which, if at rest, would gradually sink into the "*lake*." During the heat of the day, the material is exposed to the direct rays of the tropical sun and commences to melt, when the surface becomes a thick semi-liquid mass. Owing to the large amount of water that is intimately mixed with it, the bitumen, even in this condition, is not sticky, so that although the "*islands*" of this substance, which are in perpetual though slow motion, often come in contact with each other, they never appear to combine together.

As the centre of the "*lake*" is approached, the temperature of the material becomes appreciably higher, so that from giving the firm footing which is obtained near the shore the mass becomes softer and softer until it finally alters into a viscous liquid, in which state it has a constant bubbling motion without, however, any jets of steam or other gaseous emissions being perceptible, although gas is always being evolved, sometimes in such quantities that it can be readily ignited with a lighted match. The strong pungent odour of sulphuretted hydrogen is ever present there, whilst it is stated that carbon dioxide, too, is evolved (Encyclopædia Britannica, 11th edition). This same authority asserts that this bitumen continues to evolve these gases for some time after the material has been removed from the "*lake*." It is the outward flow of this liquid portion, which gradually solidifies as it moves further away from the spring owing to the heat of the sun overhead evaporating from it the more volatile portions, that causes the centre of the "*lake*" to be raised slightly higher than the ordinary level of the bitumen.

The depth of the "*lake*" has never been properly ascertained, owing to the constant motion and liquid consistency of the bitumen at the centre, though at 100 ft. from the shore the bottom has been found to be about 90 ft. below the surface level of the bitumen. In the centre boring operations have been taken down to 135 ft. below the surface, but even at that depth the samples brought up showed no difference from the material to be obtained on the surface. There is reason to believe, however, that the depth at the centre of the "*lake*" is not more than 150 ft.

On the surface of the "*lake*" is a certain amount of decayed vegetable matter upon which grow the dense undergrowth and trees already mentioned, some of which latter reach a height of from 30 to 40 ft. As these decay, the dead fragments become mingled with the bitumen of the "*lake*" and so render the purification of this latter imperative, even before it is shipped. These vegetable islands, like those composed of bitumen, are ever in motion, some having moved a distance of 25 ft. within the year. These movements are controlled by the currents and eddies of the surface water, which are occasioned in their turn by the evolution of gases below and the constant flow of fresh supplies of bitumen from the centre.

When the light circular railway upon which the trucks used to convey the broken up material to the side of the "*lake*" are run was being constructed upon its surface—in the carrying out of which the rails had to be supported upon the surface of the bitumen by means of palm leaves—this motion of the bitumen created an ever-recurring source of difficulty, for stakes which had originally been driven into the material in a true line with each other would on the day following be found to be in the worst possible alignment, some of them moving as much as a foot per day.

As has already been mentioned, the steady extraction of the bitumen from the "*lake*" is causing a corresponding shrinkage of the surface area and a lowering of the surface level. Still, as the latter is only approximately 6 ins. per year, despite the fact that the annual output reaches to more than 100,000 tons, it will be recognised that there is little fear of any shortage of this valuable commodity occurring within the next century or so. The "*lake*" is leased by the government of the island until 1930 to an American company and yields a revenue of roughly £30,000 per year, the minimum royalty payable by the company to the government for the concession being £10,000 annually. During the past year (1912) the export of this material from Trinidad to Europe reached 138,773 tons, of which 31,118 tons only had been purified prior to shipment.

The approximate quantity of bitumen in the "*lake*" has been calculated in the following way. If it is taken that 80 cubic feet of bitumen weighs on an average 1 ton, then the sinking of the surface by 1 ft. represents the extraction of 1,450 tons per acre, or, for the entire surface area of the deposit, 203,000 tons. For certain reasons that cannot be gone into here, the greatest depth in the centre of the crater may be taken as being 150 ft., so that, taking this to be the depth of the deposit, and considering the deposit as being a spherical segment in shape, then the "*lake*" should contain about 150 million tons of bitumen. The "*land*" deposits, referred to later, cover an area of about 70 acres, with an average depth of 30 ft., and so contain approximately a further two million tons. The Encyclopædia Britannica, by another method of calculation, gives the total bitumen content of the "*lake*" as being only 3,618,000 tons, which figure it then immediately goes on to acknowledge cannot be correct, since, although in the thirty-five years prior to 1908 no less than 1,885,000 tons had been removed, or, in other words, more than half the alleged contents of the deposit, there is but little shrinkage in the bulk still untouched. It can only be presumed that the compiler of those figures was unaware even of the approximate depth of the deposit, especially so as he mentions the average depth as being 20 ft., a figure apparently taken from a very old report by Cumenge, and he even goes on to suggest that the Bermudez "*lake*" in Venezuela may have a greater depth than that of Trinidad, which, if it were the case, would mean that the former, being some nine times as large in area as the latter, would contain a supply that would survive ten centuries of constant extraction of the quantities that are now being taken from the latter.

The method adopted in order to obtain the bitumen from the "*lake*" is very simple. During the cooler hours of the day, usually before dawn, the rainy season naturally affording a longer period than the hotter months, the surface is fairly brittle, and whilst in this condition it can with ease be dug up and broken by means of picks or mattocks. The holes thus formed, which are usually a foot or so deep, are gradually closed up again by fresh material rising up from below and filling the cavity. The pieces thus broken up are loaded into trucks running on the light railway referred to above, which transfers them to the shores of the "*lake*."

Formerly they were conveyed to La Brea, the port of shipment, in carts and stored there pending the arrival of the small sailing ships in which the material was to be forwarded to its various destinations. If the ships were at the time lying at anchor off the shore—for at that time there was no convenience for the mooring of vessels at the port—the material had to be put into barges, from which it was transferred into the hold of the ocean-going vessel half a mile away. As business increased and some larger quantities of bitumen were being handled, it became necessary to have some more rapid and economical method of handling the material, so that now use is made of the higher altitude of the "*lake*" above the sea coast, and a system of overhead runways erected in 1894 conveys the pieces as obtained from the "*lake*" to the factories and warehouses on the coast, where the material is either stored in its crude state or else "purified" and then run into the very light barrels in which it is shipped. For this last operation of shipping, the handling of the material is also greatly facilitated by a similar system of runways, which extend from the warehouses along the specially constructed jetty down to the wharf at which the ships to be loaded can now be moored. The runways consist of a double line of steel rope supported at intervals by steel lattice work; down the one line comes the laden iron cradle from the "*lake*," the additional weight of which is sufficient to return a similar but empty cradle up to the "*lake*" again by the further rope.

The nominally purified bitumen obtained from the "*lake*" is known as "*Trinidad epure*," but this, to say the least, is a most unsatisfactory and misleading term, since it would imply a thorough purification of the material, which, however, is far from being the case. Instead, it might reasonably be concluded that the main idea in carrying out the "*purification*" of the crude Trinidad bitumen is merely to effect a saving in freight and storage by the extraction of a portion of the worthless and undesirable admixtures. A natural consequence of this is that where this bitumen is to be used in the manufacture of certain materials such as, for instance, bitumen sheetings, bituminous felts and the like, it is absolutely essential that it shall be submitted to a further refining process in order to extract the vegetable and the mineral matter that it still contains, otherwise the tanks in which the process of manufacture is carried on would be rapidly choked up with this dirt, from which it is not an easy matter to clean the container. The writer well remembers having his attention drawn by a certain manufacturer of bituminous products, to the extreme rapidity with which his tanks became filled with dirt and his rollers clogged up; as the reason for this was beyond him he was anxious to know of some means by which to obviate it. His astonishment can be imagined when it was demonstrated to him that his so-called "*purified*" Trinidad bitumen contained a very high percentage of extraneous matter which, by falling down to the bottom when the bitumen was fused, filled his tanks.

In general it may be taken that the crude material consists of one-third of bitumen, one-third of impurities (decayed wood, vegetable matter, sand, earth, etc.), and one-third of water. The "*purifying*" process as carried on in the island serves merely to extract the water and a small portion of the foreign matter, so that the "*epure*" Trinidad is really composed roughly of one-half of bitumen and one-half of impurities. The purifying is effected by a very crude type of liquation which may be described briefly as follows:—

The impure bitumen as it is obtained from the "*lake*" is thrown into large cauldrons in which it is heated continuously for twelve hours. By the end of this time the greater part of the water that was originally contained in it has been driven off, ebullition ceases and the molten mass then becomes at rest. With the absence of motion in the liquid, theoretically, the heavy impurities should settle out and sink to the bottom, whilst those of a less specific gravity than the bitumen should rise to the top. The vegetable matter, branches and the like, which float on the surface of the molten bitumen at this juncture, are ladled off, and then the bitumen itself, still in its liquid state, is drawn away from the heavy residue at the bottom of the cauldron and filled into barrels in which it is allowed to cool.

This theoretical purification is, however, very incomplete and most unsatisfactory, since it fails to fulfil the very purpose for which it is used. All the vegetable matter does not come to the surface, nor does all the earthy matter sink to the bottom. As a reference to the analysis of the Trinidad epure which is given later clearly shows, a large quantity of these matters is still retained by the bitumen; but what is more unfortunate than all is the fact that with the steam also evaporates out a quantity of those volatile oils until then mixed in with the solid mass and which have to be replaced later when the Trinidad bitumen is being used for any purpose, by the addition of liquid or semi-fluid fluxes. As "*steam distillation*" is often used in organic chemistry and different technical industries, in order to distil over other liquids which have a much higher boiling point than water when under normal conditions, it will be understood that in the present case a large amount of those bituminous oils which under ordinary circumstances are only volatile at a much higher temperature than 100° C. are lost. It may appear rather strange at first sight that a liquid boiling at a high temperature can be distilled at a much lower one merely by passing steam through it, but this phenomenon is explained by that law of physics which states that "the boiling point of mixed liquids which do not dissolve in one another is determined by their combined vapour pressures. If this is equal to atmospheric pressure, both liquids will distil." As illustrating this, reference may be made to the manufacture of aniline, where the finished product is distilled over in this manner although under ordinary conditions its boiling point is 182° C.

Another cause for regret in the "*purification*" of the crude bitumen is the fact that the Trinidad epure is usually found to be richer in free carbon, otherwise coke, than is the untreated material. This is held to be due to the operation being carried out in open vessels, which thus permit of the surface oxidation of the hot material, whilst further, owing to the fact that bitumen is a very bad conductor of heat, it is thus extremely difficult to heat a large solid mass of it evenly throughout, except with specially prepared plant. It follows, therefore, that in this "*purification*," where the material is subjected to a continuous heat for twelve hours, those portions which are nearest the sides and bottom of the cauldron must be sadly overheated, or, in plain words, charred, even before the centre of the mass has become melted.

It cannot be wondered at that so many firms, particularly American, prefer, as the figures already given of the output for 1911 clearly prove, to purchase the mineral in its crude state and to purify it for themselves. Although the refining as done by the private buyer is based upon the same idea as is that used on the Island of Trinidad, the method of carrying it out is slightly modified. Some of these refiners, it is true, still prefer to heat the material over an open fire and so chance the possibility of the molten bitumen catching fire, but the majority now carry on the work by means of superheated steam. This is done sometimes in a closed horizontal cylindrical boiler 10 to 15 ft. in diameter and 20 to 25 ft. in length, sometimes in an open bath-like vessel approximately 10 ft. wide, some 22 ft. long and 18 ft. deep. Both are built after the Cornwall type of boiler, that is to say, with two flues about 2 ft. in diameter running across the top half and which carry off the smoke and gases from the fire box below. By this means the heat is more evenly distributed throughout the entire mass, so that the possibility of any local overheating and the consequent charring is greatly diminished.

A simple yet apparently efficacious method of refining the Trinidad "*brut*" bitumen has been suggested as follows :—

The crude mass should be heated with hot air to a constant temperature, which must not, however, exceed 120° C. at any time, until all the water that is contained in it has been driven off. When this has been done, the temperature should be increased up to, but never more than, 150° C., in order to make the mass thoroughly liquid. After the bitumen has thus been freed from water and given a sufficiently thin consistency, it should be at once drawn off and passed over a sloping wire sieve of a very fine mesh. The pure bitumen will then pass through the meshes and can be conveyed by means of a suitable channel direct into the casks in which it is to be filled for export or store. The foreign matter, whether vegetable or mineral, will be trapped on the surface of the sieve, and can be occasionally raked to the sides in order to keep the meshes open. Although the bitumen thus obtained should, theoretically, be perfectly free from impurities, yet such is the intimate nature of the mixture of the mineral matter and the bitumen, whilst at the same time the former is in such a fine state of division, that it is a physical impossibility to obtain a perfectly pure Trinidad bitumen unless it is separated from its impurities by means of solvents. This intimate mixture of the mineral impurities, and their extremely finely divided condition, which it will be recollected is found also in the bitumen extracted from the European bituminous rocks, is considered by Professor Richardson as being of great advantage when the material is being made use of in the preparation of bituminous macadam for road making.

As has been already stated, bitumen is also obtained in the island of Trinidad from the land itself as well as from the "*lake*," for the entire ground of which the island is composed seems to be more or less impregnated with this substance. The "*land*" bitumen, as it is still usually called for the sake of convenience, and in order to keep it distinct from the "*lake*" variety, is usually, however, less pure than this latter by reason of the additional earthy impurities that have become mingled with it, though in some cases it is stated that it is found in an even purer condition, especially if it is extracted from the lower part of the deposit. Queries have occasionally arisen as to whether the two types of Trinidad bitumen are identical, but the well-known United States expert, Professor Peckham, who visited the island in person and inspected, investigated, and analysed both the materials and their respective sources, as the result of disputes in that country respecting the superiority of the one over the other, very aptly uses the expression "a distinction without a difference" as applying to the two terms used. This decision was upheld in the English courts of law some three years ago, when a case was brought up for consideration in which the plaintiffs, as the British agents for the concessionaires of the material extracted from the "*lake*" deposit, endeavoured, though unsuccessfully, to obtain an injunction to restrain the defendants, who are extensive users of the "*land*" bitumen in their various bituminous products, from describing these last materials as being manufactured from "*Trinidad asphalt.*"

According to Professor Peckham, the land deposits have been formed by the leakage of the bitumen from the "*lake*" through the fissure at its side, and this leakage, which has been going on for an indefinite period, has not even yet ceased, despite the enormous amount of material that is annually extracted from the "*lake*" at its surface. The leak is located in the broken side of the crater in the La Brea property, and the outflow from it, even so far back as 1832, was described by a visitor to the island as being then immense. The grounds through which the bitumen deposits are distributed are known as the "*pitch lands*" and lie to the north of the "*lake*," the best known being the narrow stretch which presents the appearance of a glacier and runs towards the promontory of Pointe la Brea in a north-easterly direction. The length of this deposit is about a mile, and its average breadth rather more than 150 yards. This river-like mass has been dug through in various places, where the depth of the bitumen averaged from 15 to 18 ft., though at one spot excavations were made 50 ft. below the surface before the bottom was exposed. Whilst engaged in making these borings, it was also found that the deposits rest upon a layer of clay from 3 to 15 ft. thick, which was also more or less impregnated with bitumen, whilst at a depth of 80 ft. signs of peat were discovered.

The entire district between Pointe d'Or Lagune, in the east, to Pointe Rouge, in the west, contains deposits of bitumen of larger or smaller extent, which, however, are distinct from the "*lake*" material by reason of the higher content of earthy matter which they usually possess. Similar layers are to be found in the Brighton district, whilst in the neighbourhood of Pointe Rouge there has been opened up a small spring of bituminous oil, and although the output of this is too small to be of much commercial value, its occurrence is of interest, since, when it is exposed to the air and the sun, the oil thickens and gradually forms a material very similar to the "*lake*" bitumen. This is taken to prove that all the Trinidad bitumens have their origin in one common source, a fluid maltha, their condition being merely dependent upon the amount of exposure they have undergone.

Although the "*land*" bitumen is practically identical with the "*lake*" type, it is, however, obtainable in three well defined formations, "*cheese*," "*slate*" and "*stone*" or "*iron*," according to the depth from which it is taken out of the deposit. Of these the one which is most largely used is the "*stone*" variety. The first is softer than the "*lake*" bitumen which it closely resembles, except for being slightly darker in colour. It forms the lowest part of the deposit, the evaporation of the oils contained in it having been prevented by the protection from the sun afforded it by the harder material which lies above it. The second type is practically the same, but it has the peculiar property, owing, it is said, to the air enclosed in it, of having a laminar, slaty structure, hence its name. "*Stone*" bitumen is formed from the first named, but having been subjected to the intense heat of the sun, owing to it forming the surface of the deposit, it has become extremely hard and brittle, so that it only fuses at a high temperature, hence its alternative title of "*iron*" bitumen. "Manjak" as it is often, though inaccurately, called, is capable of taking a very high polish when purified—a new fracture shows a beautifully clear jet black gloss—and for this reason it is very widely used in the manufacture of black varnishes and japans where this is a desideratum. Its high melting point is made use of when it is exported, for instead of the wooden barrels required for the Trinidad epure, it is merely packed in bags containing approximately 2 cwt. each, thus affording a slight saving in both the cost of the package and in the freight. In the year 1910—11 the production of this material, which is apparently in the hands of two firms, represented a value of £3,979.

An analysis of this material made by Professor Richardson, shows an average content of 94·2 per cent of bitumen soluble in carbon bisulphide, and 5·8 per cent. of inorganic or mineral matter. It intumesces rather than fuses. The composition of the purified and of the crude Trinidad bitumens according to Cumenge is as follows :—

	Sample taken from	Free Carbon.	Bitumen.	Ash.
Crude	Trinidad " lake " (ordinary) ..	3·00	50·00	47·00
	" " (centre) ..	5·00	62·00	33·00
	" " land " ..	18·00	28·00	54·00
Epure	Trinidad " lake " (ordinary) ..	5·00	58·00	37·00
	" " (centre) ..	8·36	55·36	36·34
	" " land" ..	11·05	51·46	37·47

It should be noted that all the water had been extracted from the samples prior to the above analysis being put in hand.

A deposit of maltha in the island is now being worked by the concessionaires of the "*lake*," the residue from the distillation of which, being highly asphaltic, they have recently placed upon the British market for fluxing and road-making purposes under the name of liquid Trinidad asphalt. It is stated by them that the results obtained by the use of this material in the United States are highly satisfactory.

CHAPTER VIII

AMERICAN DEPOSITS OF BITUMEN (*continued*).

THE claim once made that the Trinidad "*lake*" was the only one of its kind in existence has been disproved by the discovery of a similar huge deposit of bitumen in Venezuela, in the state of Bermudez. In fact, in this country two distinct deposits of this material have been found and are now being worked for export, one of which is a "*lake*" of a much larger area than its older and better known rival in Trinidad, although it cannot boast of a similar depth. It is stated that this Bermudez deposit covers an area of about 1,000 acres, but in many places the depth is only some 2 ft. or so. The material that is obtained from it, too, varies greatly in consistency according to the particular spot from which it is taken, and ranges from the viscous maltha to the solid bitumen, which latter, however, is much more pure, even in its crude state, than that obtained in Trinidad. Like the bitumen from the latter the material taken from the Bermudez deposit, or "*lake*" as it is now known, although softer, is broken up with a pick or spade and then subjected to a refining process before being shipped abroad, this refining process being practically identical with the one carried on in Trinidad. An average analysis of the crude bitumen as obtained from this Bermudez deposit has been given as follows :—

Bitumen	66	per cent.
Water..	31	,,
Mineral matter	1	,,
Organic, non-bituminous matter ..	2	,,

The following comparison of refined Trinidad and Bermudez bitumens is taken from the Encyclopædia Britannica (11th edition).

—	Trinidad.	Bermudez.
Specific gravity	1·373	1·071
Bitumen soluble in carbon bisulphide ..	61·507	92·22
Mineral matter (ash)	34·51	1·50
Non-bituminous organic matter	3·983	1·28
Loss on heating to 212°F.	0·65	1·37
„ „ „ „ 400°F. for 10 hours ..	7·98	17·80
„ of total bitumen after last	12·811	18·308
Evolves sulphuretted hydrogen at ..	410°F.	none at 437°F.
Softening point	160°F.	113°F.
Melting point	192°F.	150°F.

It must, however, be acknowledged that Bermudez bitumen varies very much in composition, the water content ranging usually between 10 and 40 per cent.—crude Trinidad bitumen from the "*lake*" has a constant water content of 28 per cent.—whilst the non-bituminous organic matter varies from 1 to 6 per cent. A large proportion of this bitumen consists of the "*petrolene*" of which more will be said later; for the present it will suffice merely to state here that the "*petrolenes*" consitute the volatile portion of a bitumen, so that the greater the content of this, the more readily will the bitumen dry out and become brittle with exposure to temperatures at which this portion evaporates. For this reason it has been stated by Professor Richardson that this material is not suitable for asphalt paving purposes, though practical experience does not appear to bear out this statement. The "*lake*" is being worked by the same American company that owns the concession of the Trinidad "*lake*," and the material that has been extracted from it has only been recently placed upon the market here in England although it has been in use in the United States for some time.

This deposit lies near the river Guanaco, west of the town of Guariquen, some twenty miles away from the Parian Gulf as the crow flies. Professor Richardson has described it as follows:—

"The so-called 'lake' is situated between the edge of the swamp and the foot hills in what might be termed a savanna.

It is an irregular shaped surface with a width of about a mile and a half from north to south and about a mile east to west. Its area is a little more than 900 acres, and it is covered with vegetation, high rank grass and shrubs, one to eight feet high, with groves of large moriche palms called morichales. One sees no dark expanse of pitch on approaching it as at the Trinidad pitch lake, and except at certain points, where the soft pitch is welling up, nothing of the kind can be found. The level of the surface of the deposit does not vary more than two feet and is largely the same as that of the surrounding swamps. In the rainy season it is mostly flooded, and at all times very wet, so that any excavation will fill up with water. These conditions make it very difficult to get about upon it or to excavate the pitch easily.

"It is readily seen that this deposit is a very different one from that in the pitch lake of Trinidad. It seems to be, in fact, merely an overflow of soft pitch from several springs over this large expanse of savanna and one which has not the depth or uniformity of that at Trinidad.

"Being on a level with the mangrove swamps and with the foot hills on its other side, any large amount of asphalt could hardly be held in position here, as in the old crater in Trinidad, but would burst out into the swamp and be lost and, as far as borings have been made, they seem to indicate but a small depth anywhere as compared with that of the Trinidad lake.

"At different points there is at most a depth of seven feet of material, while the deepest part of the soft maltha is only nine feet and the average of pitch below the soil and coke only four feet. At points there is not more than two feet of pitch, and in the morichale, or palm groves, it is often five feet below the surface. At several points scattered over the surface are areas of soft pitch, or pitch that is just exuding from springs. The largest area is about seven acres in extent and of irregular shape. This has little or no vegetation upon it, and, from the constant evolution of fresh pitch, is raised several feet above the level of the rest of the deposit. This soft asphalt has become hardened at the edges, but when exposed to the sun is too soft to walk upon. The material is of a nature of a maltha and it is evidently the source of all the asphalt in the lake, from these exudations the pitch having spread in every direction, so that no great depth of pitch is found even at this point.

"A careful examination of the surroundings shows that in one respect there is a resemblance between the point of evolution of the soft pitch at the Bermudez and at the Trinidad lakes. Gas is given off in considerable quantities at both places, and in both cases consists partly at least, of hydrogen sulphide. At the Bermudez lake I was unable to determine whether it was accompanied by carbonic dioxide, but the odor of hydrogen sulphide was strong.

"The consistency of the soft pitch at the centre of the Bermudez lake is much thinner than that of the Trinidad lake. It will run like a heavy tar and does not evolve gas in the same rapid way or harden so quickly after collection. It therefore does not retain the gas which is generated in it, nor does the deposit as a whole do so to the same extent as the Trinidad pitch. Where, however, the surface of the soft pitch has toughened by exposure to the sun and air, and where gas is given off beneath it, it is often raised in dome-like protuberances, the beehives which were spoken of by early visitors to the Trinidad lake. These have a thin wall of pitch and are filled with gas which readily burns, and have been seen two feet or more in height and eighteen inches in diameter. They are, of course, found only near the soft spots.

"There is no evidence of the simultaneous boiling up of water with the fresh soft pitch that has been determined at the Trinidad lake, but that there is none at all is not certain, as at the time I visited the locality heavy rains were falling which prevented the detection of a small amount. It seems, however, improbable, as the soft pitch contains little or no water and the traces found in the samples collected are probably derived from rain.

"The edges of the areas of the soft asphalt are covered here and there with masses of glance pitch and with black and brittle cinders or coke, and which seem to have been produced from the maltha by fire. This is evidently the case, since the rank growth of the grass, which is very dry in the dry season, is particularly adapted for a rapid and intense combustion. Such fires have been even recently started intentionally and accidentally, and to them are due the condition of the present surface of the deposit and the character of much of the pitch.

"The general surface of the lake is very irregular and hard. There are many very narrow and irregular channels or depressions, from a few inches to four feet deep, filled with water, and, not being easily distinguished, one often falls into them. At the foot of the growth of grass and shrubs are ridges of pitch mingled with soil and decayed vegetation, which have been plainly coked and hardened by fires of the nature which have been mentioned. When this hardened material which forms only a crust is removed, asphalt of a kind suitable for paving is found. The crust is from one and a half to two feet in depth and very firm, while the asphalt underneath would not begin to sustain the weight which that of the Trinidad pitch lake does easily. There are breaks in the crust here and there through which soft pitch exudes as has been described."

The second deposit of bitumen in Venezuela is on the coast of the Gulf of Maracaibo, about fifty miles west of the town of Maracaibo. The deposits here cover an area of some 97 acres and are worked by the United States and Venezuela Company, the principal deposit being that of Inciarte. Here the crude material is collected, and after being roughly purified it is sent down the river Limon to Toas, from which port it is then shipped to the United States. As far back as 1902 we find that the output from this deposit for the half-year reached a total of close on 3,500 tons.

The analysis of the bitumen obtained from this particular deposit has been given thus :—

	Crude.	Refined.
Bitumen	94·13	99·07
Woody fibre	4·85	0·25
Ash	1·02	0·68

Besides these a liquid bitumen is found in the territory bordering the mouths of the Orinoco, being thus very handy for shipment, which material contains about 40 per cent. of oil. This is obtained from the stratum which is found saturated with it, from 13 to 27 yards below the surface of the ground. Borings have shown this stratum to possess a thickness of nearly 50 ft. This deposit was first worked by a German company in 1891.

Another bitumen "*lake*," but one of more moderate dimensions, is to be found in Peru, near Coxitambo, and has been worked since 1860. Other deposits there are located in the Condorocana mountain—which was known as early as 1763—at Sacmarea, Pastos de Mito and Clumpi. The material from these sources is not, however, shipped to Europe in any great quantity.

After the Bermudez material perhaps the most dangerous rival of the Trinidad bitumen is that which is obtained from the island of Cuba. Here numerous deposits of this material are to be found, some of which have been mistaken frequently for coal, a mineral which does not exist on this island, but it is principally in the neighbourhood of Havana, where they present a thickness of 18 ft., that they have been worked to any great extent. The other more important deposits are near the harbour of Cardenas (70 ft. thick), at Canas Tomasita (105 ft. thick), whilst a particularly pure variety is found at Vuelta. The purity of this Cuban material is remarkable; on an average it shows a bitumen content of 73 to 93 per cent. An analysis of the crude material gives the following figures:—

Bitumen	73·05
Water	1·25
Mineral Matter	25·69

Dumas, in describing this bitumen, to which he refers under the title of "Mexican bitumen" or "*chapapote*," says that its density is but little different from that of water, its smell, although strong, is not disagreeable, whilst it is absolutely unaltered by acids or alkalies. Alcohol has but little effect upon it, though ether and oil of turpentine dissolve out part of it. It has a very high softening point, and, as might be expected, the percentage of the "*asphaltenes*" is much greater than that found in the Trinidad or Bermudez types.

The material itself is obtained here in a slightly different way from that which rules in the island of Trinidad. Instead of being extracted from the surface of the ground, as with the material taken from the latter, shafts and galleries are driven into the deposit as if it were an ordinary mine. Here, too, are found considerable quantities of maltha, thus enabling the raw material, after having been subjected to a refining process, to be fluxed to a suitable consistency upon the spot, a very necessary procedure, owing to the lack of the "*petrolenes*," or "*malthenes*," as Professor Richardson prefers to term them. The principal places where these liquid or semi-fluid bitumens are found and worked in this island are perhaps Sabanilla, east of Cardenas, and Minas, some twenty miles from the town of Camaquey.

This local fluxing of the Cuban bitumen gives it a distinct advantage over the Trinidad type, as in the fluxing of the latter, such as when required for rock asphalt work, etc., foreign asphalt oils are usually used, the exact kind varying with different firms. Very often Scotch "*shale grease*" is employed for this purpose in the United Kingdom—a similar product obtained at Autun being used in France for a like purpose—though American malthas and Continental "*bergteers*," or "*goudrons minérals*," are also not infrequently preferred. The controversy as to what forms the most suitable flux has led to the employment of many varied types of oils and greases with more or less successful results, whilst petroleum residues, by reason of their comparative cheapness, are often substituted for the more expensive though naturally produced maltha. This undesirable feature in Trinidad bitumen is eliminated from the material shipped from Cuba, by the fluxing process being carried out before despatch, with the result that, further mixing being thus rendered unnecessary, the reputation of the bitumen cannot be prejudiced or made to suffer thereby, unless, of course, a deleterious adulterant is wilfully added.

The bitumen to be obtained in this island has been worked spasmodically for some decades, but the political restlessness of the people and the incorrect ideas of its possibilities have prevented its proper development until recent years. One of the largest deposits here, the writer has been given to understand by one of the principals of the firm in question, has recently been taken over by a well-known firm manufacturing bituminous materials in the United Kingdom, so that no doubt a great impetus will be given to the adoption of the Cuban material in this country on that account.

A monster block from one of the deposits here, the Angelo Elmira mine, situated some five miles away from Bejucal, at that time in the possession of the West Indies Company, was on exhibition at the World's Fair at Chicago in 1893, and turned the scale at over a thousand pounds.

The presence of bitumen here has been known for centuries, in fact from the time of the conquest of the island by Spain, for in Oviedo's "History of the Antilles," published in the early part of the sixteenth century, express mention is made of a spring of "*pitch*" near the coast in Puerto Principe and of the occurrence of "*pitch*" upon the shores of Habana Bay, the first being apparently maltha and the second solid bitumen. At that time, however, the use of both these types was limited to the caulking of the ships sailing in these latitudes, and no doubt the presence of these materials so ready to hand in nature was one of the principal reasons why this island was so often made use of by men-of-war of various nationalities, as well as by the "*buccaneers*" so beloved of our younger days, for that operation, so very necessary in that district, of "*careening*" or cleaning and repairing the hulls of their vessels.

In the nineteenth century we find numerous references to these materials, all more or less voluminous in character, in the memoirs of the various travellers and navigators who visited this island, from Humboldt, who called here in 1803, onwards.

One of the most important deposits of bitumen is found near Mariel Bay, the proprietors of which declare there are apparently some millions of tons, containing in the crude state about 60 per cent. of pure bitumen and only 3 to 4 per cent. of water. Thousands of tons of this material have already been extracted and shipped away both to the United States and to Europe in both crude and refined conditions, packing in bags being sufficient in both cases owing to the very high melting point even of the second—126° C.—though it is customary in the case of the latter to ship it in barrels.

Near Cardenas there are extensive wells of maltha. These are sunk some 80 ft. into the rock, and the amount of the material that is extracted from them is constantly replenished by further quantities of fresh material oozing in through the sides. In the bottom of the Bay of Cardenas itself are to be found deposits of a very pure bitumen, so pure in fact that by the very simple method of dissolving it in turpentine, a very serviceable black varnish is obtained. This material has been collected for the past forty years by mooring a lighter over the place of operation, which is approximately 100 ft. below the surface of the sea, and then loosening pieces of bitumen by the very crude expedient of dropping a pointed iron bar into it from the vessel. When a sufficient amount has been thus broken off, a native diver is sent down, who fills it into a common scoop net in which it is brought to the surface. This bitumen is much like cannel coal in appearance, but it has a much more brilliant lustre. From the Constancia deposit near Diana Key, fifteen miles from the town of Cardenas, which has an area of about 200 yards, it is stated that some 30,000 tons have already been taken without appreciably reducing the deposit which, like that at Trinidad, is levelled up with new material. Near Villa Clara there is an unusually large deposit of this material, the thickness of the bed being 12 ft. It resembles lignite in appearance, and for more than fifty years it has supplied the material for the manufacture of the illuminating gas for that city.

The Encyclopædia Britannica (11th edition) gives the following comparative composition of refined Trinidad and Cuban bitumens :—

	Trinidad.	Soft Cuban.	Hard Cuban
Water	0·17	0·13	0·11
Volatile bitumen..	57·81	64·03	8·34
Sulphur	10·00	8·35	8·92
Ash (earthy matter)	28·30	19·51	16·60
Fixed Carbon	9·72	7·98	66·03
Melting point	185° F.	115° F.	160° F.

The West Indies appear to be singularly fortunate as regards the presence of bitumen, which ranks next to iron as the principal mineral product, and owing to the entire absence of coal deposits in that region, it is used locally, as in Barbados, for fuel and also, as mentioned above, in Cuba, for the manufacture of gas. It is affirmed by the mine owners that from a ton of the bitumen is obtained 3,000 feet of gas, 60 gallons of oil and half a ton of coke, which latter finds an industrial use as fuel, whilst the oil is used to advantage as a flux for the more solid bitumen.

That obtained from the island of Barbados is found in the chalky soil of the Scotland district, so called from a fancied resemblance it bears to the scenery of that country, and in a length of cliff called Burnt Hill in the Consett district. This latter has been successfully exploited, and a large tonnage has already been extracted. Owing to its very high degree of purity, this particular type of bitumen was greatly in demand for high-class varnishes and similar products, but its production has now fallen from 342 tons in 1909 to 174 tons in 1911. Although the bitumen contained in the land deposits in the island of Trinidad is sometimes given the same name, the true "*manjak*" is the Barbadoan bitumen.

The following comparative analyses of these two substances are interesting :—

	Barbadoan "manjak."	Trinidad "glance pitch."
Specific gravity..	1·123	1·139
Melting point	420° F.	360° F.
Soluble in CS_2	97%	88%
Ash	2·32%	7·44%
Loss on heating	2·61%	9·4%

According to W. Merivale, who first developed these deposits, there is an enormous reservoir of maltha beneath the island which is still trying to force its way to the surface.

In the island of San Domingo there are extensive deposits both of solid bitumen and of maltha. Only recently the writer received a prospectus of a company then about to be floated in order to exploit some of these, which naturally gave a glowing account of their possibilities, but up to the present nothing further has been heard by him of the enterprise. The rather unsettled state of the government of the island is, of course, prejudicial to a large export trade in this material being developed.

The principal deposit here is near Azua de la Compostela, about fifty-five miles to the west of San Domingo city, where it is said that the adjacent country abounds in it.

A large export trade is done with the United Kingdom in Mexican bitumen. This material, however, is not a true natural bitumen like the ones mentioned above, but is the residue left from the distillation of maltha, numerous occurrences of which are to be found in that country, particularly along the coast of the Gulf of Mexico and in the states of Tampulipas and Vera Cruz. It is credibly affirmed by the firms who are now using this material that it gives equally as good results as those obtained by the use of a natural bitumen, but this seems to be a matter of opinion. Professor Richardson, however, does not appear to have a very high opinion of the material, which, he believes, owing to the large quantities of volatile matters which it loses upon heating, will not prove of any great importance in the paving industry, although no doubt a certain proportion could be incorporated with other and more satisfactory bitumens if it were a matter of economy to do so. This material is very short in fibre and cannot be drawn out into a thread of any length.

In the continent of North America itself bitumen is to be met with very extensively and in very varied forms, from asphaltic oils, semi-fluid malthas, the peculiar rubber-like "*wurtzilite*" or "*elaterite*," the brittle, difficultly fusible "*grahamite*" and "*glance pitch*," to the impregnated limestone and sandstone. The territory, too, ranges from Texas and California in the south to Alberta province in Canada in the north. To the European consumer, however, but few of these are of direct interest, the majority finding a sufficient home demand for their output, whilst the high freights required for others, particularly those in the western states, effectively prevent their successfully competing with the other bitumens at present on the European market. How the opening of the Panama canal will modify this state of affairs remains to be seen.

In California both the solid and the liquid types of bitumen are found, as well as a thin flowing asphaltic oil which finds a very extensive use for road spraying. The different kinds are marketed in Europe and find a ready demand particularly for paving purposes.

Other well-known deposits of bitumen here are those in Colorado and Utah, where the solid material is that known as "*gilsonite*" or "*uintahite*," the latter name being derived from Uintah county, Utah, where it is found. This material is black in colour with a most brilliant lustre and breaks with a coarse conchoidal fracture. Where a vein is exposed to atmospheric action, it becomes a dead black, but this change is merely superficial, for when this surface is removed, the material found behind it shows its customary brilliance. When pulverised, it forms a very fine chocolate brown dust, and if fluxed with suitable Californian malthas, it forms a peculiar rubber-like mass which, however, is rather short in fibre. It is a very pure type of bitumen, the best qualities containing as much as 99·5 per cent. as extracted from the earth. It has a slightly lower density than other bitumens and has a much higher softening point. It possesses but a low percentage of "*petrolene*," with the result that, as might be expected, it is a brittle material.

The type known as "*wurtzilite*," and found principally in Utah, is of a very unique character, though it is not to be met with in sufficient quantities to enable it to be used to any appreciable extent in commerce. It is a tough, lustrous material, difficult to fuse and to dissolve. Although somewhat short in fibre, it is very rubber-like in character when cut in thin strips, so that it is difficult to fracture. It does not fuse even at high temperatures, but it is fluxed with heavy malthas by gradually "cracking" it at high temperatures. Its scarcity, however, precludes its extensive use so that the fluxed gilsonite, as mentioned above, is usually employed in its place.

"Grahamite" is another solid form of bitumen found in various parts of North America, but it is distinguished from the various other bitumens in that it is infusible. When it is heated, it swells up with the evolution of gases and can be softened sufficiently to enable it to be drawn out into threads. It has another distinguishing feature in that it has but a comparatively low sulphur content, and it can be distinguished from gilsonite from the fact that, whilst the latter is brown when in a pulverulent condition, grahamite is quite black when crushed.

The liquid or semi-fluid malthas in America are found principally in Texas, California, and Indian territory, where they permeate and saturate strata of sandstone from which they are usually extracted by heating the rock. Towards the end of 1911 endeavours were made to tap the soft bitumen whose existence under the Salt Lake, Utah, near its northern shores, has been known for some time, but the writer has not yet heard of it being actually placed on the market.

The material found in Canada is, as its local name of "Albert coal" would imply, a very hard and lustrous bitumen. When placed in a flame it fuses, burns almost without smoke and falls into burning liquid drops. It dissolves in naphtha if slightly heated, more readily in carbon bisulphide, and forms a brilliant black varnish, as it is usually quite free from mineral matter. It is however, stated that this deposit is being exhausted and that it is now only used for Canadian requirements.

The American natural rock asphalt can be divided into that consisting of impregnated limestone and that of impregnated sandstone. Perhaps the most important of the former are the deposits which are found in Oklahoma and in Uvalde county, Texas. These, contrary to the best European types, show numerous cavities which are filled with pure bitumen, whilst in other places in the same rock portions are found which are totally unimpregnated, thus giving the face of the deposit a very mottled appearance. The average percentage of bitumen found in these rocks is stated to be 14 to 15, and owing to this high percentage it is usual to crush and heat it without the addition of any further bitumen when preparing it for compressed work. Another deposit of bituminous limestone is also met with in Indian Territory, but this is of very imperfect impregnation, and the average percentage of bitumen is only five to six.

The naturally impregnated sandstone is, however, of much more frequent occurrence, being found in Kentucky, Utah, Missouri, Indian Territory, Texas and California. With the sandstone, the bitumen acts merely as a binder, and does not truly impregnate the mineral as in the case of the limestone. The most important fields are those in Kentucky, which show an average impregnation of 6 per cent. The material has been used for paving purposes in a similar way to the compressed rock asphalt powder, but although the pavements thus prepared give a fair amount of success, they cannot compare in that country with the artificial mixtures that are used for similar purposes. A deposit of this material has been found about ten miles east of the celebrated Mammoth cave, in which the impregnated sandstone is a very fine siliceous rock, which has a bitumen content of from 5 to 25 per cent. The sand is very hard and each grain is coated with a film of bitumen of from 7 to 15 per cent.

CHAPTER IX

EXTRACTION AND PREPARATION OF ROCK ASPHALT

The rock asphalt as it is despatched from the factories which are run in conjunction with the different mines is prepared in no fewer than five distinct types, according to the work to which it is to be put. The best known are, of course, the " mastic " and the " powder " forms, but besides these, large quantities are also sent away as the crude rock just as it is drawn from the mine, as the " crude powder," *i.e.*, the crude rock merely crushed without the addition of any bitumen, or a richer rock to give it the percentage of bitumen necessary for compressed work, and as compressed tiles made from the prepared powder.

During the commencement of the past year (1912), the writer inspected in person the asphalt mines, quarries and factories at Eschershausen, Brunswick, and under the guidance of the works manager of the Union Vorwohler Asphaltgesellschaft had the pleasure of having all the details in connection with the extraction and preparation of the material as carried on there, from the blasting of the live rock to the despatch of the finished material in one or other of the foregoing forms, fully explained to him.

The village of Eschershausen itself is but a small place and contains quite a number of picturesque old half-timbered, slate-roofed houses, although a large number of the more recently erected dwellings are hung with cement tiles. It nestles at the foot of the Hils mountains, in which latter are found the veins of limestone impregnated with bitumen. The mountains are pierced with galleries at different points, and by means of these the various asphalt mining companies in this district obtain access to the veins as these appear in their particular property.

Passing through the village, it is noticed that the road from the station is paved with rock asphalt tiles which have been made from the prepared powder as produced from the material obtained from the rock asphalt quarry here. Despite the fact that these tiles were laid down some eight years ago, they proved upon inspection by the writer to be still in perfect condition and, as the manager of the firm which owns the particular quarry from which the powder used in their manufacture was obtained, pointed out, not one of them is cracked and the surface is practically as flat as when first the pavement was laid down, despite the fact that all the traffic to and from the station passes over it. The particular morning chanced to have been wet, yet no "basins" retaining water were to be seen on the pavement, thus clearly showing the durability of this class of paving which, besides, presents an extremely pleasing and neat appearance.

On leaving the village behind the road leads to the factories of the various asphalt producing firms, in which the raw rock is worked, and then a moderate rise in elevation brings one to the mouths of the galleries themselves. The entry to any one of these is identical, consisting merely of a small cutting into the base of the hill, and a short walk of a hundred yards or so on a medium downward gradient inside the gallery brings the visitor to the face of the rock then being worked, each layer of the impregnated material—in this particular instance there are two—being got at from a different gallery in the mine. The bituminous rock in the mine proved—to the writer, that is—rather difficult to distinguish from the dark coloured unimpregnated stratum of clay immediately between the layers, especially with the dim light of the oil lamps provided, but the sound obtained by tapping the rock with a hammer soon showed the difference between the two. The workmen, however, have no difficulty in distinguishing between the two classes of rock, but could point out on the face of the live rock exactly where the one stratum ended and the other began.

The rock is first drilled with a hand drill and a charge of ordinary black powder is then inserted into the cavity so formed. It is found that ordinary black powder is much more satisfactory to use for this particular purpose than is dynamite, owing to the latter having a tendency to split the rock too much. The fuse is lighted, the workmen retire to a suitable distance for the explosion, after which they again go forward to break down the masses of rock that have been thus loosened, by means of heavy hammers. These masses are further broken up if necessary, to allow of their being loaded into the iron tip trucks which, running on a light railway which connects the mine with the factory, transfer the rock from the underground vein to where it is stored in the factory in readiness for use in the different processes or for despatch as crude rock.

Before returning to the factory itself, the quarry here which is also worked for the extraction of rock asphalt, was next visited. As distinct from the mines, which, as before mentioned, are at the base of the mountains, this quarry is away up on the summit, necessitating a very stiff climb. It has been referred to on previous occasions how bituminous rock generally when exposed to the atmosphere loses its dark colour, and this is a matter which immediately strikes one upon arriving before the face of the quarried rock. On the way up the hill, too, trucks have been passed which contain a greenish-white broken mineral, and the stone itself where exposed in the quarry shows a similar colour, so much so that the casual observer would not dream that such a rock had any bitumen impregnating it at all. Yet immediately the face of the rock is broken down, also by blasting with common black powder, the dark colouration of the rock asphalt is at once apparent. The powder obtained from this rock is not very rich in bitumen, the guaranteed content as given by the quarry owners being 4 per cent., but the fact that the rock has already been weathered seems to make it especially advantageous for rock asphalt work which will be subject to exposure to extreme atmospheric conditions. This was the rock asphalt from which the paving tiles remarked in the street leading from the station were made. The depth of this stratum of bituminous rock is stated to be over 16 ft.

Returning to the factory, the broken pieces of rock asphalt, which have been seen sent from the mine and the quarry in trucks, are broken up smaller, approximately to the size of an apple, and are then fed into a special type of disintegrator. The use of an ordinary disintegrator is unsatisfactory with rock asphalt, since the bitumen contained in the latter material causes the pieces of rock to become greasy in a very short space of time, and so to clog up the working of the machine. The type adopted for this work therefore consists of a number of concentric drums, one working within the other, the sides of which are composed of a number of sharp edged steel rods. When the disintegrator is revolved, the centrifugal force that is occasioned causes the pieces of rock to be thrown against these rods with a moderate violence until they are broken sufficiently small as to be able to pass between the rods. Here the pieces find themselves in a second chamber similarly provided with rods, so that the rock is broken up still smaller, and this operation continues until a powder is formed which is sufficiently fine as to pass through a sieve of a very fine mesh, which is placed round the disintegrator for the purpose of retaining any coarse powder that may be thrown out with the finer grade.

The rock asphalt powder thus formed is the base upon which all other types of rock asphalt materials are made. A number of rock asphalt contractors nowadays prefer to purchase the asphalt powder in this form, the so-called "crude powder," and then to "*cook*" their own mastic in their own works with their own materials. When this is done by firms of repute, such a method of procedure is highly commendable, since it assures them of being in a position of being able to personally guarantee the constituents and the manufacture of the material. At the same time, however, it opens a door also to less scrupulous firms, who are thereby enabled to adulterate and to cheapen the mastic to their own liking, either by the addition of an insufficient quantity of bitumen, by using a low grade bitumen if not actually a coal tar or similar artificial product, by adding powdered limestone or a similar mineral adulterant, or by insufficiently cooking the material. It is not incumbent upon them to stamp their blocks with the name of the mine from which the rock asphalt they use originally came, and even if they do so, they have a large number of stamps from which to choose. With the rock asphalt mastic as imported direct from the factories which work in conjunction with the mines, the specifier is in a safer position, since the Customs authorities, in carrying out the Trade Marks Act, insist that upon each block of this material that enters this country shall be branded the place of origin. It is this brand that constitutes in part his safeguard if he insists that all blocks of rock asphalt mastic that may be used upon work under his control shall bear the brand of the particular mining company whose material he has decided upon for that contract. This, however, is impossible as long as the "or equal" clause continues to be inserted in his specifications.

From the powder obtained from the crude rock by means of the disintegrator as just described is prepared the special rock asphalt powder as used for compressed work. In only few instances does the asphalt rock as taken out of a mine contain naturally sufficient bitumen to form a suitable powder for this class of work, so that the quantity of bitumen impregnating the rock has to have assimilated with it additional bitumen, in order that the total amount shall be such that experience has proved to be most suitable for that particular type of rock asphalt. This proportion varies with different rocks and seems to depend upon the class of rock and the method of impregnation. When, however, the mine produces an extremely rich rock as well as a poorer variety, it is usual to blend the two together in such proportions as to arrive at a like result. It has been recommended in some quarters that to obtain a material showing a suitable percentage of bitumen, rocks from different mines should be blended, but the advantage obtained by this means is questionable, as the more richly impregnated rock is invariably softer than the less impregnated one, so that a pavement formed from such a mixture has not the capacity of wearing evenly that is shown even by a similar mixture, but formed of rock of different impregnations and obtained from the same mine. This prepared powder, when produced by mines in which no such extremely rich layer can be found, has necessarily to be prepared by enriching the rock with added bitumen. This is done by thoroughly "*cooking*" a quantity of the crude powder with the requisite amount of bitumen until the latter is thoroughly merged into the whole. When this stage is reached, the material is again passed through the disintegrator and finally packed in bags containing approximately 2 cwt. each in which they are sent away to the various consumers.

From this prepared rock asphalt powder are formed the compressed asphalt tiles. A special press has been built for their manufacture by the firm of C. Lucke, Eilenburg, who specialise in presses for particular trades, which press exerts a surface pressure on each tile of 120 tons. The powder is first slightly heated before being used, in order to drive off any minute quantity of water that it might still retain, and also to bring it to that temperature which is found to be most suitable for the work of compression, and it is then filled into moulds of the size of the tile required (usually 25 cms. by 25 cms.). These moulds are then placed in the press, the powder they contain is subjected to the intense compression that this machine is able to exert, when firm, sound and extremely durable tiles are formed. The thickness of these varies from 1 to 2 ins. according to the particular purpose for which they are required, a side walk, for instance, not requiring such a thick tile as would a much used roadway. They are packed in strong wooden crates, bound with wire, which contain approximately 3 cwt. each, and in which they are despatched both by rail and water.

The rock asphalt mastic, however, is prepared from the crude powder itself, and the work is carried out in a special plant which is known technically as a "*cooker*." Its use has been alluded to in the manufacture of the prepared powder. It consists of a cylindrically shaped boiler in which are fitted strong rotating arms. The special boilers used for this purpose are usually of such a size as to contain 3 to 5 tons of the finished mastic, and are built by several of the Continental engineering firms who make a speciality of rock asphalt tools and machinery. They are customarily ranged in couples, and are heated from a fire box below, the waste gases from which, after passing round them in the covering jacket, find their exit in a flue fitted at the top of the boiler. The agitators are fixed upon an axle running through the boiler, and this axle in turn is connected with a driving shaft. So that there may be no possibility of the material coating the sides of the "cooker" during the operation, these agitators are made so that in their revolutions their radius is only slightly less than that of the inside of the boiler, with the result that no material is left untouched.

The finished mastic usually contains in all 14 to 16 per cent. of bitumen, so that the content of the crude powder being known, the amount of extra bitumen required to bring about this desired percentage is easily calculated. In the process of preparation of the mastic, the major portion of the bitumen which will be required for the operation is first placed in the "cooker," which is then heated. This bitumen, like that used in the preparation of the prepared asphalt powder for compressed work, is usually the refined Trinidad material fluxed down to a suitable consistency, though now that other bitumens have proved their worth for this purpose, which do not require such fluxing, there is no doubt that as time goes on their use will be preferred. The fact of these other bitumens being much more pure than even the refined Trinidad bitumen means that a less quantity is required in order to bring about the requisite bitumen content. Thus in the Lobsann and the Russian mastic factories, a local bitumen is employed; in certain Austrian and French factories the Albanian type is used, whilst some German firms have for some time past been adopting Cuban and Mexican bitumens.

The bitumen is first melted in the boiler to a thick liquid, for if it is allowed to fuse too thinly there is a liability of the material either charring or else catching fire, and then the crude powdered rock is added by degrees. This is effected by means of small flap doors which are made in the side of the cylinder, through which the powder is shot in quantities of approximately 2 cwts. (*i.e.*, a bag) at a time. It is usual to regulate the time of this filling so that the powder is thrown into the boiler immediately the slowly rotating arm of the agitator has passed the door, in order that there may be no fear of the bag being caught by it and so dragged into the mixture. Two doors are usually made in each "cooker," on the same side of the upper half of the cylinder and next to each other, so as to secure a more even distribution of the powder. The two arms of the agitator are so arranged that they are at right angles with each other, so that when one has just passed its respective door the other is approaching the second door. By this means the two doors can be fed alternately, and the mixture receives fresh agitation with every 90 degrees made by the rotary axle.

This gradual addition of the powder enables the entire mixture to be evenly and intimately blended with the bitumen, but further than this, it materially assists in the convection of the heat applied to the "cooker" throughout the mass, for, were it all inserted together, the bad conductivity of heat possessed by the powder would cause that portion nearest the shell of the "*cooker*" to be burnt before that in the interior would be barely warmed. When the powder thus gradually added appears to have thoroughly absorbed the amount of bitumen originally placed in the boiler, the remainder of the arranged quantity of bitumen is then thrown in, and the further amount of rock asphalt powder added until the exact quantities of the two materials as required for the operation have been put into the boiler. The entire mixture is now constantly agitated at a temperature of about 200° C. for a period of five hours, when the fused mass is drawn off through a suitable treacle valve into an iron tip truck, from which it is transferred into the moulds the shape of which the mastic blocks are to take, and in which it is allowed to cool. The material that first makes its appearance is a small quantity of unmixed powder which, having become lodged in the outlet, has not been reached by the agitators. This is received into a separate bucket and thrown to the back of the "*cooker*," so that by the time it passes through the outlet a second time it has become intimately mixed with the bulk.

The moulds that are used for the formation of the rock asphalt mastic blocks are made up of metal parts which permit of a ready setting up, and are usually circular, six-sided, semi-rectangular, and square in shape, though others even than these are at times to be met with.

A number of these moulds are assembled together so as to render the filling of the one after the other an easy matter. They are usually set upon a concrete floor which has been previously dusted over with a quantity of the crude powder in order to prevent the mastic from adhering to the concrete when cooling. So that the moulds shall not stick to the sides of the block when cold it is customary to give them, prior to their being used, a coat of whiting to which—when the grey sides thus caused to the block are objected to, which colour, of course, disappears if the block has been weathered—is added a quantity of lampblack, or else it is substituted by a soap solution. This last method, however, although leaving the sides of the desired natural colour, is not always successful for the principal purpose of eliminating the sticking of the material to the mould.

On the face of these blocks is impressed the name and sometimes the trade mark of the particular mining company by which the mastic has been made, and as this is the only real guarantee that the architect and engineer can have that the material that is being used for his work is of the type that has been specified, it should invariably be demanded that every block of the material employed shall have impressed upon it this distinguishing mark.

The blocks thus formed are stacked in the open ready for immediate shipment in bulk, without any packing of any description, and each block nominally weighs between

60 and 65 lbs., though this weight is never true, owing to the loss of corners and other small pieces which are accidently broken from the blocks during transit.

It will be remarked that there is no pressure employed in the making of these blocks, so that, contrary to the crude rock or even to the samples which may be made up from the mastic, they invariably show a number of " blowholes " when fractured. In inspecting rock asphalt mastic in its block form, therefore, this fact must be borne in mind and the presence of such blowholes ignored.

Although the different types of bitumen added to rock asphalt in the manufacture of the mastic appear to give equally satisfactory results to those obtained by the use of Trinidad epure, a certain amount of caution has to be employed with the use of some, owing to the extreme readiness with which their " *petrolene* " content evaporates out to leave a brittle and therefore useless solid. There are, however, less reputable firms who make use of the cheaper petroleum residues and even coal tar products in the preparation of their material, and although this latter is, for this reason, initially low in price, its use only leads to the early disintegration of the work done with it. In France, too, the shale oil as obtained from Autun is extensively employed, though it fails to give as excellent results as does the properly fluxed bitumen.

A further caution must be given regarding certain other low priced German rock asphalt mastics which, being manufactured by firms which do not belong to the syndicate which has been referred to in an earlier chapter, are obtainable at much lower rates, sometimes at a figure as much as 20 per cent. lower than the standard fixed for the true natural product. These are often manufactured from time-worn rock asphalt which has been lifted from old asphalt work. This is sometimes mixed with new material, though very often not, and then blended with a sufficient quantity of bitumen, petroleum residue, or even coal tar products, according to the price to be obtained, the process of manufacture being the same as the " cooking " of the true natural rock asphalt mastic.

This material is much inferior to the true product, and that it could not be otherwise will be recognised when it is borne in mind that by exposure to the atmosphere it has lost a large portion of those malthenes so requisite for the flexible nature of the work for which the mastic type of rock asphalt is specially employed, and also that it has amalgamated with it the detritus and dust inevitable in streets from which the old material is customarily obtained. Work done with this material rapidly wears into holes or cracks, or else forms rough unsightly parts, as is known to their cost by the innocent victims upon whom it has been inflicted. Such material, being formed from substances derived ultimately from the natural rock, comes under the heading of natural rock asphalt mastic, but it may truthfully be said that there is no greater enemy to rock asphalt and rock asphalt work generally than this inferior and remade material.

The idea of utilising this old material in the manufacture of rock asphalt products is not even confined to the mastic material, but compressed asphalt tiles and the prepared asphalt powder for compressed work which have been prepared from it are also to be found on the market, selling, of course, at a much lower rate than what is required for the genuine material, and the same warning equally holds good for them too.

An architect or engineer who has had the opportunity of comparing side by side the two, the genuine product and the prepared article, in actual use, not merely in small hand samples, will have no hesitation in deciding upon the one which is the most suitable and which gives the most satisfactory work and results.

There are on the market, in England especially—for upon the Continent their use appears to have been discarded to a very great extent—blocks which are prepared from the rock asphalt mastic for use as a paving material. They do not give such good results as do those which have been prepared from the compressed powder, but being initially cheaper, their use is sometimes preferred. These are usually prepared by mixing together suitable proportions of rock asphalt mastic and bitumen with grit, crushed stone and other fillers, the final mass in its molten condition being filled into moulds and subjected to an intense hydraulic compression, as in the case of those made from the compressed powder. Even these have their substitutes, composed of a mixture of bitumen and mineral matter into which natural rock asphalt does not enter at all, but these give but very poor lasting results when used.

Of late, increasing attention has been devoted to the use of bituminous macadam for road making, and this material will be found referred to in the chapter on macadams, in conjunction with tar macadam, a material to which, except for the use of bitumen as a binder instead of tar, it very closely approximates.

In compressed work, of course, no further material is required other than the powder itself, but for the asphalt mastic work and for the making watertight of the joints in the pavements made up with the tiles, whether composed of the compressed powder or of the gritted mastic, a bitumen is required. The exact type of this seems to vary almost with every user, each apparently having a personal preference for some special one. Thus some firms are found who will still uphold the use of the refined Trinidad bitumen fluxed with shale grease, whilst others, on the other hand, with less conservativeness, allege their preference for the more newly marketed types. In any case, whatever the exact type may be, its qualities should be such that whilst it will retain its elasticity at the extreme cold to which the finished work will be subject, it will not liquefy or soften to too great an extent at the extreme heat that the work will be submitted to in summer from the sun.

As with practically every other trade, novelties have been prepared in the different classes of the rock asphalt material, and only recently the writer had submitted to him samples of a coloured mastic, a coloured bituminous paint, and a hydraulic asphalt powder which only required the addition of water to cause it to set. The sample of the second was insufficient to enable satisfactory conclusions to be drawn, but in the other two cases the writer has occasion to believe that the method of manufacture necessitates the addition of a large amount of foreign matter to the natural rock asphalt, and as this does not act solely as a filler as in the case of grit, etc., it leaves it very much open to question whether its presence will not act detrimentally to the mixture. This line of thought is caused by the handling of the two samples referred to, which in the case of the first is really too soft to be able to withstand continuous traffic, even if laid in the interior of a building, where it is intended that it shall be used as a floor covering to do away with linoleum and the like. An oil is apparently employed to carry the colour, and although it seems to be well and evenly distributed throughout the sample, it seems also to prevent the bitumen of intercalation from cohering as firmly together as it should. Then, too, the surface readily retains dirt, which rapidly discolours the original tint and leaves an effect which would not be countenanced for a moment in any public building. The hydraulic powder, on the other hand, when set, results in the formation of a very hard brittle solid, which has not the elasticity looked for in asphalt mastic work, and so could not withstand much vibration or alternate expansion and contraction of the structure in which it may be used. If, as is surmised, the hydraulic set is obtained by the use of a cement, then the limestone and marl which constitute this latter, being in such a finely divided condition, is capable of absorbing a large amount of bitumen, which, if added to the point of saturation, would, by forming a protective coat around each grain, obstruct the proper setting of the cement. If, on the other hand, an insufficient quantity of bitumen were added, the result would be an unevenly impregnated material, which is very strongly condemned by various authorities for asphalt mastic work, and one in which the bond is not occasioned by the adhesion of the bitumen as in the case of the ordinary asphalt mastic, but by the coherence of the grains of mineral matter. This bond, not being resilient, would naturally crack under tension, and where the material is used as a dampcourse—for the principal idea in its adoption is to do away with the present difficulty of applying asphalt mastic to damp walls—would render it ineffective for the very purpose for which it was intended.

CHAPTER X

TESTS AND ANALYSES

THE ever dominating idea of cheapness and short-sighted economy even in rock asphalt work, has resulted, as can only be expected, in the placing before the unwary consumers, of adulterated bitumens and, too often, substitutes for the real article, which, whilst initially cheaper and apparently just as good, fail to maintain the claims of durability that have been made for them, to the dissatisfaction of all parties concerned in their use.

Then, too, the range of materials over which a choice can now be made covers so many types that it is necessary to define certain conditions that the particular one required for a particular purpose shall fill. The following pages will show what an advance has been made in the demand for quality in bitumen since a date so recent as 1893, when Delano merely mentions that "the best way to test the quality is to draw it out into threads; the longer they stretch, the better the sample." How he would reconcile several modern bitumens with the statement that "bitumen to be good should be free from dross, non-evaporative and contain no oils that will evaporate at 480° F. (250° C.), be perfectly black, not brilliant, and at 70° F. (21° C.) have the consistency of beeswax," the writer is at a loss to imagine, seeing that many, of which the Trinidad epure may be taken as an example, contain a large content of "dross," if under that term be implied all matter, mineral and organic, that is not bitumen; that all bitumens lose a certain amount of their "petrolene" content when heated; that some are brown in colour; that no less an authority than Professor Richardson states that "all the native bitumens are lustrous if pure"; and that many, such as gilsonite, glance pitch, etc., are extremely hard at ordinary temperatures, whilst some of them are very difficult, in fact, almost impossible to fuse.

With regard to rock asphalt, it must not be overlooked that, as previously mentioned, a series of purely chemical tests is unsatisfactory, since the artificial varieties, being composed of the same materials, will give identical reactions. It is imperative, therefore, that this product shall be submitted to both chemical and physical tests should the question be involved whether or no the sample under consideration is one of natural or of artificial formation. The tests given in the following pages are such as can reasonably be performed by persons who are in the habit of handling both bitumen and bituminous compounds, but the more delicate ones, which require an intimate knowledge of analytical chemistry and the use of delicate and expensive apparatus, such as the ordinary person or firm would not have an opportunity of using, are not given, particularly so since for practical purposes the ones which are to be found here are usually sufficient. For the more delicate ones the analytical expert in these materials should be called in.

It is always necessary when handling large quantities of a naturally produced material that a type sample shall be periodically taken from the different consignments and carefully tested. With standard qualities obtained from firms of high repute this, of course, is usually unnecessary, though at the same time it is often interesting to compare even in these cases the figures obtained from the analysis of the sample from bulk with those of the nominal analysis. Particularly is this essential, however, in the case of prepared material, such as residuums, where it is not always possible to obtain the material of an unvarying quality owing to the slightly altered conditions which arise around each individual distillation.

At the outset, the preparation of a uniform sample is of the utmost importance. If this is not properly and carefully effected, then the whole analysis is quite worthless, and the result may even lead the investigator altogether astray.

In the case of finely pulverulent substances, such as the crude or the prepared rock asphalt powder, this preparation of a satisfactory sample presents no great difficulty, but in all cases certain rules of procedure must be followed in order to obtain a correct average sample. As Professor Richardson truly remarks, there is a very great difference between a sample of a material and a specimen. Whilst the latter is usually selected in order to bring out most prominently the best characteristics of the particular material for any special work, the former is chosen as showing the average composition and character. In submitting any material to tests, it is the sample and not the specimen that must be handled.

To obtain a sample that may be regarded as an average type it is essential that it shall not be drawn from only one spot in the bulk. Portions should be taken from the consignment at different places and then these intimately mixed together. With a powdered material this is a simple matter, but when the investigation of solids in lump is being carried on, it is necessary to crush each sample before mixing. Nor must it be forgotten that the larger the size of the sample the more typical of the entire bulk it will be. In blending the different samples, a good sized quantity of each should be taken, and the resultant mixture can then be diminished to such a quantity as may be deemed most suitable for analytical purposes.

It should be borne in mind also that the finer the grains into which the material is comminuted, the speedier the test will be. Powdered materials, of course, require no further crushing, but solids must be ground up to a more suitable condition, and this is usually effected by pulverising them in an iron mortar, though when a very fine powder is desired, porcelain, agate, or even steel mortars are sometimes employed. Moderately plastic substances can often be reduced in this way if the mortar is set in a bath of cold water, in order to prevent the rise in temperature which would otherwise be occasioned by the friction that is developed in the process of crushing. In this case, however, great care must be taken that none of the water is allowed to get inside the mortar, as moisture is one of the various component parts of the bitumen or rock asphalt that has to be detected and determined. When even this is found to be impracticable, the only alternative is to cut the sample up into small pieces with a clean dry knife, taking the greatest care to handle it as little as possible.

In analysing an impure bitumen, the principal matter to be taken into consideration is the quantity of that body that is soluble in a known solvent, and the melting point of the bitumen thus extracted. The simplest method of doing this is perhaps as follows :—

A weighed quantity of the material, after having been powdered, is left for some days in a desiccator. It is then taken out and carefully re-weighed. After being replaced, a further suitable time is allowed to elapse, when the sample is again weighed, and if no difference is to be found between the last two weights, the loss in weight, as shown by the difference between the first two weights, gives the amount of water that had been previously absorbed or become mixed mechanically (as distinct from chemically) with the bitumen. Should no loss in weight be detected, then the bitumen is thoroughly free from water. The actual procedure of this experiment will be described a little later.

The powdered bitumen thus dried is now placed in a tall, narrow-necked flask—usually an Erlenmeyer flask (cone shaped)—which is provided with a thoroughly airtight cork, and then covered with approximately ten times its weight of pure carbon bisulphide. The flask is now closely corked up and the contents repeatedly agitated for some days. The carbon bisulphide is an excellent solvent for bitumen—such solubility being, in fact, one of the tests for a bitumen—and readily extracts it from rocks containing it, or from its impurities if the crude mineral is so treated. Further than this, it is very volatile, boiling as it does at 48° C., so that after being used it can readily be evaporated without needing the higher temperature requisite for the other solvents of bitumen at which the latter often undergoes a partial chemical change. The narrow-necked flask is used in the extraction so as to reduce the surface area of the liquid to a minimum, and so to retard the evaporation of the solvent which goes on even at the ordinary temperature.

After a few days the solution thus made is filtered through a previously weighed filter paper, into a shallow porcelain bowl, which has also been previously weighed. It is recommended that the filter paper be folded in pleats instead of in quadrants as is the customary manner, since by doing the former a larger filtering surface is obtained, hence a quicker filtering operation and less fear of the solvent evaporating upon the filter paper and so depositing the bitumen dissolved in it there instead of passing it through in solution. The residue remaining on the filter paper is carefully and thoroughly washed with a further quantity of carbon bisulphide until no more of it dissolves, *i.e.*, when the liquid passing through the filter paper is uncoloured with bitumen, when the paper is allowed to dry. In that condition the paper and its contents are weighed, and the increase in the weight of the paper gives that of the extraneous matter which was previously mixed with the sample of bitumen. This may be organic matter with or without mineral matter, or even only the latter. If these are also to be analysed separately, the residue is carefully taken from the filter paper and weighed. Following this, it is put in a small porcelain basin and heated on a sand bath over a Bunsen flame. Any organic matter that may be present ignites when the basin becomes red hot, and finally burns completely away. If there are any mineral bodies present mixed with these organic substances, they remain unchanged even when the basin is brought to a constant white heat and that temperature sustained for a long time. When it is seen that no more of the contents of the basin will burn away, it is allowed to cool, and the residue which remains is then analysed for its properties. According to this mineral matter, it is possible to determine the place of origin of the bitumen, but as this requires an intimate knowledge of the different bitumens and an acquaintance with the rules and tables of inorganic analysis, it is not given here, the more so as it is usually sufficient for the practical man, if he knows whether there are organic or mineral impurities in the bitumen, without actually requiring to particularise as to the exact mineral or organic compounds that may be present.

The filtrate in the basin is, of course, pure bitumen dissolved in carbon bisulphide. It is put in a water bath and heated to about 48° C., when the solvent quickly evaporates out and leaves the bitumen behind as a dark amorphous mass. As this still contains traces of the solvent, it is advisable to raise the temperature to 110° C. for a short space of time before taking the final weight. Care must be taken, however, that this increased heat is not sufficient to drive off the more volatile oils of the bitumen itself. By subtracting the weight of the basin from the weight thus obtained that of the pure bitumen in the sample under consideration is obtained, which, when added to that of the impurities, should be equal to the weight of the original sample.

As is well known, bitumen contains certain bodies which are volatile when subjected to heat, and others which will withstand very high temperatures without evaporating. The volatile elements have been termed "*petrolenes*" and the non-volatile ones "*asphaltenes*," though owing to false ideas that have at times been created by the use of the former term, Professor Richardson prefers to give them the name of "*malthenes*." As a general rule, a bitumen is harder in proportion as it contains more asphaltene to petrolene, until finally some of the very hard types are reached in which but little trace of the latter is to be found.

The first scientific investigation of bitumen seems to have been carried out on this line by Boussingault in 1836. He submitted the Pechelbronn bitumen to distillation and obtained a distillate to which he gave the name of "*petrolene*," whose chemical composition he determined as $C_{80}H_{64}$, and which he pointed out was isomeric with that of oil of turpentine. To the non-volatile portion he gave the name of "*asphaltene*." These terms are now, however, often misapplied, with the result that the term "*petrolene*" is given to the portion which is soluble in petroleum spirit, ether or acetone, and "*asphaltene*" to that portion dissolved by boiling turpentine and cold chloroform. Many engineers fix a limit to the proportion of the one to the other in a bitumen to be used in road making and similar work under their control, and it will therefore be readily understood that a bitumen should be analysed for this comparative composition. Many methods are now in vogue for this purpose, by means of which it is possible suitably to extract the one fraction from the other.

One of these methods consists in placing a weighed quantity of the bitumen to be tested into a distilling apparatus and covering it with water. When the apparatus is heated, the petrolene distils over with the steam and condenses as an oily liquid, which, since it floats upon the water by reason of its lighter specific gravity, can be readily separated from it. A satisfactory determination, however, is only possible when the distillation has been carried on for such a length of time that the water coming over is absolutely odourless, and this condition is only reached after the bitumen has been constantly heated with the water for several hours.

"*Petrolene*" is also soluble in boiling alcohol, but in order to obtain a result which can never be more than moderately satisfactory, the boiling operation must be kept up and the inevitable loss of alcohol constantly replaced for a very long time, so as to extract the last traces of the petrolene.

For the practical man, though, the following method of estimating the quantity of petrolene and asphaltene contained in a sample of bitumen is perhaps the most suitable and at the same time the simplest to carry out. A weighed quantity of the bitumen is placed at the bottom of a porcelain bowl which is provided with a porcelain lid in the middle of which is a small opening. It is then placed over a strong Bunsen flame, which is so regulated that the contents of the crucible are kept at an even temperature of about 250° C. At first the heat must be applied very gently, otherwise the mass, which at times swells up very strongly, will boil over, but after the greater part of the vapour has been evaporated the bowl, having reached the required temperature, is kept constantly there for some hours. As soon as it is seen that it has been heated for a sufficiently long period, that is to say, when no further quantity of vapour is to be seen rising from the crucible, the latter is allowed to cool in a dessicator and then weighed. It is again heated for a second time, but to 260° C., at which temperature it is kept for an hour or so, and afterwards again cooled in the dessicator and its weight taken. If no variation in the two weights is to be observed, the operation is complete and the substance left behind in the bowl is pure asphaltene, whilst the loss in weight is that of the petrolene.

The determination of the melting point of a bitumen can be done by a very simple piece of work, to which, however, at the same time is joined the difficulty that it is very hard to recognise with any degree of exactitude the true point at which the mass, which at first is only softened throughout, changes into a liquid. This difficulty is further increased by the non-conductivity of the material, which results in the outer portion of the sample being completely fused and in a liquid condition even before the interior can be truthfully accepted as being very soft. The test is usually done in the following manner. The bitumen is put in a shallow porcelain basin, which in its turn is placed in a glass beaker standing upon a tripod, and the whole is then heated with a small Bunsen flame. Within the beaker and near the basin, so that it can register the temperature of the air surrounding the latter, is hung a thermometer. In order to find at what temperature approximately the bitumen melts, the apparatus is first of all heated fairly rapidly, until it is observed that the sample has melted, when the temperature which occasions this is noted. A second sample of the bitumen is then treated in the same way, with the exception that it is heated to a temperature some 10° C. lower than that which fused the previous sample. If at this heat the fresh sample is not melted, the temperature is gradually raised until the formation of a glossy surface on the bitumen shows that the melting point has been attained. In order that the result to be recorded shall be as accurate as possible, this operation should be repeated with other samples for several times and the arithmetic mean of the various readings taken.

One of the most important causes for the submission of samples of bitumen to analysis is to ascertain whether the alleged bitumen is of natural or of artificial origin. As a rule, however, the artificial bitumen usually found on the market is composed of, or contains, the products of coal tar. With these there are always variable quantities of free carbon, from which one would conclude that certain constituents of the coal tar decompose under the strong heat which is used during its distillation and separate out as carbon. This carbon is present in the finest condition possible throughout the entire mass, and as it is insoluble in all the solvents known up to the present, its quantity can be easily found if a weighed quantity of the suspected bitumen is treated with a suitable solvent. It is best to use for this purpose the hydrocarbons of the benzol series, and the powder which remains behind upon the filter paper upon the filtration of the liquid should be well washed with the hot hydrocarbon until nothing further dissolves, when the black mass left behind is pure carbon.

Another simple method of determining the amount of free carbon in a bitumen is to heat a weighed quantity of the material which has been previously reduced to a fine powder, with three parts of aniline and then to pour away the thin liquid and the matter which is held in suspension by it, into a small plate of unglazed porcelain. The solution of bitumen is at once soaked up by the porous porcelain, and a black mass of a flaky consistency only is left on the surface, which can be easily collected with the blade of a knife and put into another vessel. This second vessel is then heated until the last traces of aniline evaporate out, when the weight of the black mass gives the amount of the free carbon in the sample that has been tested.

In such cases where it is merely required to find out whether a so-called pure natural bitumen consists of, or contains, an artificial product, the test for free carbon furnishes a very good stopping place for the determination of the question. In this case, however, so as to obtain an exact result, the powder should be treated with carbon bisulphide, ether and chloroform successively, in order to extract the carbon in a thoroughly pure form. Since pure natural bitumen often contains a certain amount of ash as well, the weight obtained when a sample of it is being thus tested does not give the true weight of the free carbon. To find this, the residue after the extraction of the soluble bodies, must be heated in a clay crucible with a strong flame for some time, so as to burn up all the carbon in it, when the residue, which now consists solely of ash, is again weighed. The loss in weight is that of the pure carbon that was previously contained in the material.

Another of the very important tests in the analysis of bitumen is always to solve the question whether the material has been adulterated or not, and the addition of coal tar products can be detected in a sample of so-called natural bitumen, instead of testing for free carbon, as just mentioned, which takes up a certain amount of time, by making the following test :—

Eight grammes of the substance to be tested are reduced to a very fine pulverulent condition and then shaken up in a closed vessel with 5 gms. of benzine —free from water—until a very dark coloured solution has been formed. This is filtered, and in the meantime a mixture is made up of equal parts of benzine and 85 per cent. alcohol. Into this mixture a few drops (five or six) of the dark solution are added and the whole is then thoroughly shaken. After this is done, the vessel is allowed to stand, when its contents will separate out into two layers, the upper one being the benzine and the lower one the alcohol. If the alcoholic layer is colourless, the original substance is a natural bitumen only, but if that layer takes a golden brown colouration, then an artificial product is present.

Even when dissolving the substance about to be tested in the benzine only, an indication is recognisable by one accustomed to carrying out this test, as, whilst the natural product dissolves out with a pure brown colour, coal tar products give a strong yellowish green fluorescence. However, it is best for the ordinary practical man to continue this test through to the end, as the result will then clearly prove the composition of the sample without any possibility of doubt.

There is also a very simple method to adopt in order to tell one artificial bitumen from another, consisting of merely holding the product in question over an open flame and then smelling the vapours which are given off. Besides coal tar residues, there are often employed others, such as those made from wood tar, turf tar, or stearin, each of which has its own distinctive odour, which is easily noticeable when the material is heated, and, when once known, will be readily recognised again. In cases where a query may arise it is usually sufficient to heat a small portion of the pitch, either coal tar pitch, turf tar pitch, stearin pitch, etc., according to the doubt, and to compare the odour arising from it with that which is given off by the material then being tested.

Another definite test for the presence of coal tar pitch in a suspected material is based upon the fact that, as already pointed out, it contains a quantity of free carbon in contrast with the natural bitumen which contains none. Natural bitumen presents a uniform brownish appearance when a very little of it is fused upon a hot microscope slide and examined under a microscope. In the suspected sample the free carbon may be seen suspended in the bituminous matter like small black dots, though to the naked eye the mass appears to be a true bitumen.

A means of determining the exact character of a material, providing that it is not a mixture of two or more, can be found by noticing the effect of concentrated sulphuric acid upon it. True bitumens give a colourless, or at the most, a very faintly coloured liquid, whilst coal tar products show up intensely brown. The method of procedure is as follows :—

A quantity of the substance is digested in carbon bisulphide, and the clear solution thus obtained is then filtered off. This filtrate is now evaporated to dryness and the heat applied continuously until the material becomes hard and brittle after being cooled. Of this, a tenth part of a gramme is taken and shaken up for a few minutes with 5 c.cs. of fuming sulphuric acid in a stoppered flask. The mixture is then allowed to stand for twenty-four hours after which 10 c.cs. of water are added drop by drop, the whole being constantly agitated all the while and kept from becoming too hot when necessary, by holding the flask under a stream of water from the tap, and finally filtered. If the conditions of the tests are kept uniform, *i.e.*, if the same weight of the sample and the same volumes of carbon bisulphide, sulphuric acid and water are taken in every instance, an approximate qualitative comparison of the samples may be made according to the following colours :

Rock asphalt	faintly coloured
Trinidad bitumen	slight brown
Petroleum pitch	no colouration
Shale oil pitch	hair brown
Coal tar pitch	very dark brown
Bone pitch	intense brown

A further test to differentiate between natural bitumen, petroleum residue, and coal tar pitch, has been thus described by Kovacs :—

" A sample of the substance is first extracted with carbon bisulphide and filtered. The filtrate is then dried in a water bath and finally heated to 110° C. This dried residue is dissolved again in two and a half times its weight of carbon bisulphide, thus forming a concentrated solution of the alleged bitumen in carbon bisulphide. A cubic centimetre of this solution is now put into a flask with 2·5 c.cs. of oil of turpentine, and should the material consist of coal tar pitch, a light brown solution and precipitate is formed, whilst with pure bitumen the solution remains dark in colour and forms no deposit. To the original solution is now added absolute alcohol in the proportion of one to ten, when a brown precipitate is formed if coal tar pitch is present ; a black, sticky, pitchlike precipitate if it is natural bitumen, and a black, flocculent deposit if it is petroleum pitch. If this precipitate is now filtered and dried to 90° C. to 95° C., the coal tar pitch obtained is powdery, dull and of a light brown colour; the natural bitumen is black, sticky with a fine gloss, and can be drawn out into fine threads if it is warmed in the fingers; whilst the petroleum pitch is black, dull, earthy and can be broken between the fingers with the greatest ease.

"If one cubic centimetre of the original solution is shaken up with only five cubic centimetres of absolute alcohol, then coal tar pitch gives a brown deposit, petroleum pitch a black slimy precipitate and bitumen a black precipitate. The liquid is a reddish brown with petroleum pitch and light brown with both coal tar pitch and with pure bitumen, hence the earlier distinguishing test. On the filter paper, when dried to 90° C. to 95° C., the precipitated coal tar pitch and the pure bitumen are shiny, pitchlike and bind together when heated, whilst petroleum pitch on the other hand is dull, easily broken and leaves behind it a transparent oily brownish red stain on the paper."

Besides the foregoing tests for purity, it is also necessary to test the bitumen for composition and quality, and for this purpose the solid and liquid types have to be treated separately.

With the crude solids, one of the first tests is that for moisture. For this Professor Richardson suggests two alternative methods, one by heating in a steam oven and the other by drying in a desiccator. Of the two, the writer much prefers the latter as being the easiest and simplest to carry out, whilst at the same time the first has the objection that the second has not, in that a certain amount of the light oils contained in the bitumen also evaporate out with the steam. The simplest method to be adopted then is as follows:—

A portion of the sample is placed in an ordinary mortar, which is provided with a lid through which the pestle is able to pass. In this the material is reduced to a coarse powder of which a weighed quantity is placed upon a large dry watch glass, the weight of which has been previously noted, and so spread over it that as large a surface as possible is secured. In this condition it is placed in a desiccator and left there for some twenty-four hours. It is then weighed, and the loss found is the weight of the moisture which has been extracted during that time. The sample is now ground to a very fine powder, and again put into the desiccator, where it is allowed to remain, until upon weighing at intervals of twelve hours it is found that it loses no further weight. The total weight thus lost by the powder is taken as the amount of moisture originally present in that quantity of the sample which has been treated, and the percentage content is calculated from that.

The actual test used for this investigation when carried out in the laboratory is the fractional distillation test, when the moisture comes over in the first fraction, from which it is allowed to settle. As the fractions are collected in graduated cylinders, the amount of water thus collected is readily read off and its weight calculated. In carrying out this test, however, it is usual to dissolve the bitumen in benzol prior to the actual process of distillation.

The tests for the specific gravity of a bitumen are carried out in different ways, according as to whether they are liquid, semi-fluid, or solid. In the case of the first, the hydrometer is employed, for the second, an apparatus known as the picnometer, whilst the amount of water that a weighed quantity replaces forms the base of the test for the third.

Another test with which it is desirable to be acquainted is what is known as the penetration test. For this, however, a specially built apparatus is necessary which, being both expensive and delicate in operation, will rarely be employed by the practical man, its use being relegated rather to the technical laboratory. In brief, the penetration figure, as the result of this test is called, is the distance in one hundredths of a centimetre that a No. 2 needle will penetrate a sample of the material under consideration in a space of five seconds when under a superimposed weight of 100 grms. and at a temperature of 25° C.

When the material is too soft to allow of this test, and yet is too viscous to permit of the use of the float, it is usual to make use of an Engler's viscosimeter. This consists of a metal vessel which contains the material to be tested, in the bottom of which is a conical outlet, the internal diameters of which are 2·9 mms. and 2·8 mms. at the top and the bottom respectively. Under this outlet is placed a graduated cylinder so as to catch any droppings from it. The sample is now heated by means of an oil or a water bath, and the outflow of the substance through the outlet at a certain fixed temperature, is noted. The outflow of water is taken as the unit, and this, at 25° C., is 11 seconds for 50 c.cs., and 22·8 seconds for 100 c.cs. The usual figures for light flowing oils, viscous and semi-liquid malthas are approximately 100 c.cs. at 25° C., 50 c.cs. at 50° C., and 50 c.cs. at 100° C. and over respectively.

When any bitumen or a bituminous product is to be heated before use in any manufacturing process, especially if it is a liquid in its natural state, it is necessary to determine the flash and the ignition points. This is sometimes done very crudely by heating a sample in an open basin, but the results so obtained are very unsatisfactory and cannot be depended upon. A proper oil tester should always be used, and this instrument consists of a metal receptacle for the sample, which sits in an oil bath and is heated from below by a Bunsen burner. The receptacle is fitted with a lid through which passes a thermometer, which, by dipping in the sample, indicates the temperature of the latter at the various stages of the test. A small hole is also made in the lid so as to allow of the insertion of a tiny gas jet. This jet is made by connecting a small piece of glass tubing having a small bore to the gas service, and arranging the pressure of this so that a small gas flame of about 15 mms. is formed. The oil bath is now heated gradually, so that the temperature of the sample increases at a rate of about 5° C. per minute, and the test flame is inserted in the chamber from time to time without, of course, coming in contact with the sample itself. Finally a bluish flame will be seen formed when the test flame is dipped into the vapour, and when this stage is reached, the temperature of the sample is taken and the reading so obtained is known as the flash point.

To determine the ignition point the thermometer is now raised out of the sample, though still left in the closed chamber, and the test is continued by further increasing the temperature. When the oil itself takes fire when the test flame is inserted, the ignition point of the sample has been reached, and the degree at which this occurs is also noted from the thermometer.

As the volatility of the malthenes is an important point in the use of a bitumen for industrial purposes, it is customary to submit liquid, semi-fluid, and even low melting solid bitumens to an evaporation test. For this purpose a vessel is used which has a perforated lid. Through this latter pass two thermometers, one dipping into the sample that is being tested and the other being suspended in the space above it. The sample is now heated to a temperature of 165° C., at which it is kept for a period of five hours, during which the temperatures as shown on the thermometers should not vary from that mentioned by 2° at the very outside. The sample is then allowed to cool and the loss in weight noted, after which it is usual to again test the resultant product for specific weight, the float test, penetration test, etc. At times, though it must be admitted that they are of very infrequent occurrence, this test is also carried out at other temperatures as well.

A test of more recent growth is that for the "*carbene*" content. The fraction of a bitumen known by this name is that which is soluble in carbon bisulphide but insoluble in carbon tetrachloride. This test is of particular value when it is believed that a bituminous material has suffered from overheating during the process of manufacture that it has undergone, since such over-heating increases the percentage of the bitumen which would respond to this test.

As distinct from the amount of "*free carbon*" that a bitumen contains, it is sometimes required to ascertain the percentage content also of what is known as "*fixed carbon*," *i.e.*, that carbon which is present in the bitumen but in a state of chemical combination with some other element or group of elements to form an organic compound. To determine this content, a gramme of the material to be tested is placed in a crucible, preferably of platinum, provided with a close-fitting lid. This is submitted to the full play of a Bunsen burner, the flame of which is so arranged as to completely surround the crucible. This is kept up for a period of seven minutes, when the crucible is removed, placed in a desiccator and carefully weighed after cooling. The lid is now removed and the contents of the crucible burnt to an ash, again placed in the desiccator and weighed after cooling. The weight of the ash as thus obtained is then deducted from the weight of the residue obtained from the first heating of the sample, and the result is the weight of the so-called "*fixed carbon*" that is found in the particular sample then tested.

A bitumen which contains an appreciable quantity of paraffin is very undesirable for various manufacturing processes as well as for paving purposes. It is therefore often necessary to determine the percentage of this matter in a sample of bitumen, in order to ascertain if the latter is suitable for some particular purpose. To do this, 100 grms. of the sample are taken and distilled as rapidly as possible to a dry coke, whilst the distillate is collected in a suitable vessel and weighed. From this distillate 5 grms. are taken and mixed with 25 c.cs. of ether in a 100 cms. capacity flask, after which 25 cms. of alcohol are added. After the flask and its contents have been submitted to a freezing mixture at a temperature of —18° C. for half an hour, the liquid is then filtered by means of a filter pump, the upper portion of which is packed round with a freezing mixture in order to keep the liquid which is being filtered at the temperature mentioned. The mass left on the filter paper is the amount of paraffin contained in the sample treated, and when weighed the percentage content of it in the material itself can easily be calculated. It must be confessed, however, that this test is not always too satisfactory in actual practice, and it is therefore usually used merely to obtain an approximate idea of the paraffin content of a bitumen.

As coal tar and its products are now largely used in a similar manner and for similar purposes as bitumen, a few remarks on the principal tests for such products may not be out of place.

Coal tar is usually examined only as to its specific gravity, as this figure at once demonstrates if, and to what degree, the crude tar has been distilled. Before ascertaining this, however, it is absolutely essential that the tar shall be free from water, and this condition is arrived at by the simple expedient of allowing it to stand for at least twenty-four hours in a narrow-necked flask, which is stood in a water bath by means of which the tar is kept at a constant temperature of 50° C. The water which separates out is then removed by decanting it off the tar and afterwards removing any small quantities which may remain floating on the surface by absorbing them with blotting paper. The tar is now allowed to cool to the temperature of the room—that is to say to about 15° C.—and as the usual instruments for determining specific gravity cannot be employed with viscid tar with any degree of accuracy, it is best to make the test in the following way :—

A cylindrical weighing tube of 50 c.cs. capacity, having a groove filed through the stopper, is used, and its specific gravity is determined by (*a*) first weighing the tube when empty and (*b*) when filled with water. After this, it is emptied and dried, and then filled with about two-thirds its capacity of the water-freed tar. In this condition it is placed for an hour in hot water until all the air bubbles have been expelled from the tar, when it is again allowed to cool. When it is cold the vessel and its contents are again weighed. (*c*) The tube is now filled up with water, the stopper inserted and the excess of water carefully removed, after which a further weighing is carried out during which the tube is stood in a large vessel of water at a temperature of 15° C. (*d*) The specific gravity sought is now calculated from the following formula according to the results obtained from the foregoing experiment :—

$$\frac{c - a}{b + c - (a + d)}$$

To accurately test the quality of the tar it is necessary to find the yield of the various constituents contained in it, and this is done by distilling a sample of about 250 c.cs. on a small scale at a rate of about 40 to 50 drops of distillate per minute. This distillate is collected in fractions divided at the temperatures of 170° C., 270° C. and 315° C. The mass which then remains behind in the retort is regarded as the residue. If there is water in the tar, it passes over with the first fraction, in which it forms a lower layer, since the light oils, by reason of their inferior specific gravity, lie upon its surface.

In the residue thus formed is always to be found a certain amount of solid matter made up of ash and "free carbon." As for certain purposes a high proportion of this is prejudicial to the material prepared from it, it is customary to find in the specifications, especially for material for road spraying, etc., a maximum limit beyond which a material will not be accepted. It is therefore necessary to determine this content in a tar, and the method adopted in this case is as follows :—

Ten grammes of the tar is exhausted with 25 c.cs. of glacial acetic acid and 25 gms. of toluol. It is then passed through a weighed filter paper and the latter afterwards well washed with toluol and dried to 120° C. The increase in the weight of the paper is that of the ash and free carbon contained in the quantity of the tar taken for the test, and when multiplied by ten it gives the percentage of these solid bodies that are present in the tar under consideration.

Coal tar pitch is usually examined only for its softening and melting points, and this in some factories by the "mastication" test only. This latter consists merely of placing a sample of the pitch between the teeth and noting the results. Soft pitch is readily pressed out flat; medium hard pitch will barely receive the impression of the teeth, whilst hard pitch crumbles between the teeth and falls to a powder. For more accurate examination, the apparatus of Kraemer and Sarnow is employed. Twenty-five grammes of the pitch to be tested are melted down in an iron pan which is heated over an oil bath to 150° C., so that the pitch forms an even layer approximately 1 cm. thick at the bottom of the pan.

A glass tube having an internal bore of 5 to 7 mm. and open at both ends is now taken, and one end dipped into the molten pitch. The upper end is closed with the finger, the tube is removed from the pan and the pitch is allowed to solidify inside it, after which the excess of pitch which adheres to the outside of the tube is carefully removed. There now remains in the tube a column of solid pitch about 5 mm. in height. Upon this is poured about 5 gms. of mercury, and then the tube is tied to a thermometer and both hung in a beaker of water which acts to them as a water bath and which in turn is heated by an ordinary water bath. Heat is applied gradually to the outer bath until it is noticed that the mercury commences to penetrate into the pitch. The temperature at which this occurs is recorded as the softening point of the pitch. In the case of soft pitch, this temperature should be between 50° C. and 51° C., for medium hard pitch between 60° C. and 70° C., and for hard pitch between 80° C. and 89° C.

To ascertain whether a coal tar pitch has been made from blast furnace tar or the tar produced from gas works, and for certain purposes this is a matter of paramount importance, the simplest method is to ascertain its ash content, the experiment being carried out in a similar manner to that adopted for bitumen. If the resultant figure is high, then the material is a blast furnace pitch, but if it is under 1 per cent., the sample is of a gas works pitch.

When rock asphalt mastic or any other product of rock asphalt is being tested, the procedure is to first extract the bitumen contained in it, which is then submitted to the various tests given above for natural and artificial bitumens, and afterwards to analyse the rock itself separately. The separation of the bitumen and the mineral matter may be done in the following manner :—

A sample of the mastic is crushed to a fine powder and then extracted with carbon bisulphide until no more of it can be dissolved out. The material thus dissolved is then regarded as bitumen and tested as such after the carbon bisulphide dissolving it has been driven off. The residue is mineral matter, and the proportion of this which is limestone is ascertained by treating the whole with hydrochloric acid when the limestone is dissolved out, leaving behind it small quantities of other materials such as sand etc., according to the particular type of rock asphalt that is being tested.

In addition to this, however, the four following qualitative tests are recommended to the practical man as being both simple to execute and quickly carried out, for it must be borne in mind that whilst it is one thing for a material to meet a chemical standard, it does not necessarily follow that by fulfilling these chemical conditions it will also fulfil the essential physical ones.

(1) Mastic should be able to be cut with a knife. If the material proves to be too hard or of too stony a nature, it proves that there is an insufficiency of bitumen or that the bitumen has not been suitably fluxed, and therefore liable to speedy segregation.

(2) Cuttings of the mastic must resist tension at the ordinary temperature of the room—say 20° C. If the rock is too soft, if it has been fluxed too much, if there is too great a quantity of bitumen than is necessary, the material will be too soft to hold together properly, with the result that any work that may be done with it will readily receive indentations and rapidly form into ruts and holes if subjected to much vehicular traffic.

(3) When held above a lighted taper for a minute or so it should give off the smell of bitumen only. Should the smell of tar or pitch, as found in the gas works and such places where these products are treated for any purpose, be distinguished, then the sample is either an artificial asphalt or one that has been adulterated with a coal tar product.

(4) When held for some time over a gas flame it should soften, but it should never run or begin to ignite. If it burns, then the mastic contains too much flux—in all probability a petroleum residue at that—and for practical purposes the material will prove to be too soft, whilst further, after being subjected to a constant summer heat, it will rapidly become brittle—owing to the evaporation of the volatile portions of the flux—and so quickly decay.

ANALYSES, ETC.

Rock Asphalts.

	Val de Travers.	Seyssel.	Lobsann.	Ragusa.	S. Valentino.	Pont du Château.
Bitumen	10·15	8·15	12·32	8·92	8·83	11·40
Limestone	88·40	91·30	71·43	88·21	80·00	77·52
Aluminium and iron oxides	0·25	0·15	5·91	0·91		
Sulphur	—	—	5·18			
Magnesium carbonate	0·30	0·10	0·31	0·96		
Sand	—	—	3·15	0·60		
Insoluble in acids ..	0·45	0·10				
Undetermined ..	0·45	0·20	1·70	0·40		

	Rocca Morice.	Mons.	Limmer.	Vorwohle.	Sysran.	Cesi.
Bitumen	12·46	10·20	14·30	8·50	30·50	7·15
Limestone	77·53	84·63	67·00	80·04	66·23	73·76
Calcium sulphate ..	2·63	—	—	—	—	1·72
Aluminium and iron oxides	2·17					
Sulphur	—	—	—	4·03	—	3·02
Magnesium carbonate	4·71	—	17·52	0·55	3·27	—
Sand	0·50	—	—	—	—	14·24
Insoluble in acid ..	—	—	—	4·77	—	0·10
Undetermined ..	—	—	1·18	2·11		

American Rock Asphalts.

	California.	Kentucky.	Texas.
Bitumen	15·13	5·76	12·05
Sand	83·40	94·22	—
Limestone	—	—	87·94

Crude Bitumens.

——	Sele-nitza.	Cuban.	Mexi-can.	Trini-dad.	Vene-zuelan.	Californian.	
						Hard.	Soft.
Bitumen	72·69	24/68	35/94	35/40	45/95	99·10	99·68
Mineral matter ..	17·19	73/26	55/4	41/26	40/2	0·36	0·20
Organic ,, ..	1·00	2/1	8/2	10/4	7/1	0·54	0·12
Water	9·12	1/5	2	14/30	8/2	—	—

Solubility of Bitumens.

Solvent.	Lobsann Bergteer.	Trinidad.	Maracaibo.	Barbadoan.	Syrian.
Water	Insoluble	Insoluble	Insoluble	Insoluble	Insoluble
Dilute acids ..	,,	,,	,,	,,	,,
Alkalies ..	,,	,,	,,	,,	,,
Alcohol	Partly	5%	Slightly	Partly	5%
Ether	Entirely	57%	Partly	,,	44%
Chloroform ..	,,	Completely	Completely	Completely	Completely
Oil of turpentine	,,	,,	,,	,,	,,
Melting point ..	(liquid)	130/165° C	130° C	110° C	135° C

Chemical Composition of Bitumens.

——	C.	H.	O.	N.	S.	Authority.
Pont du Château..	77·52	9·58	10·53	2·37	—	Ebelmen
Abruzzi	81·83	8·28	8·83	1·06	—	,,
Cuba	82·67	9·14	8·19		—	Wetherill
Coxitambo ..	88·63	9·69	1·68		—	,,
Pechelbronn ..	86·60	11·40	0·40	0·30	1·40	Kayser
Egypt	85·29	8·24	6·22	0·25	—	Boussingault
Dead Sea	80·00	9·00	—	0·40	10·00	,,
Syria	80·50	9·06	—	0·38	10·06	Kayser
Trinidad	78·80	9·30	—	1·40	10·00	,,
Barbados	87·04	9·56	—	—	2·67	,,
Maracaibo ..	81·65	9·59	—	—	—	,,

SOLUBILITY IN PETROLEUM SPIRIT AND SULPHUR CONTENT.

Solubility in Petroleum Spirit.					Sulphur content.	
——	Ash.	Soluble.	In-soluble.	Bitumen soluble.	Sub-stance.	Organic matter.
				Per cent.	Per cent.	Per cent.
Val de Travers ..	90·24	9·76	—	100	0·41	4·20
Fine Syrian ..	0·68	48·16	51·16	48·49	6·13	6·19
Trinidad	37·76	36·24	26·00	58·22	3·47	5·58
Stearin pitch ..	5·50	71·05	23·45	75·18	0·04	
Stockholm pitch ..	0·84	91·46	7·70	92·23	0·01	
Resin pitch ..	0·58	86·94	12·48	87·45	0·26	
Coal tar pitch ..	1·06	18·70	80·74	18·90	0·41	

SPECIFIC GRAVITY OF BITUMENS.

Mexican	1·04
Gilsonite	1·04
Bermudez	1·05
Wurtzilite	1·05
Maracaibo	1·06
Californian	1·06
Manjak	1·08
Albertite	1·08
Syrian	1·10
Grahamite	1·16
Cuban	1·30
Trinidad	1·40

CHAPTER XI

PHYSICAL PROPERTIES OF ROCK ASPHALT

In considering the use of rock asphalt for road making purposes, it is necessary to handle the question both as regards the type of the rock that is impregnated, and the nature of the bitumen which impregnates it, together with the proportion of the latter and the state of impregnation.

It must always be borne in mind that the impregnation of a rock with bitumen results only in a mixture, more or less intimate according to circumstances, but not in a combination, so that although at times they may be masked, the chemical properties of the rock are not changed. Thus for example, any of the sulphides that may be mingled with the rock will always be capable of conversion into sulphates as the result of atmospheric oxidation. Still, the action of chemical or physical reagents can be withstood by the bitumen which, to give a further example, would protect the limestone from the attack of cold hydrochloric acid. The properties, however, that are most interesting from our point of view are resistance to crushing, wearing, etc., properties which are subject to certain conditions that will be gone into in the following pages.

To begin with, bitumen is found distributed in the rock that it impregnates, in ways which vary according to the state of division in which the rock chanced to be at the moment of impregnation. Thus it is possible to distinguish between an impregnation in bulk, in the powdered form and in the molecular state.

In the last are included those rocks which for some chemical or physical cause, owe their origin to a precipitation from an aqueous mass. Such are the sandstones, deposits of "geyserite," limestone "travertins," tufas, and perhaps some of the clays, to mention only the most interesting from our particular standpoint. These are a few examples of rocks which during their sedimentation found themselves in the presence of a bitumen itself in such a condition as to be susceptible of mixing with them at the moment they were in that molecular state. The Trinidad "lake" deposit probably comes under this category.

It is rare, however, to find rocks that have been impregnated with bitumen in their massive or even in a fragmentary state. An exception to this is, of course, the material that is obtained from the mines at Acquafredda, which, as has already been pointed out, does not segregate as do the other types of natural bituminous rock, upon being heated. This rock has a cohesiveness of its own, so that in this case the bitumen does not play the part of a cement binding together the integral grains, but is merely a material filling up the voids in the rock. To this type of impregnation is given the term of "*porous* penetration." The presence of the bitumen, though, greatly increases the capacity of the rock to resist crushing, since the fact of the viscous substance being confined in its pores in such a way that it cannot be extracted by the most powerful pressure that may be exerted upon the rock, prevents that alteration of shape which results in a fracture with the unimpregnated rock. Thus an unimpregnated sample which breaks under a pressure of 95 kgs. per square centimetre is able to withstand a pressure varying from 153 to 189 kgs. per square centimetre when impregnated with 12 per cent. of bitumen.

The majority of the naturally impregnated rocks are those which have received their bitumen content whilst in a powdered state. They segregate under the influence of heat, so that roads made from the rock asphalt mastic or the compressed rock asphalt powder are merely formed by coating the surface with a covering produced by the re-union of a pulverulent material with a bituminous cement. The characteristic of this impregnation is that each grain has its own coat of bitumen, the adherence of which to those coating the other grains surrounding it occasions the cohesion of the rock, and as this adherence varies according to the consistency of the bitumen, the cohesion of the rock also varies with the temperature. To distinguish it from the "*porous penetration*," this impregnation is known as "*bitumen of intercalation.*"

In order to ascertain the respective values of different rocks for road making, Messrs. Durand-Clay and Debray carried out experiments by means of which to determine the coefficient of wear of two compressed powders, one made from a bituminous limestone and the other from a natural bituminous sandstone, both materials being obtained from the same district. The method adopted was to find the thickness which was worn from a rectangular prism when loaded with an evenly distributed weight of 300 gms. per square centimetre and rotated round a circle 1 metre in circumference for 1,000 times. Under these conditions the ordinary sandstone as used for paving purposes has a wearing coefficient of 53, whilst the bituminous limestone was found to vary between 42 and 49 as against the bituminous sandstone whose figures were from 51 to 60.

The same difference was observed when the point of resistance to crushing stress was considered. Blocks of equal sizes were made of the two materials, and though that composed of the bituminous limestone broke under an average pressure of 328 kgs. per square centimetre, that made with the bituminous sandstone only resisted up to a pressure of 217 kgs. per square centimetre.

A further point for consideration is the power that the rock possesses of retaining the bitumen which impregnates it. M. Daubrée, in seeking to explain the difference in the richness in bitumen between the impregnated limestone and sandstone of the Sulz unterm Wald district, placed pieces of the unimpregnated rock of both types into a bath of Pechelbronn bitumen, the operation being assisted by slightly heating the latter. Although viscous at the ordinary temperature, the bitumen was quickly absorbed, impregnating the whole mass in both cases right through to the centre. Whilst the limestone absorbed 17 to 24 per cent. of its own weight of bitumen, the sand, even with the assistance of additional heat, only absorbed 8 to 9 per cent. Further than this, however, the bitumen was so absorbed by the limestone that even when it was pulverised into a fine powder and immediately submitted to boiling water, it could not be brought back to its original colour again, although at that temperature this particular bitumen is perfectly fluid. With the sand, although some of the bitumen is retained, it is, however, a much less quantity than is the case with the limestone.

Clays and marls have a still greater affinity for bitumen than even chalk. It need only be pointed out again that at Pechelbronn the greatest difficulty in the extraction of the bitumen is caused by the clay which is present in the impregnated rock, and this clay retains the bitumen impregnating it most firmly, so much so, in fact, that in refining, a rich residue is always left which, known as "*calphonium*," consists of clay intimately mixed with bitumen and from which the latter cannot be extracted economically by the usual industrial methods. The same difficulty is met with in the purification of the crude bitumen extracted from the Trinidad lake, which substance may also be looked upon as a clay impregnated with some 50 per cent. of bitumen and mixed with a certain amount of water.

This property of clay has been made use of from the most ancient of times, the Babylonians having used it, as a reference to an earlier chapter will show, in the formation of bituminous dampcourses for their buildings.

The bitumens, too, show so many differences amongst themselves that it is also necessary to examine the composition of the rock in detail according to the use for which it is intended. The principal properties for our purpose are fusibility and tenacity; for they possess widely differing melting points, and it is, of course, essential that they shall not fuse at the extreme heat to which they may be exposed. Fusing proper is really preceded by a viscous state, and it is with reason affirmed that it is to this viscosity that the elasticity of work done with the asphalt mastic or compressed rock asphalt powder is really due, for when extracted the bitumen which naturally impregnates the rock asphalt is usually soft, if not actually semi-fluid. A bitumen which is hard and solid at the ordinary temperature would not admit of this flexibility, whilst one which is liquid or easily flowing would be too soft to withstand the pressure exerted by traffic upon it. Both can, of course, be suitably modified, the one by the use of a suitable flux and the other by evaporating from it the more volatile portions. In the first case, however, precautions must be taken to use a suitable flux, *i.e.*, one that will truly blend with the original bitumen, will not "bleed" in hot weather or dry out and leave the bitumen in its first stage; whilst in the second case the process of heating must be carefully controlled, otherwise a decomposition of the bitumen will result, giving rise to entirely new products with totally different properties from the ones desired.

The tenacity of the bitumen in its viscous state diminishes as its fusing point is approached and increases as the temperature is lowered, becoming fairly weak in the hot weather during which the bad condition of some rock asphalt roads is particularly noticeable. In order to compare the tenacity of two bitumens in their viscous state, it is usually sufficient to note whether they can be drawn out into threads, and the fineness of the thread that is obtainable before it breaks. Blown oils and cut back infusible bitumens usually form no thread at all, but merely break in two when any tension is exerted upon them.

The bitumen which impregnates the rock must also be considered as regards the type of impregnation, and for this it is essential to distinguish between the proportion of bitumen of "porous penetration" and that of intercalation. In other words, a proportion of bitumen which would be considered satisfactory in a pure limestone which is non-crystalline and non-compact would be too great for a more compact and crystalline one, since in the latter case the proportion of bitumen of "intercalation" required would be less, with the result that the bitumen of porous penetration would be increased accordingly. Thus the crystalline Seyssel rock requires a less proportion of bitumen in its mastic form than does, for example, the Limmer type, whilst this latter again requires less than the still finer Val de Travers material. This point is one that is very often overlooked, the value of a rock asphalt in many instances being considered as being enhanced or otherwise according to the percentage of the bitumen that it can show. This is to be regretted, as it has the tendency to cause the mastic now on the market to be made too soft for first-class work, merely in order that it can show a large proportion of bitumen.

We have already remarked that the material which is obtained from the mines at Acquafredda in the Abruzzi, must have been impregnated in bulk, since it will not segregate when it is heated. It only contains, therefore, bitumen of "porous penetration," and as it is successfully used for the making up of compressed rock asphalt powder roads, it may be reasonably concluded that the amount of bitumen necessary to penetrate the pores of the rock is sufficient for this class of work. At the same time, this does not mean that a certain amount of bitumen of intercalation would be objectionable; rather it would appear that a percentage of this latter would be of advantage, for even with our present methods of compressing the rock asphalt powder after it has been spread upon the road, it is impossible to eliminate all the voids between the grains of the material when finally compacted, so that the presence of the bitumen of intercalation would, by acting as binder, leave the bitumen of porous penetration free to fill these voids, and so give an additional watertightness to the layer. On the other hand, tests made with a rock composed essentially of a felspathic sand, and bound—not penetrated—with 8 to 9 per cent. of bitumen, have shown that the simple intercalation of bitumen around the grains of a rock asphalt that cannot have been impregnated in bulk does not preclude its use for compressed work for which it is used to a great extent in America.

With the asphalt mastic, which is spread without pressure, the cohesion, and to a minor degree the filling up of the voids between the grains, must necessarily be effected by the bitumen of intercalation. As already pointed out, the percentage of bitumen as found in the different types of rock asphalt mastic differs according to the type of the rock that is impregnated with it, but it is now usual to increase this figure above the nominally desirable one in order to secure a product that will be moister, and so spread more easily and freely under the workman's float. The pressure and the motion given to the material during the operation of spreading causes this excess of bitumen to rise to the surface of the layer, where it forms a kind of black varnish over the asphalt mastic, though for roads and pavements it is rubbed with a fine sand or dust before cooling, so as to afford a foothold upon it for traffic.

The influence of the regularity of impregnation with bitumen of a rock asphalt, although it has been keenly disputed, does not seem to have ever been settled. For a long time it was believed that a regular impregnation was essential for satisfactory work, but now it is usually recognised that it is sufficient to examine the state of impregnation only. Thus M. Bartet, whilst speaking of a mineral the irregularity of whose impregnation was such as to give it almost the appearance of concrete, says:—

"We are not afraid of the concrete nature of the mineral, for as has been actually proved, this mineral considerably increases its homogeneity when it is reduced to a powder and slightly heated, the unimpregnated limestone apparently attaching itself to the bituminous threads so that the white specks are very soon only perceptible here and there. (It should be remembered that all bituminous rocks when sufficiently magnified show a large number of white spots.) A piece of compressed work was made with it in our presence and then ground down at a grindstone. Its wearing co-efficient was 6·21, whilst that of a piece of Val de Travers, as obtained from old streets, when subjected to a like test, showed a co-efficient of 6·63. As compressed rock asphalt powder when laid on roads loses in thickness in the course of time without being appreciably reduced in weight, there is apparently not so much wearing away as an additional compression, so that the sample of the old material should have resisted this wearing test even better than that freshly made."

As the Italian rock asphalt generally has been considered preferable for compressed asphalt powder work, samples taken from different mines were examined by Herr Dietrich, of the Berlin Technical School, at the request of the Italian government. The rocks tested were taken from (*a*) Acquafredda (*b*) St. Angelo and (*c*) Cesi. In these he found the following characteristics :—

(*a*) The rock is very hard, crystalline, and not uniformly impregnated. It does not fall to a powder under the influence of heat like the natural bituminous rocks of other localities, but retains its cohesion. It contains 9·14 per cent. of a bitumen which is tenacious and strongly agglutinating. When this bitumen has been extracted from the rock, a residue of almost pure calcium carbonate is left with a few spangles of mica.

(*b*) This rock has the same hardness and texture as the above, with the same bitumen impregnating it. Its bitumen content is 6·69.

(*c*) This rock is compact, of a dark chestnut or black in colour, and is very well impregnated with a bitumen, the content of which reaches 12·26 per cent., and is of the same nature as the preceding. This rock is more suitable for use in the manufacture of the rock asphalt mastic.

The conclusions arrived at by Herr Dietrich as a result of these investigations are as follows :—

"The limestone of the rock asphalts mentioned is so crystalline and compact that the bitumen cannot properly impregnate it ; further the powder prepared from it, as well as that made by heating and recompressing it, contains an appreciable number of white specks, which are usually regarded as being objectionable in material which is to be used in compressed rock asphalt powder work. In practice, however, these do not preclude the use of the above mentioned rocks for the work in question and should not diminish its durability if care is taken to reduce the rock to a very fine powder.

"The bitumen contained in the rock asphalt is rather harder than that to be found in other types of rock asphalt used for compressed asphalt work, so that this rock should be used for preference in those towns that are not subject to intense wintry cold. However, the bitumen can be made softer by a suitable sprinkling of the heated powder with petroleum that has been previously heated for a considerable time at 100° C., and then carefully and repeatedly mixing the material."

Two types of rock were taken from the Acquafredda mines, one showing a percentage of bitumen of 9·14, whilst the other only possessed 7·38. Of these, Herr Dietrich mentions that:

"The proportion of bitumen in the first rock is very favourable to the utmost stability and hardness in roads constructed with it in the ordinary way, but the second rock is not so suitable, as it would not be possible to prevent damp and frost from penetrating the surface of the road unless the asphalt powder was very firmly compacted and rammed again after being again well warmed.

"The experiments proved conclusively that it is not necessary to heat the powder for a lengthy period in order to get rid of that amount of the liquid bitumen which might by chance be there, but it is more necessary to keep the rock asphalt powder at 100° C. to 130° C. in order to evaporate absolutely every trace of moisture, for it is when it is thoroughly free from water that the powder is best applied to the road."

The conclusions of Herr Dietrich express the inconveniencies which arise from the use of a powder which is not homogeneous even after the preliminary heating, and they clearly show the utility of holding to the condition referred to by M. Bartet, as to the homogeneous impregnation of the bitumen throughout the asphalt powder before compression.

The following are the results of further tests made to investigate the effect of heating the asphalt powder immediately before use, as regards its effect upon compression. The wearing coefficient of the rock asphalt powder when used hot was 4·64, but when compressed in its cold state it was 5·60, even when compressed under a much heavier weight. Both samples were similarly affected by a superimposed pressure of 160 kgs. per square centimetre, each losing a third of its thickness, although it must be remembered that the one made up of the powder in its cold state had previously received a far greater initial compression than had the other. Of two samples, one made up of the hot and the other of the cold powder, both were heated to 160° C. and immediately afterwards placed under a hydraulic press, when the first began to lose its shape under a pressure of 60 kgs. per square centimetre ; under 80 kgs. the edges began to open, and under 110 kgs. per square centimetre the thickness was decreased by two fifths. The second sample lost its shape and fractured under a load of 25 kgs. per square centimetre, and when this load was increased to 30 kgs. the lateral faces separated.

In the case of work carried out in rock asphalt mastic, the possible variations arising from different degrees of heat or of pressure during the progress of the work are of course absent. With it, instead, the life, durability and general condition of the work are dependent upon the quality of the material only. In this case, too, a certain amount of judgment must be exercised with the degree of heat at which the mastic is fused, but so long as this is such that it reduces the material to a thickly flowing mass without allowing it to burn, it does not play that great part in the binding of the material when spread, as is the case with the rock asphalt powder. The work done with the rock asphalt powder has one very important advantage over that carried out in the rock asphalt mastic in that, since it contains a less proportion of bitumen, the heat of the day has a less effect upon it. It is owing to this fact that the mastic form of rock asphalt cannot be used with any satisfactory degree of success as a road covering where the surface is to be subjected to much vehicular traffic, or if the loads to be drawn over it are very heavy. On the other hand, for pavement work the mastic is to be preferred to the powdered form, as here it gives much more satisfactory results. This apparent incongruity finds an explanation in the fact that the powdered asphalt surface, having been placed in position with pressure, requires also a certain amount of pressure constantly passing over it in order to enable it to retain that compactness which, by sustaining the close layer that has been formed upon the surface of the powder by the initial pressure, is conducive to durability. With the mastic, on the other hand, constant pressure would result in the gradual displacement of the material immediately beneath the weight, when, as in the summer months, it is also subjected to a high degree of heat. Being, however, more coherent than the powdered form, by reason of its higher percentage of bitumen, it is thus able to better withstand the friction occasioned by foot traffic than is the compressed material. This resistance to foot traffic is assisted too by the fact that it is usual to add to the mastic when used for this purpose a percentage of small grit, the purpose of which is to harden the surface of the material against the wearing action of the traffic, a method which could not, for obvious reasons, be adopted in the case of the compressed asphalt powder.

With bituminous macadam the dominating idea is still somewhat similar to that borne in mind in the case of the rock asphalt mastic, but here the work is essentially to lay a road-forming material, the pieces of which are to be held in position by being coated with the bitumen in such a way that the latter forms a bond between the adjacent pieces, and not merely a road surface. The adoption of the bitumen as the binder has as a result the absorption of a certain amount of the pressure and vibration caused by the traffic passing over the surface, which there is no doubt plays a very important part in the breaking up of ordinary macadam road surfaces. The putting down of a richer bituminous layer upon the bituminous base serves as a further shock-absorbing cushion, and, in addition, as a dust preventative.

The formation of the bituminous macadam has been carried out in two distinct ways, one by the penetration of the macadam road after the latter has been laid, with a semi-fluid bitumen—the "penetration" method—and the other by mixing the mineral aggregate with a solid bitumen prior to use—the "mixing" method. Both methods have their adherents, but the former would appear less susceptible to that evenness of bituminous intercalation that is so necessary for this kind of road surfacing, whilst the latter offers less possibility for the element of chance, and so is to be preferred. Where, of course, the intention is merely to adapt an existing water-bound macadam road into a bitumen-bound one, the first method is the only one that can be reasonably used. This subject will be found treated in more detail in a later chapter.

CHAPTER XII

THE CARRYING OUT OF ROCK ASPHALT WORK

As a paving material many advantages can be claimed for rock asphalt, of which mention may be made of the following. Such roads show extreme durability, permit of the greatest ease of traction over their surface, are easily repaired, are economical to maintain, are free from vibration, facilitate cleaning, create an absence of dust and mud, are pleasing in appearance, have numerous sanitary qualities, are poor radiators of heat, are essentially noise deadening, and provide an ideal surface for motor traffic. Of its disadvantages the principal ones arc the difficulty of horse traction on gradients of more than 1 in 60 and the greasy surface created in damp or foggy weather.

For roadmaking the material is used in three different forms—as the prepared powder for compression *in situ*, as the prepared tiles ready for immediate placing in position, and as the mastic. In all cases, however, it is absolutely necessary for the well-being of the finished road that an irreproachable foundation be provided for the rock asphalt surface. With regard to this, it must be borne in mind that it is this foundation which supports the weight of the traffic passing over the road, the rock asphalt surface merely fulfilling the purpose of forming an unchangeable elastic protective coating against the wear of the foundation by such traffic. If the foundations are not suitably prepared, so that it settles or becomes distorted under the weight it is called upon to bear, the asphalt layer, by following its modified profile, soon becomes full of hollows and ruts even if it does not actually crack.

The road should be excavated so as to allow of the laying down of a 6-in. layer of concrete and the thickness of the rock asphalt layer that may be decided upon. The street itself should be brought to as plane a surface as possible, all dips and rises being levelled up, as this item is of great importance to the durability of the rock asphalt surface. It is recommended, too, that before the asphalting work is put in hand, the various water and gas mains, electric conduits, sewer pipes and the like should be tested, so that there will be little possibility of a need to open the surface of the road again from such a cause. The subsoil being thus suitably prepared, the cement concrete foundation is put down, and for this purpose it is found that concrete made from natural cement is useless, as it does not possess the requisite firmness and solidity. Only the best Portland cement should be used, and the best results are said to be obtained with a **2 : 3 : 9** mix. This is laid and given the camber that the finished road is to show, after which it is left to set for seven to ten days, according to the weather conditions. Any hollows in the concrete should be levelled up with a cement mortar made up of a **1 : 1½** mix. No concreting should be done in frosty weather, and it should not be permitted for the concrete to be retempered or otherwise treated. Ample time should be given the concrete to mature, as upon this depends the wearing capacity of the roadway to a large extent.

It is essential for the compressed powder work that it is done on a dry foundation, in as dry weather as possible, whilst the powder itself must be free from moisture. If this matter is overlooked or scamped, the moisture forms cavities in the hot powder which, by preventing the coherence of the bituminous grains, gradually create holes and cracks in the surface. Before laying the powder, too, it is necessary to bring it to such a temperature that all dampness shall be driven out without, however, evaporating any of the valuable bitumen. This temperature, which varies between 90° C. and 150° C., is dependent upon the particular type of rock that is being used. Thus the Val de Travers rock asphalt powder is heated to a temperature of from 130° C. to a maximum of 150° C.;

the Seyssel material to a temperature of from 110° C. to 120° C., whilst that obtained from the Sicilian mines only requires to be heated to 90° C. This heat, besides evaporating the moisture that may be present in the material, also leaves the powder in a more suitable and pliant consistency for compression than when cold.

When compressed, the rock asphalt powder is reduced some 40 per cent. in bulk, so that when marking out on the kerb the height to which the layer of the hot powder is to reach this must be remembered. The heating of the material is done in both fixed and portable boilers according to the position of the work, and usually requires some three or four hours to properly and evenly heat the powder all through. From this boiler the hot powder is transferred into wheelbarrows in which it is taken to the site upon which it is to be spread, its heat being conserved during transit by a protective covering of tarpaulins or asbestos cloths. It is now laid across the road in stretches and then raked out into an even layer according to the depth to which it is to be laid. Following this, the material is rammed down with hot rammers, weighing approximately a stone, until just about level, when it is smoothed with hot irons to a level surface, and on this a fine dust can be swept over before the entire surface is finally well rolled with a 10-ton roller until the rock asphalt powder thus compressed is cold.

Roads made in this way are very satisfactory where the traffic is heavy and so helps to consolidate the material, but for light traffic the rock asphalt mastic has superseded it.

It has been stated that the weather resistance of the rock asphalt surface is increased by mixing in with the powder litharge and glycerine. The best results are obtained when to a hundred parts of the powdered rock asphalt are added fifteen parts of litharge and ten parts of glycerine. With this addition it is affirmed that the asphalt powder gives an extraordinarily firm layer, probably owing to the formation of lead glyceride. Instead, too, of heating the powdered rock asphalt, in which case the concrete surface, as mentioned above, must be quite dry, it is stated that the powder can be spread in a cold condition if it has been previously moistened with a solution of rubber in petroleum spirit.

A type of rock asphalt paving that has not received in the United Kingdom the attention and adoption that its possibilities would merit is the compressed rock asphalt tile. This class of material, as has already been mentioned, may be divided under two headings, those prepared from the crushed rock and those prepared from the mastic form of the rock asphalt. Allusion, too, has already been made to the superiority of the compressed form of roadway over that prepared from the rock asphalt mastic, and a like difference is to be found in the durability of the respective kinds of tiles.

An inevitable drawback with the use of the compressed asphalt powder when laid *in situ* is the large and expensive plant that is requisite for the proper carrying out of the work. When the area to be so covered is appreciable, the overhead charge per yard entailed by the use of this plant is not very noticeable, but when only small stretches are to be laid, or if some small repairs are necessary, or should the work have to be executed in provincial districts in which such plant is not permanently situated, this standing charge greatly increases the price of the work. It is therefore to eliminate this expense that the tile prepared from the rock asphalt powder is now used.

The preparation of these tiles closely follows the line of procedure that is adopted in the laying of a compressed rock asphalt powder pavement in that the powder is first raised to a suitable degree of heat and then subjected to an intense compression. As a result of this it would appear that the material thus compressed in the factory is much more sound than when the material is worked in large quantities in the open, as, whilst the question of the prevailing atmospheric and climatic conditions is entirely absent, the small area that is subjected to compression at a time—25 cms. square—entirely does away with the possibility of slack places, such as are found in compressed roads where for some reason or other the roller or rammer has not exerted the same pressure as upon the surrounding material (at times the cause of disintegration in compressed asphalt work), since the hydraulic press exerts the same pressure upon each of the tiles, and this pressure, too, is evenly distributed over their entire surface. Further than this, a pressure much in excess of that possible in work on roads can be used, thus materially increasing the already great durability of the ordinary compressed asphalt powder by creating a much denser and therefore a much more coherent material.

Economy is also effected in the work of laying itself, for instead of the large squad of men that is demanded by the process of laying the powder *in situ*, only the men actually employed in the setting of the tiles are needed.

Granted, therefore, that a surface equal, if not actually superior, to that formed by the spreading of the powder, can be obtained by the use of the compressed asphalt powder tiles, it follows that their use is extremely advantageous in narrow, yet heavily travelled alleys or narrow streets where the requisite rolling of the surface is impracticable, for short stretches of work, or in districts to which the carriage of plant and the transference of skilled labour would render the adoption of the compressed asphalt powder itself prohibitive. On the Continent it is quite usual for the road contractors to cover work of this description with a guarantee for ten years, and the writer has personally come in contact with roadways so formed which have undergone the traffic of the past twenty years without becoming appreciably worn or pitted.

It must, however, be understood that the tiles formed of the compressed asphalt powder are serviceable only in such places and under such conditions as those in and under which the asphalt powder compressed *in situ* would, under ordinary circumstances, be permissible. That is to say, they can be used with advantage for roadways and carriageways where the bulk of the traffic is vehicular, *i.e.*, compressive, but not where the traffic is mainly pedestrian, *i.e.*, frictional. The reason for this has already been discussed, and is based upon the fact that whilst the vehicular traffic augments the compression so necessary for the homogeneity of the work done with the compressed rock asphalt powder, foot traffic tends to loosen the bond between the individual grains which are then gradually removed either as dust or by adhering to the cause of their release.

For the actual work of laying down the tiles manufactured from the compressed rock asphalt powder it is, of course, essential, as with all other methods of rock asphalt roadmaking, that a firm and level concrete foundation is first provided upon which to set the tiles. This should be from 3 to 6 ins. thick, according to the volume and the weight of the traffic that will be passing over it, and should also be brought to the particular camber it is desired that the finished road shall possess, since the tiles, being perfectly flat, cannot of themselves create any fall or slope for drainage. According to the exigencies of the traffic, too, the tiles are prepared in varying thicknesses, being usually between 1 in. and 2 ins. thick.

The method of laying the tiles itself is a simple matter and one that can be easily done by any labourer of ordinary intelligence. In order to obtain a seal between the adjacent tiles when laid, and also to prevent any possibility of dust or wet working their way through the joints, it is usual to use a flexible bitumen. This material is heated in a suitable small cauldron, and, with a small quantity of this at his side, the layer begins to put down the tiles immediately upon the concrete foundation with butt joints. Before placing them in position the edges of each that will come in contact with the edges of other tiles already in position on the road are first dipped in the molten bitumen, somewhat after the manner adopted in the putting down of wood paving, and this bitumen, by adhering to the grains of both adjacent tiles, results in the final work becoming, for practical purposes, one homogeneous sheet of compressed asphalt powder.

The work is commenced from the kerb on the one side to that on the other, but where manholes, tramway rails, sewer grates, or the like may occur in the road surface, it is usual first of all to lay around them two or three courses of wood blocks so that, should they have to be lifted or renewed at any time, the work can be done without any interference with the asphalt tile surface. In the case of tramway rails, the use of a grooved concrete kerb has been suggested, in which to fix the rails and so allow the asphalt tiles to be laid flush up to the kerb. Occasionally the fitting of the asphalt tiles around these obstructions necessitates the use of a smaller size than the standard one of 10 ins. (25 cms.), and for this purpose a special cutting machine has been built with a guillotine action by means of which a tile can be cut into pieces without the powder forming the tile being loosened or otherwise injured at the point of severance. With but little experience a workman can lay a very large stretch of road per day in this manner.

In some cases the manufacturers of these tiles have recommended that, instead of dipping the edges of the tile in the molten bitumen in order to obtain a bond, the tiles should be laid in their original condition, and then, after the work is completed, a thin wash of pure Portland cement should be brushed over the surface and into the crevices. This suggestion has also been made by Delano, but, as Köhler points out, the intrusion of the cement into the joints between the tiles prevents that adhesion which is absolutely necessary if a homogeneous sheet of rock asphalt is to be the result.

Upon occasion the writer has seen instances where, after the compressed tiles have been laid in the customary manner, the surface has then been coated with a thin (say $\frac{1}{4}$-in) layer of ungritted rock asphalt mastic to serve as a wearing coat. Whether any additional advantage is to be derived by so doing is a very moot point, though for pavement work there is no doubt that such a method would do away with the weakness demonstrated by the compressed asphalt powder of wearing away under foot traffic.

The initial cost of these tiles has perhaps a great deal to do with the present paucity of their use in the United Kingdom, but their ultimate economy, both as regards cheapness in laying, durability, ease and cheapness of repair—should any be required by the breaking up of the road surface for any purpose—should be at once apparent. The rock that is usually employed in their manufacture is either Limmer or Sicilian, the other types being either too soft or too rich in bitumen to allow of satisfactory use for this purpose. They are made 25 cms. (approximately 10 ins.) square and in thicknesses varying from 1 to 2 ins., according to which the prices range from 3*s*. 6*d*. to 6*s*. per super yard.

The tiles which are manufactured from the rock asphalt mastic are better known in the United Kingdom than are the compressed asphalt powder type, if only from the fact that whereas the latter are almost exclusively imported from the factories abroad, the former are actually prepared in England by various firms. As with the compressed asphalt powder tiles, the process of manufacture closely follows the procedure of asphalt mastic laying *in situ*, in that the mastic is fused with additional bitumen and heavily gritted. In addition to this, however, they are also subjected to hydraulic pressure, and whilst this without doubt results in the reduction of the number of voids in the mass, it is a question whether this extra operation serves any other useful purpose. With the compressed powder the mass is held together by the mutual coherence of the particles, for which compression is essential, but in the case of the mastic, the bond is obtained by the intercalating bitumen, that is to say, by adhesion and not by cohesion. It is perhaps this unnecessary pressure upon the asphalt mastic tiles that causes them to be much more brittle than is a piece of an asphalt mastic pavement if cut out from work done in the ordinary way but without any pressure other than that exerted by the " rubber " during his work.

In any case, there is not the necessity for the mastic tile that there is for the one prepared from the compressed powder. In the spreading of asphalt mastic the plant is easily moveable and the number of men employed in the work is small. The material being put down and spread in a molten condition fills up any uneven or irregular surfaces in the concrete foundation in a way that the solid tile cannot possibly do. The ordinary rock asphalt mastic when laid has a certain amount of elasticity, but the tile, owing to the very fact of it being compressed, although much harder, has attained its increased hardness at the expense of becoming non-elastic and therefore more brittle. Although the writer will not take the extremist view voiced in a recent article in one of the Continental rock asphalt trade journals that, "the presses used in the manufacture of mastic asphalt tiles are mostly regarded as scrap iron and the tiles themselves as things of the past; although there are probably a few still to be found in odd streets, it is, however, time to send the last of them to the museum," he must confess that the results obtained in cases which have been brought to his notice where they have been used, have not created a very high opinion of their durability.

It must, however, be acknowledged that they are much cheaper than any other type of rock asphalt paving, and where this initial economy is a desideratum, the fact is of great importance. Their highly gritted condition and their compression too cause them to be much harder than the ordinary mastic pavement, with the result that they are able to withstand the wear and tear of the traffic passing over their surface much better. Their inherent weak spot is, however, at the joints, where, unless the greatest precautions are taken, dust and moisture intrude, which, with the advent of frost, render the pavement liable to rupture.

The method of laying them is identical with that adopted with the tiles prepared from the compressed asphalt powder, and here, too, the alternative ideas of bitumen and a liquid Portland cement grout have been advanced for the filling in of the joints. In the former case, however, it is doubtful whether the thin coat of bitumen can obtain a lasting bond with the cold mastic upon which it is placed, whilst in the second case the mutual binding power of the cold rock asphalt and Portland cement is also open to question.

These asphalt mastic tiles are usually made in a rectangular shape measuring 4½ by 9 ins. and vary in thickness between $\frac{1}{2}$ in. and 2 ins. Their price ranges from 2*s.* to 5*s.* 6*d.* per super yard, according to their thickness.

The idea of employing tiles prepared from rock asphalt for paving purposes is by no means of recent date, as some may imagine, for as far back as December, 1871, we find that the pavement in Threadneedle Street was laid with blocks measuring about 6$\frac{1}{2}$ by 2$\frac{3}{4}$ by 13 ins., manufactured from the impregnated sandstone obtained at Maestu in Spain. The surface thus formed, however, failed in places, and after being repaired was finally taken up in January, 1872, a month and a half after it was laid, and replaced with compressed rock asphalt powder.

The use of rock asphalt mastic as a paving for either roadways or footpaths is steadily replacing that of the compressed rock asphalt powder, and the method of its employment will be found in the following chapter.

CHAPTER XIII

THE CARRYING OUT OF ROCK ASPHALT MASTIC WORK

Owing to the ease and readiness with which it can be applied to brick, cement or masonry walls, and to roofs, whether formed of wood or concrete, rock asphalt mastic is being recognised more and more as a medium for dampcoursing, flat roof covering, or lining to tanks and similar receptacles for liquids.

When it is laid on concrete, care should be taken that the latter is finished off to a smooth and even surface, with the necessary falls (for which a slope of 1 ft. in 40 ft. may be taken as a fair average) allowed to the outlets or channels. Special attention should be given to this by the concretor, so that when the asphalter comes on to the job he can set out his work and ensure that, after completion, there will be no hollows left where water can accumulate in wet weather and leave unsightly marks where it has evaporated in dry weather. The concrete, to be ready for the covering coat of rock asphalt mastic should have reached that point (easily recognised by the experienced asphalter) when the water used in the mixing of the concrete has so thoroughly bonded the material that it is taking its final moment of setting into a hard mass; that is to say, the "initial set" of the concrete, not the ultimate hardening. If the rock asphalt mastic is laid on "green" concrete (*i.e.*, not properly set), the hot material draws the moisture into the asphalt mastic, causing bubbles which, if pricked, show a clean hole through the asphalt mastic down to the concrete. On the other hand, the asphalt mastic does not go down so well when the concrete has become too dry, as the surface film of weathered concrete appears to prevent the proper bond between the two materials.

All channels or gutters should be finished off smoothly and evenly by the concretor in the same way, the edges to these, as well as the terminal edges at cornices, etc., being finished to a clean, sharp edge or neatly rounded off.

When coke breeze concrete is used, particular care must be taken that the breeze is clean and properly burned, as the presence of any small unburned or partially burnt pieces of coal is deleterious to both concrete and asphalt work alike, as the tar, pitch or gases from them will at once blow when the hot asphalt mastic is applied to the concrete, creating far more blow-holes than are formed by moisture in ordinary concrete. This entails considerable extra expense in the making good to these holes by extra rubbing, etc., not to speak of the possibility of later trouble by fractures which gradually develop from this cause and which are almost too small to locate immediately. This blowing will even occur under these conditions (as the writer knows from experience) in the laying of the top coat of the asphalt mastic, with disastrous results. Free lime also is detrimental to the longevity of rock asphalt work.

When the asphalt mastic is to be laid upon wooden roofs, the boarding should not be less than 1 in., closely cramped together and well nailed to the joists, which should be well braced so as to make the whole as rigid as possible, and placed at 12-in. to 15-in. centres, according to the span of the roof. The necessary fall may be obtained either by sloping the joists or by nailing taper pieces upon the latter before the boards are fixed. A good fall of 1 ft. in 40 ft. should in any case be allowed, and this fall must be obtained in the timber, not by any increased thickness of the asphalt layer. Rock asphalt mastic when laid on boards is successful in most cases, but it is necessary first to cover the boards with a layer of clean bituminous felt. Felt which contains tar or pitch is absolutely detrimental to rock asphalt mastic and invariably causes trouble later. The risk in laying the asphalt mastic on boarding is that any shrinkage or warping of the boards may cause a fracture in the material, which, being unable to anneal again, may extend into an open crack, when trouble will arise through leakage. The weakest part in such work, however, is at the junction of the horizontal work with the skirting or vertical work. Here a movement of the building or the above mentioned warping of the wood will often drag open the joint in the asphalt and leave an aperture through which water readily finds its way, to occasion damage below. Where the rock asphalt coat finishes into a gutter or over the

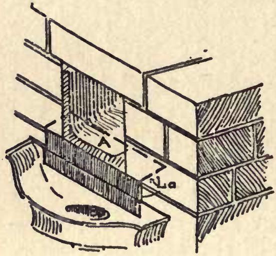

Fig. 1.

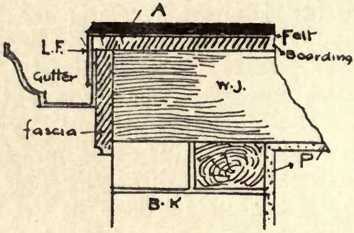

Fig. 2.

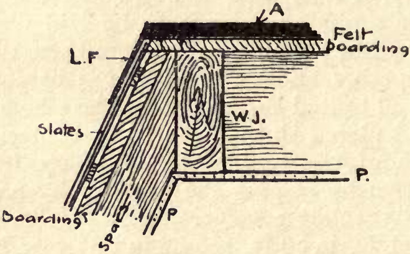

Fig. 3.

A, Rock Asphalt. B K, Brickwork. L A, Lead Apron.
P, Plaster. L F, Lead Flashing. W J, Wood Joists.

edge of the roof, a lead flashing 4 in. to 6 in. wide should be used, and the asphalt mastic then worked over it, as shown in Figs. 1, 2 and 3.

In this case the weak place, either from movement or from settlement, is at the turn-over, and it is to diminish the possibility of damage to the rock asphalt coat at this point that the lead flashing, to which the rock asphalt adheres quite readily, is used.

The actual laying of the asphalt mastic is an interesting study from the start, the work being done by skilled workmen in a gang made up of a layer, a rubber, a potman, and a labourer, though extra labour is often required according to the position and the size of the work to be put in hand. The nature of the rock asphalt mastic as used for this work has been given in earlier chapters, but in all cases a proportion of 10 per cent. to 20 per cent. of clean dry grit is allowed to be added to the asphalt mastic where the roof about to be covered with it is to be used later for traffic or promenade purposes, in order to increase its hardness and its power of resisting friction. This grit, the type of which varies according to the locality, between limestone, whinstone, granite, and small pea gravel, is spread in a thin layer on iron plates and dried over the asphalt boilers, after which it is added to the hot material in the pot and well stirred in.

The plant used consists of a two-case boiler (two or more of these boilers being used as required, according to the size of the work to be done) with a pot, usually having a loose bottom, and a stirrer. Each of these boilers will contain about 8 to 10 cwt. of the rock asphalt mastic per operation, and this, when spread, will give approximately 8 superficial yards of ¾-in. work. Besides the boiler, iron buckets are used for the transference of the fused material from the cauldron to the spreader, wooden floats for the spreading and rubbing operations, gauges, preferably of wood, are required to form the limits of each bay, the level surface of which is tested from time to time with a wooden straight-edge. For vertical work, skirting, channels, etc., certain other minor tools are also used, but the foregoing are the ones of chief importance.

The "spreader" is the foreman of the gang, and he is therefore responsible for the actual putting down of the work. A skilled man should thoroughly understand the class of material that he is using, should appreciate any difficult points which may at times appear to interrupt the progress of the work and be able to cope with them as they arise. He should see before he starts operations that the necessary falls have been allowed for by the principal contractor (the rock asphalt work should not be put in hand until such falls are put in to his entire satisfaction), that the concrete, if he should happen to be laying the asphalt mastic upon this material, is sufficiently set, that the work is clean and free from dust and moisture, after which he then sets out the work so as to be done in a proper manner. After suitably arranging the gauges so as to mark the limits of the particular bay that he intends to put in hand and the thickness of the layer of the asphalt mastic to be put down, he has the material, after it has been fused to a suitable consistency in the boiler, brought to him by the labourer in a special form of iron bucket out of which it is tipped on to the space before him, where he then spreads it evenly between the gauges and brings it to a smooth surface with a wooden float.

The " rubber " follows the layer or " spreader " as the first man is alternately called, and scatters a fine dust or sand (which should be of a soft nature, for if it is too sharp or gritty it scratches the surface of the coat) upon the hot material. He then rubs the surface until it is left smooth, taking out at the same time any blow-holes there may be in it and making them good with fresh material. The use of the dust in this operation is to allow the float which is used to rub the asphalt mastic—hence the name given to the particular workman whose duty it is to do this—to work freely over it whilst in a warm state without lifting it in any way, and to leave a surface over which water will easily run. For this purpose soft grey sea sand and the dust that is left behind after the screening of crushed whinstone has been successfully used by the writer. Much depends, however, on the exact locality in which the work is being executed and the type of stone to be found in it, whether a suitable rubbing dust can be found in the vicinity. The result of this rubbing of the material is that, owing to the fact that a certain amount of pressure must necessarily be employed, any excess of bitumen that may be in the material is brought to the surface, whilst the body of the rock asphalt mastic as laid is made more compact.

The work of the "potman" consists of getting the material cooked in readiness for the layer, and his duties are certainly important. Upon his knowledge of the cooking of the asphalt mastic depends to a very large extent the ultimate success of the work. He must keep his pots clean and free from any coating or deposit that may form on the sides and bottom during the fusing of the mastic. If this is not done, the lining thus formed in the pot, acting as it does as a non-conductor of heat, prevents the proper convection of the heat given out by the fire below, with the result that the material at the bottom of the pot is burned and charred before that at the sides is even melted. Any material thus burnt is worse than useless, since, if it is laid during the progress of the work, wet easily percolates through it, owing to the fact that, by being charred, the bitumen, that is to say, the waterproofing medium, has become oxidised, leaving a charcoal-like mass, honeycombed and porous. A clean pot is therefore most important, and after the day's work is done, the pots should be dismantled and the sides chipped with a cold chisel and hammer, so as to remove all dirt, scale, etc. Further, the potman must, during the progress of the work, keep his pots so regulated by constant stirring that the material comes out of the boilers for use by the layer uniform in quality, since the bitumen has a tendency to rise to the surface of the mass and the grit to fall to the bottom of the pot if the mixture is not carefully watched.

The material, which is imported in blocks weighing approximately ½ cwt. each, is broken up into small pieces with a hammer and built up in the pot so that the heat will circulate through it and cook it evenly and regularly, and a percentage of bitumen is added. A fire is then lighted under the boiler, and for this purpose coke is the best fuel, as it burns when once lighted with a more even temperature than wood or coal. The time required to cook the material is from three to four hours, and the maximum temperature attained should average between 275° F. and 280° F., as this softens the rock into a mass of readily worked mastic and allows the natural moisture in the rock to evaporate without charring it.

When sufficiently fused, the asphalt mastic will readily leave the spatula or evaporate spittle. Where the boiler is set up it is well to place a bunker of sand below the firebox, so that the heat from the boiler will not cause any damage below.

The labourer carries the buckets of the molten material from the boiler, tips them before the spreader as required by him, and attends upon the other workmen generally. In order that the mastic shall not stick to the inside of the bucket, he usually fills into and empties from this

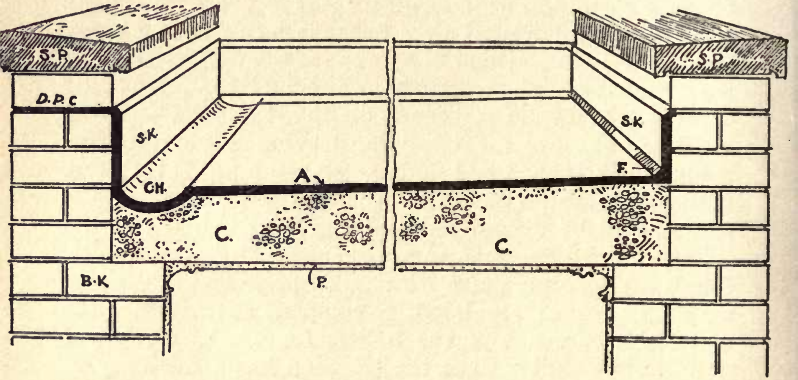

Fig. 4.

A, Rock Asphalt in two layers. B. K, Brickwork. C, Concrete. C. H, Channel. F, Fillet. D.P.C., Damp Proof Course. S. K, Skirting. S.P, Stone Parapet. P, Plaster.

article the cinders drawn from the boiler fire before surrendering it to the potman for re-filling, in order to coat the interior of the bucket with a deposit of fine ash.

For roofing work the asphalt mastic is laid from $\frac{3}{4}$ in. to 1 in. thick in two layers of $\frac{3}{8}$ in. or $\frac{1}{2}$ in. respectively. Wood gauges about $1\frac{1}{2}$ ins. wide by $\frac{1}{2}$ in. or $\frac{3}{8}$ in. thick nominal (the rock asphalt will finish above the thickness of the gauges, so that these should be a little less than the required thickness of the layer) are laid to form bays up to which the work is levelled, these gauges being removed after the work hardens and relaid as required. When laying two-coat work great care must be taken to keep the under coat thoroughly clean, so that the second or finishing coat will adhere to it in a proper manner, and this it will do if the bottom coat is not left exposed too long before the finishing or top layer is put down. To ensure that the joints (*i.e.*, the edges of the bays) of the two coats do not come directly one over the other, the top bays should be set back some 6 ins. or more from the outside edge of the bottom layer, thus breaking the joint. Round the walls a skirting is placed, the usual height of which is about 6 ins. The material for this work is applied to the wall with a trowel, and then smoothed up

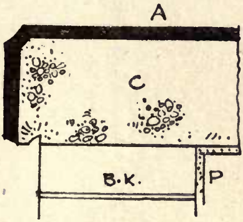

FIG. 5.

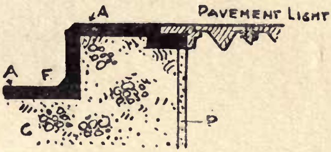

FIG. 6.

A, Rock Asphalt. B.K, Brickwork. C, Concrete.
F, Fillet. P, Plaster.

to an even surface with a tool called a "spatula," but before it is put in hand the joint of the brickwork where the skirting is to terminate should be cut out by the bricklayer $\frac{3}{4}$ in. by $\frac{1}{2}$ in., in order to allow of the mastic being tucked into it so as to form a watertight joint with the brickwork (see Fig. 4).

At the junction of the horizontal work with this skirting a fillet in asphalt mastic is formed, in order to cement the vertical and horizontal work together and to strengthen the joint. Slabs of asphalt mastic of the requisite width are sometimes made and fixed to the walls with wet cement, the joints being made good with hot mastic and then the finishing coat applied, but they are not altogether satisfactory, and effect no saving in the labour item.

When the asphalt mastic is to be dressed direct over the coping, it is usual to finish it in the way shown in Fig. 5.

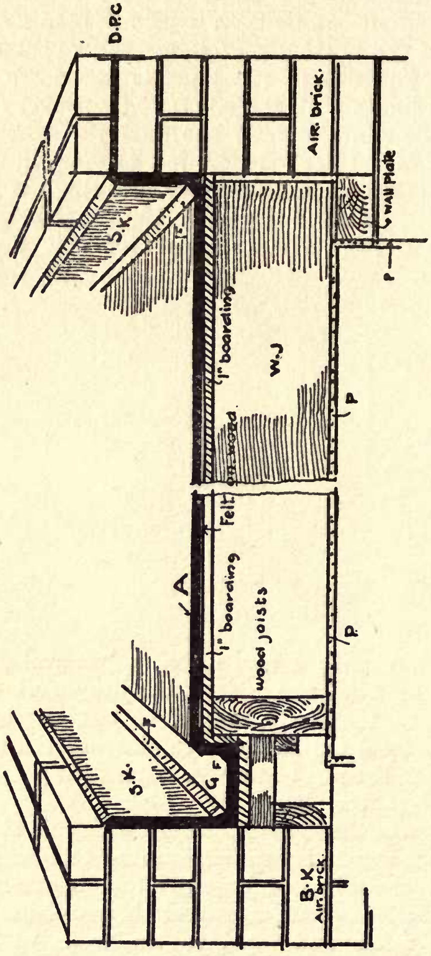

FIG. 7.

A, Rock Asphalt in two layers. B.K, Brickwork. G, Gutter. F, Fillet. S.K, Skirting. D.P.C, Damp Proof Course. P, Plaster. W.J, Wood Joists.

If the lights upon the roof are of the sunk " pavement light " type, the frame is painted with bitumen and bedded into the asphalt mastic coat whilst in its soft condition, so as to obtain a permanent and waterproof bond (see Fig. 6).

When rock asphalt mastic is to be laid upon a boarded roof, the boards must first be covered with a suitable felt, which is nailed into position with butt joints, before the hot mastic is put down (see Fig. 7). The work is then carried out in the way just described, but for the skirting, if this is to be applied to vertical woodwork, such as at lantern lights, as shown in Fig. 8, it is necessary to use

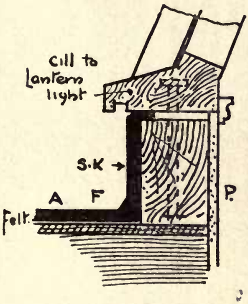

FIG. 8.

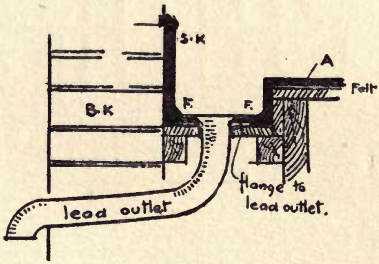

FIG. 9.

A, Rock Asphalt. B.K, Brickwork. F, Fillet. P, Plaster.
S.K, Skirting.

groups of large-headed clout nails, wire netting or expanded metal of light weight, in order to obtain a proper key for the asphalt mastic. Wire netting in particular requires careful fixing, as it is liable to sag. Where the drainage of rain water is effected by an inside gutter in conjunction with a swan neck outlet (Fig. 9), a lead flange is required to be provided round the outlet to which the rock asphalt mastic is worked.

For vertical work, where the rock asphalt mastic is to be used as a lining to a tank, as a vertical dampcourse, or a similar purpose, the joint of the brickwork should be cut out as before, every third or fourth course, thus creating a tie for the asphalt coating. There is a patent brick upon the market in which a deep groove is cut in the face in such a way that the edges of the recess thus formed are "herring bone" in character. Designed originally

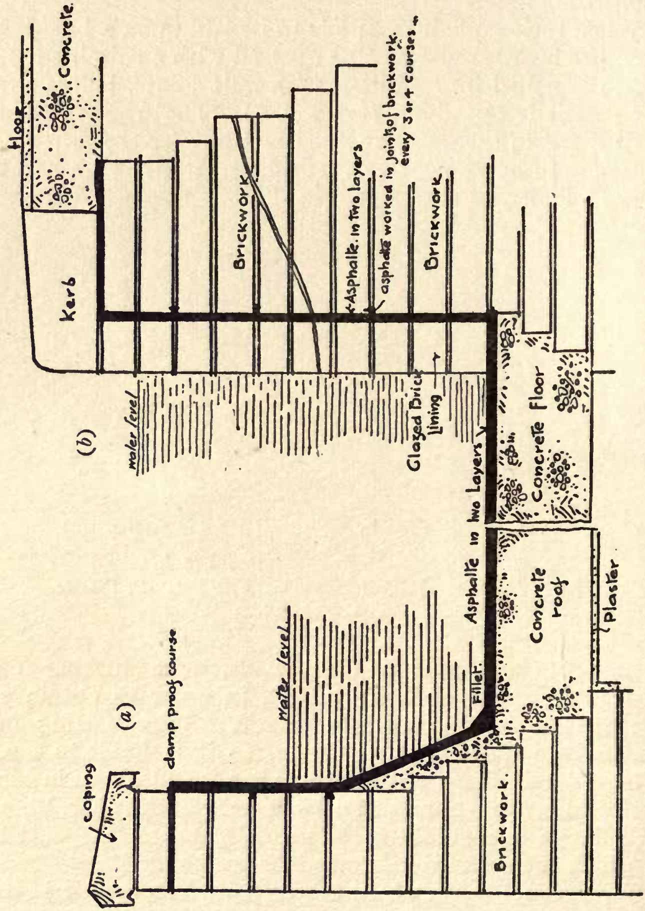

FIG. 10.

to give a bond to plaster work when the latter is placed directly upon a wall without the intervention of laths, it is found that they also give a successful bond with rock asphalt mastic, and so render unnecessary the raggling of the brick joints to form a key for vertical work when they are used.

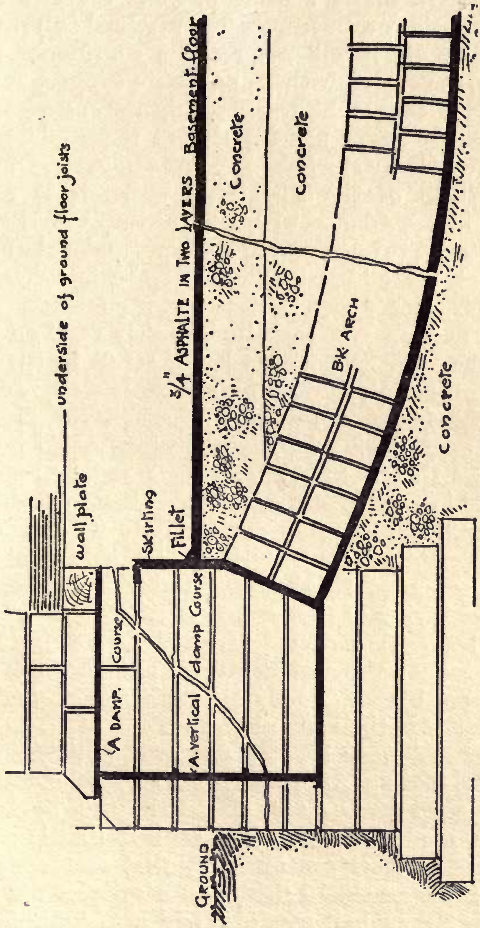

FIG. 11.

Although rock asphalt mastic where used for a lining can be left without any brick or cement facing (see Fig. 10, *a*), when the purpose is merely the storage of water, such as in the case of a tank or a swimming bath, where it is used as a lining for the purpose of checking the entry of water or dampness, it should be faced up with brick or concrete, particularly bearing in mind the fact that the asphalt mastic is a waterproofing material only, and that, although tough, it will not resist a continuous pressure unless it is provided with an adequate support or weight. This matter cannot be too strongly impressed upon the reader, as the writer has found that there is a tendency at times on the part of the general contractors to reduce the thickness of the sustaining walls, from economic motives, in accordance with the thickness of the coat of asphalt mastic to be placed upon them, under the mistaken belief that the added thickness of the latter will compensate for the reduced thickness of the former.

Where necessary, it can also be safely fixed on the outside of the walls (the joints being raked in the vertical work in order to provide the necessary key), across the top of the footings and then through the floors, any pressure on the outside of the vertical walls holding it in its place there. Should any pressure be exerted upon the layer of rock asphalt mastic from below, such as from springs or tides, the only remedy is to weight down the asphalt mastic by covering it with a sufficiently heavy layer of concrete, the head of water being kept down during the laying of the asphalt mastic by the sinking of a sump hole. A concrete inverted floor (Fig. 11), laid ready to receive the asphalt mastic and then filled to the required level, considerably strengthens this and is also more liable to withstand pressure.

For vertical work in extremely wet positions, such as basements, footings, etc., where it is very difficult to obtain a proper bond for the asphalt mastic, even by keying at the brick joints, plates of the asphalt mastic are often substituted. These are made by first scattering a thin layer of finely crushed brick upon a suitable flat surface. Upon this the asphalt mastic is laid in the ordinary way, but whilst it is hot, the material is cut into pieces of the desired size for the particular work. After these have cooled, the crushed-brick-covered back is coated with a rich Portland cement mix, and the plates applied to the wet wall, the joints in which have been previously raked out in the ordinary way to form a key. The cement in setting bonds to both the wall and the crushed brick,

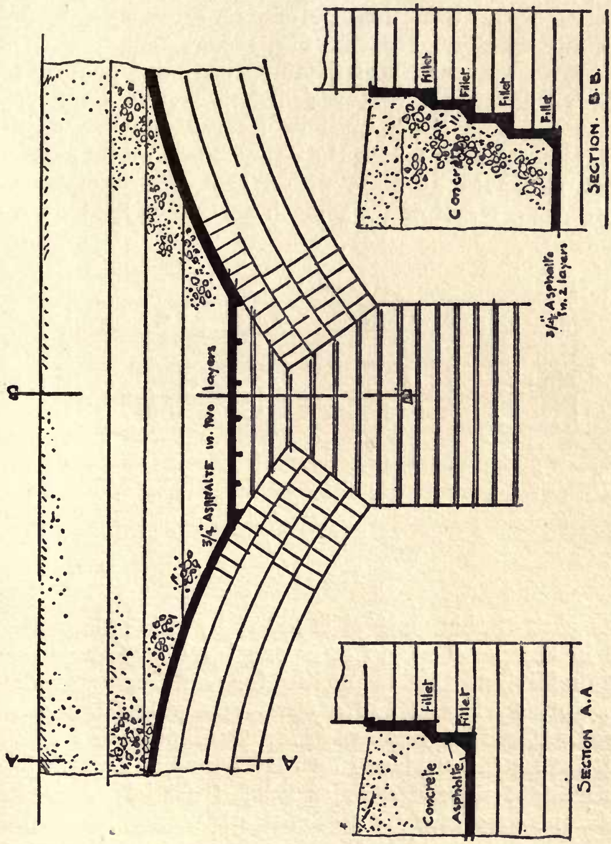

FIG. 12.

binding the two firmly together. When the wall has been thus covered, the joints between each plate are raked out and the cavity carefully pointed with the rock asphalt mastic.

Rock asphalt mastic can also be used with advantage by engineers and surveyors as a damp course for brick or masonry bridges, etc., but where the idea is to form a roadway, a layer of sand about 2 ins. thick should be spread over the surface of the rock asphalt mastic, so as to make sure that no possible damage can be done to it by the unloading of ballast, etc. (see Fig. 12).

Where rock asphalt mastic is used as a dampcourse for heavy buildings or structures, although it is a question whether, should there be any lateral movement, the following method of laying the dampcourse would prevent it, yet it would at least prove that the dampcourse had not, as a result of its smooth surface, helped such a movement.

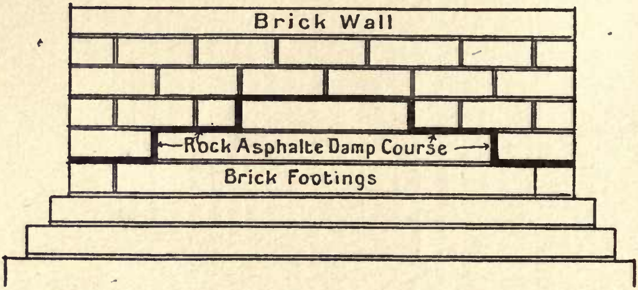

FIG. 13.

The cost of this method is naturally more than when fixed in the usual way, *i.e.*, at one level, but the reader must understand that in putting forward this suggestion, the point of view of the asphalter only has been considered. The idea was conceived through such a movement having taken place in a very heavy building, where the architect suggested as at least a partial cause that the dampcourse used (in this case a bituminous one) had helped this movement. Whether laid in this way or at one level, however, the mastic can be slightly grooved before it is quite cold so as to form a key for the mortar.

By reason of its very durable nature when subjected to foot traffic, its noiselessness and the ease with which it can be kept clean, rock asphalt mastic is now largely em-

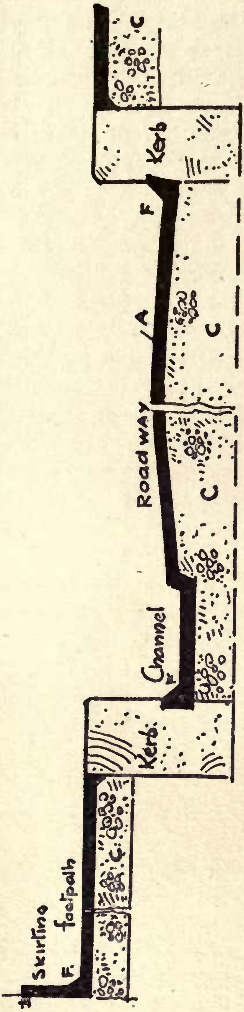

FIG. 14.
A, Rock Asphalt in two layers. C, Concrete. F, Fillet.

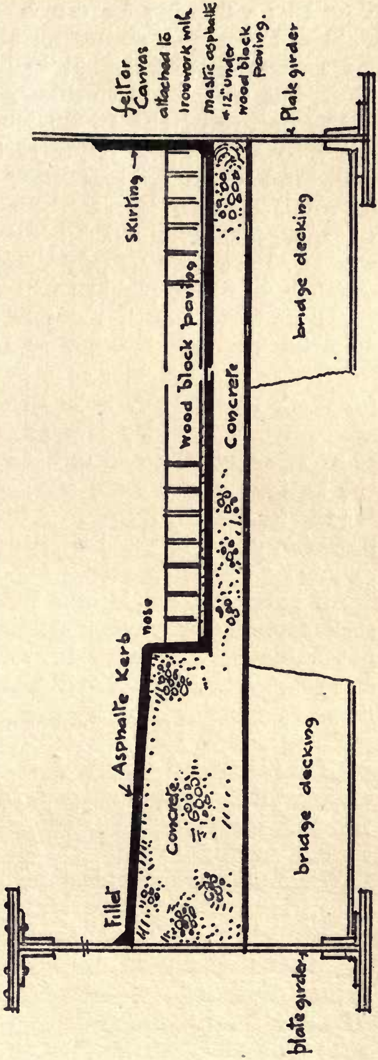

FIG. 15.

ployed as a flooring for warehouses, breweries, factories, stables, byres and numerous other buildings. In these cases the material is laid in the same manner as for roofs, but to a total thickness of 1 to 2 ins., according to the nature of the traffic it will have to sustain. In order to give it the requisite hardness to enable it to withstand the continual wear and tear of handcarts, barrows, etc., to the top coat of such work can be advantageously added 15 to 20 per cent. of grit in the same way as already mentioned for roofing work, which is to be subjected to traffic. When used in horse stalls or loose boxes, the fairly smooth surface of the material has no influence and does not in practice create the theoretical difficulty of not affording a proper foothold for the horses. It must be remembered that the animals are invariably bedded in peat moss litter, straw, sawdust or similar material, and this is spread in a thick layer over the bottom of the stall, and so gives the necessary grip for the feet of the horses. At the entrance to the stable, however, it is desirable to groove the surface of the asphalt mastic for this purpose.

An extensive use is now made of the mastic type of rock asphalt for pavements and such roadways as are not subjected to much heavy traffic. The method of carrying out this work is similar to that adopted for floors as mentioned above (see Fig. 14).

Playgrounds and other open spaces are thus coated with advantage, whilst a result of the roller skating movement has been the creation of open-air skating rinks, the surfaces of which have been formed of the gritted rock asphalt mastic.

When rock asphalt mastic is used on ironwork, bridges, etc., the steelwork should be properly cleaned with a wire brush and a coat of a bituminous solution applied, as in this case it is necessary to seal the mastic coat securely down in order to avoid fracture by vibration. When laid on such structures, even if they are to act as roadways and the covering to receive the weight of the traffic, formed of tar macadam or some other material, a dampcourse of rock asphalt mastic, applied as before described, preserves the steelwork from rot and corrosion. To allow for contraction and expansion, a joint can be left at intervals, and this should be half filled with sand and then on this a layer of bitumen run in, or a narrow strip of bitumen sheeting placed on edge can be substituted. Where the ironwork finishes against the abutments or walls, a lead flashing dipped in bitumen can be used and the coat of rock asphalt run over it.

If it is necessary to carry the waterproofing material up the sides of the girder plates, the steelwork should be well cleaned and painted with a coat of bitumen, and then a layer of clean bituminous felt or canvas (which should also be carried about 6 ins. under the horizontal work) can be stuck on to this, thus supplying the requisite support for the vertical asphalt mastic work. Whilst describing the methods to be employed for laying asphalt mastic direct on to steelwork for bridges one fully realises the difficulties arising around such work. The questions of recurrent shock, the effect of vibration, the unequal distribution of loads, etc., all tend to the conclusion that a bed of bituminous concrete upon which to lay the rock asphalt mastic would give the best result, at any rate until a more general record of the results of tests under these conditions is available. When ordinary cement concrete is used as a foundation upon these structures, it powders with the vibration and the shock, resulting in a destroyed base and a consequent damaged asphalt mastic surface.

Rock asphalt mastic cools off readily in two or three hours after being laid, and can be used immediately after for traffic. The present day requirements all tend to a demand for a cheap material for waterproofing and road work, and this has brought on to the market many artificial materials designated "asphalts" but which still have to prove that the wearing and waterproofing qualities of the natural rock are possessed by them. The manufacturer of artificial asphalt has not wrested from nature her secret method of blending, which leaves the natural rock asphalt so impervious to water, naturally elastic, and, so far, inimitable for certain purposes to which it is now put.

Natural rock asphalt mastic, when properly laid with the best material, has a long life, and the necessity of demanding lengthy guarantees when the workmanship and the material is of the best class is absent and should not, therefore, be encouraged. A knowledge of the nature of the particular material that is being used and the method of its application will proclaim its longevity to the expert. A fair maintenance term of two years should be sufficient, if the work be placed with a reputable firm of contractors, and the offer of a lengthy guarantee (such as fifteen or twenty years) should carry but little weight in the placing of a contract. In certain work which includes resistance to water the factor which principally determines the life of the waterproofing medium is not so much the durability of the latter as the capacity of the weight placed upon it to hold back the pressure. In such cases it is customary for the rock asphalt work to be carefully examined before being covered in, and then, if it is found to be satisfactory, for the asphalt contractors to be relieved of any further responsibility.

It has been recognised abroad that the demand for lengthy guarantees with this work, whilst of little practical value, demands the reservation by firms who do large numbers of extensive contracts, of huge sums which, from the strictly actuarial point of view, must be kept locked up in order to cover all possible contingencies. For this reason the tendency, in the United States especially, is to be satisfied with a guarantee for such a period (usually twelve months) as will enable the authorities to discover how the work will withstand all extremes of weather and traffic. By that time, too, any weaknesses that may be in either material or workmanship will have developed and become recognisable to the engineer.

The following records are included here, as they speak for themselves as to the natural elasticity of natural rock asphalt mastic. In one case, the asphalt mastic was used as a tank lining, and after the floor of the tank had been partly covered, a big pressure of water was let on. This got under the coat of asphalt mastic at the open edge and lifted it up in the form of bubble which at one part was 10 to 12 ins. high and had an area of about 15 super ft. The asphalt mastic remained in this position without any sign of fracture for five or six hours, when it eventually sank into its normal place again. In another case a footpath had swollen up considerably from the rain, and the expansion of the wood blocks exerted such a pressure on the kerbstone as to cause the asphalt mastic to camber. When, however, the wood blocks dried out again, and so withdrew the pressure, the layer of rock asphalt went back into its place again without damage.

A rock asphalt floor recently inspected by the writer was of more than usual interest, owing to the fact that, instead of the customary Portland cement concrete, as a foundation was used what is best described as a " rock asphalt concrete," upon which the finer material was laid to a smooth finished surface in the ordinary way. Although being at least forty-five to fifty years old, it was still in fair condition, though in parts the floor had been worn down to the bottom layer, some of the larger aggregate of which was exposed and exhibited gravel graded from 1 in. downwards.

SPECIMEN SPECIFICATION FOR ROCK ASPHALT MASTIC WORK.

The asphalt mastic to be prepared from the natural rock by an approved mining company, brought to the site of the work in the original blocks, on the face of which shall be clearly stamped the brand of the mining company by whom it is prepared, and laid by skilled workmen.

No sand or gravel to be added unless specially mentioned. The asphalt mastic to be kept well stirred when being cooked. Care to be taken that no burnt or charred asphalt mastic is left amongst the material being laid. To prevent this, the boilers are not to be left burning overnight. Where grit is used, it must be well dried on a pan over the boiler before being mixed with the mastic.

All vertical work to be finished to a smooth and even surface, and the necessary fillets at angles and base, stops, mitres etc. to be allowed for.

Where the asphalt mastic turns over into eaves, gutters, or on to slates, a lead flashing to be provided and fixed by the plumber before the asphalt mastic is laid.

The concrete or boarded roof, etc., prepared to receive the asphalt mastic must be truly laid to falls by the concretor or carpenter, and in the case of the concrete must be finished with fine screed to a smooth and even surface. All joints where skirtings or vertical work are against walls, etc., to be raked out by the bricklayer and pointed after the asphalt mastic is fixed. When laid on boards, the felt used as an underlay to be of a clean nature, free from tar, pitch, or any other injurious compositions.

The general contractor to provide the use of the necessary scaffolding etc.

The whole of the work to be left by the asphalter in perfect order to the satisfaction of the architects.

SPECIMEN QUANTITIES FOR ASPHALT ON CONCRETE, BRICK WALLS, ETC.

..Super yards. $\frac{3}{4}$ in. natural rock asphalt mastic as specified, laid in two layers to break joint on concrete, finished to a smooth and even surface with the necessary falls to clear the water readily, measured elsewhere.

..(Or if on boards.) Do. do. do. in two layers to break joint, including felt underlay, upon boards laid to falls measured elsewhere.

..(Or if for vertical work.) Do. do. do. but to vertical walls, at every fourth course the joints to be raked by bricklayer to form key for asphalt mastic.

..Lineal feet skirting and fillet against walls or under slates, (joints to be raked by bricklayer and repointed after asphalt mastic is fixed).

..Lineal feet. Extra labour only nosing to gutter.

..Lineal feet. Extra labour only to channels.

..Lineal feet. Extra labour only working asphaltmastic round outlets.

PRICING OF ROCK ASPHALT MASTIC WORK.

BY MEASUREMENT.

Horizontal work at per super yard.

Vertical work at per super yard.

Skirtings, 6 ins. and under at per lineal foot, 1*d*. per in. being added for work above this height.

Fillets, extra to skirting, at per lineal foot.

Gutters, by girth, at per lineal foot.

Channels, extra labour only, at per lineal foot.

Eaves or nosings, extra labour only, at per lineal foot.

Outlets through walls, at per outlet.
Cesspools, at per cesspool.
Felt underlay, at per super yard (though usually included in the price of the asphalt mastic work).

By Daywork.

Labour.		Materials.		
Asphalter	at per hour.	Asphalt mastic	at per	ton.
Rubber	,,	Bitumen	,,	cwt.
Potman	,,	Gravel	,,	ton.
Labourer	,,	Felt	,,	yard.
Railway fares, etc., at actual cost.		Fuel	,,	ton.
		Use of plant	,,	day.

CHAPTER XIV

MACADAM ROADS

THE work of J. L. Macadam in revolutionising the methods until then in vogue for the making up of roads is too well known, and has already been sufficiently dilated upon to be gone into in detail here. In brief, the discovery upon which his system is based was that if angular fragments of hard stone of suitable size were bound together under pressure into a compact mass, a surface would be formed which would be impervious to water and, above all, extremely durable.

Despite these advantages, however, macadam roads, in common with all others made up with stone and dirt and waterbound, have the objectionable feature of creating dust by reason of the disintegrating action of the vehicular and pedestrian traffic that passes over their surface, the one being the result of crushing caused by the pressure, and the other the result of friction. With the dust also comes its attendant evil in wet or damp weather of mud, so that, especially of late years, when rapid motor transit has caused the raising of the dust in dry weather and the scattering of the mud in wet weather to become pronounced nuisances, efforts have been, and are still being made, to at least mitigate this evil, even should its entire abolition prove impossible.

To arrive at this result different methods have been adopted, such as the use of an agglutinating agent or the surfacing of the road with a hygroscopic compound, but by far the most successful are the ones which embody the use of a tar or bitumen as a binder of the road material itself.

The use of these materials, however, whether as a surface coat or as a binder, has recently caused an outcry from the more æsthetic people that this treatment of the roads, whilst more or less successfully retarding the creation of the dust evil, is destroying the pleasing (?) whiteness of the country highways, replacing this with a dismal uninspiring black. This is incorrect. A tar or a bituminous macadam, when once the excess of the binder, which invariably forms a kind of varnish on the newly made surface, is worn off, displays a gray colour which varies in tint according to the particular stone that has been used for the aggregate, This, it would be imagined, is far more restful to the eye than the glaring whiteness of the untreated roads, especially when this latter is accompanied with a blinding dust in windy weather.

Where economy is a dominating factor there is no doubt that of the two binders mentioned, the first named, being the cheaper, will always have the preference where initial economy is essential, and within certain limits this material is of great value. With regard to this though, it should be pointed out that the ever increasing demand for tar, occasioned by its use in the preparation of tar macadam and the tar spraying of roads, as well as extended requisitions in those trades in which it is already used as a raw material, such as the manufacture of dyes, roofing felts, lining papers, disinfectants, paints, varnishes, cattle washes, building compounds and the like, is causing a corresponding steady increase in price, until it is becoming a moot point whether in the process of time coal tar and its products will not be equally as expensive as the true bitumens, unless, of course, the price of the latter goes up in sympathy.

In any case, it must be borne in mind also that the tar is produced in the largest quantity at that period of the year when it is not used upon roads, *i.e.*, during the cold and wet winter months, whilst during those months in which the work of road-making and surfacing are most put in hand the output of tar is extremely limited; in fact, in many of the country towns in which its use for this purpose would be especially advantageous, the quantity made at that season is practically nil. To the writer's mind a most inexplicable attitude that is taken up by the gas committees of some of these small country towns is the false economy of selling the tar which is made at their works instead of transferring it to their highways departments. In order that a mere twenty shillings a ton may be obtained for their tar—for that is all that is obtained in the majority of the cases that have been brought to the notice of the writer—the gas committees prefer to condemn the ratepayers to the dust-creating, waterbound highways.

The tar is applied to the roads in two ways, either by mixing it with the broken metal prior to spreading the latter, and so forming the well-known tar macadam, or by spraying the surface of the road itself with the tar in a hot condition, but the durability of the resultant coat of tar-bound or tar surfaced material is entirely dependent upon the quality of the tar which is employed in the work. To fully appreciate this most important point, it must be clearly understood that coal tar is not a definite chemical compound. Instead, it is a mixture of a variety of compounds of the hydrocarbons, hence the wide range in quality of the different coal tars to be obtained. The component parts of the tars can, however, be grouped together for the present purpose under the headings of (*a*) gas liquor, (*b*) light oils, (*c*) medium oils, (*d*) heavy oils, and (*e*) pitch. Of these, the ones requisite for road work are (*e*), (*d*), and a portion of (*c*).

The gas liquor is useless, in fact, it is worse than useless, for its presence in the crude tar, with which a large portion of the tarred roads have hitherto been treated, is the principal cause of the present outcry against river pollution and the resultant fish destruction which has been occasioned by the surface water draining from these roads into the adjacent streams. Under this term is considered the water and ammoniacal compounds that have been formed during the destructive distillation of the coal, the greater part of which are trapped in the gas producing plant, but an appreciable quantity is still retained by the crude tar. When the latter is used upon a road the water evaporates out, and the ammoniacal compounds, being either volatile or soluble, also disappear.

The light oils are, as their name implies, that portion of the tar which is volatile at very low temperatures. In practice, all those oils which evaporate out of the tar at a temperature below 105° C., are grouped under this heading, and it is this ready volatility that renders them unfit for road work, since their presence thins the tar, with the result that the latter does not coat the stone so well, and their disappearance after the road has been treated renders the surface brittle and liable to early segregation, owing to the additional quantity of pitch that has to be added to the tar in order to give it the necessary body.

The pitch gives the body to the medium and heavy oils, but contains a certain percentage of free carbon, the presence of which, in more than a certain proportion, is inimical to the sound road. It is for this reason that specifications for road-making and tarring specially refer to this subject and declare the maximum of free carbon which will be permitted in the tar to be used. In gas-works tar, much less of this free carbon is to be met with than in blast-furnace tar, whilst water-gas tar is almost entirely free from it.

To obtain a suitable tar, therefore, it is best that only a gas-works tar be considered, and that even this should be first submitted to a refining process. It is possible, it is true, to purchase tar which has already been distilled, but this is expensive, and whilst it has the volatile elements extracted, there is also the possibility that some of the other oils may have further been taken out for business purposes and the tar "cut back" again with the superfluous oils. This abstraction can be readily detected by the analyst by a suitable comparison of the quantity of distillate obtained at certain degrees of temperature, but as this requires an expert to properly carry through the test it has not been included in the chapter on analysis.

The road surveyor and engineer are recommended to purify their own crude tar when it is possible to obtain it from gas-works in the vicinity. The principal point to keep in mind here is to keep the temperature low, otherwise valuable oils may be lost and the percentage of free carbon increased by local overheating. In the majority of instances a proper distilling plant will be out of the question, but the process can be equally well carried out in large cauldrons if care is taken to keep the fires steady and so that the temperature never exceeds 170° C. The practical cessation of ebullition in the cauldron at this temperature will show when all the light oils and water have been driven off, though if it is desired to make certain of this, a quantity can be heated in a glass retort to that temperature, and if no distillate is obtained, it proves that the operation is complete.

When the tar is obtained from one constant source, it is usually possible to determine in the above manner exactly how long the cauldron should be heated, and then it is only necessary to instruct the workman as to the length of time to continue the operation without any further trial, though it is always advisable to make periodical tests in order to check the figure thus obtained and adopted.

There are now to be had various road-making compounds which, as their names imply, have been prepared for coal tar, and which give fairly satisfactory results when properly used. They are to be had in varying consistencies, so as to be suitable both for surface spraying and road binding, but they are naturally much more expensive than water-freed tar itself. In a communication issued by one of the firms who manufacture these specialities it is stated that the material they produce "is prepared from selected crude tars. The oils removed in the refining process are removed for the purpose and only to the extent necessary to leave the main product of the desired test. The amount of oil removed is seldom over one-fourth of the raw material, and often less than one-tenth." This candid statement of the composition of a well-known road-making compound should be interesting to those highway engineers at present using tar as a binder.

For tar spraying, of course, only tar is required, but in the preparation of tar macadam it is customary to add to this a proportion of pitch in order to give a certain amount of body to the binder. This pitch, for the same reason as for the tar, should be one made from a gas-works tar in preference to one made from a blast furnace tar, and if it is of the "medium soft" variety there is less chance of an excess of free carbon than with the "hard" type—which has undergone a further distillation than the former—although slightly more is necessary.

The mineral aggregate used for the tar macadam varies in different localities according to the stone that can be most economically obtained, but usually it is limestone, whinstone or granite chippings, though iron slag has also been used on a fairly large scale with every success. The particular class of rock which should be employed depends to a great extent upon the severity of the traffic which will be passing over the roadway when the tar macadam is put down. Where, therefore, the traffic is light, it is infinitely better to have a softer stone than granite, but if the traffic is very heavy, limestone has a great tendency, especially in warm weather, to become marked with the wheel tracks and to become "billowy." Slag, it may be added, holds a larger amount of tar than does limestone, by reason of its porous condition.

It need hardly be mentioned that the more care that is taken in the choice of the materials and in the work of intimately mixing them, the better will be the results afterwards obtained when the tar macadam has been laid. One of the most imperative requirements in the mixing operation is a suitable degree of heat. The stone must be warm and dry, the mixture of tar and pitch must be hot and of a readily flowing consistency, and the tools to be used must be similarly heated. Without this heat, no real bond can be obtained between the stone and the tar; if the stone is cold, it chills the tar; if the tar is not sufficiently heated, it cannot penetrate the pores of the stone to form an adhesive film round each; and if the tools are cold, the tar clogs, and by sticking to them makes the proper working of the mass almost impossible.

Mixing machines are to be found on the market for the preparation of tar macadam, and if the expense of purchasing one is considered justified, their use can be throughly recommended as giving an excellent mixture in a very short space of time. They are extensively adopted in the United States for the preparation of the material used for the bituminous roads in that country, and two or three of the engineering firms there who manufacture these articles have also inaugurated branches in the United Kingdom for their production. The American types are without doubt the most advantageous, for with them every part of the operation can be done on the same machine without any loss of time, whilst no permanent firebox or power drives are needed as with the British types that have come under the notice of the writer. These machines can be easily adapted by contractors and others who have much concrete work so as to mix that material also; in fact, in America, where it is customary to lay the bituminous macadam or cement upon a foundation of concrete, it is usual first to employ the machine to prepare the concrete, and then, the foundation being laid, to make the bituminous surface layer in the same machine, thus effecting an economy in both plant and labour.

When their use is not permissible by reason of the small quantity of macadam required at a time, for their cost is rather high, the mixing must be carried out by hand, in which case it must be remembered that the smaller the bulk mixed at each operation, the less possibility there will be of an uneven mixture. A satisfactory amount, and one which is very suitable for arranging the proportions of the mixture is a cubic yard of stone at a time, to which should be added by degrees sufficient of the pitch and tar mixture to allow of each fragment of rock being well and properly coated. These proportions will vary according to the absorptive capacity of the particular type of rock used and the size to which it is crushed, whilst the proportion of pitch to tar will depend upon their respective qualities, and the time of the year in which the tar macadam is to be laid. Thus a mixture which is suitable for summer working would consolidate too rapidly in winter, whilst on the other hand, a material that would be satisfactorily worked in winter would prove too soft for summer handling.

The actual operation of making up the material is as follows :—

The stone is first screened free from dust and then separated into suitable sizes. The stone thus gauged is now placed upon a heated iron plate in a shallow layer and constantly raked, so as to enable it to be well and evenly heated. In the meantime the tar, which has previously been freed from water and the light oils, as mentioned above, is placed in a tar boiler, heated, and the proper proportion of pitch added, the mass being constantly stirred during the whole time so that the two materials intimately mingle together. If the shovels to be used in the mixing are ranged about the fire of the boiler or used as stirrers for the tar, they will be heated in readiness for use. A certain amount of caution must be used in heating the tar, for the sole reason of such application of heat, it must be understood, is to bring the tar to a suitable consistency and not to evaporate any of the oils, those detrimental to the tar macadam having been already eliminated. Too high a degree of heat, therefore, only means an unnecessary loss of material, an inadvisable alteration in the quality of that material, whilst, contrary to the effect of cold, the heightened temperature causes the binder to become too thin and so to run off the stone instead of coating it.

The hot stone is piled up in the form of a cone, and a hollow formed in the apex in which the hot tar is poured. The mass is then turned well over with the heated shovels until no stone is left uncoated. Regarding this coating operation, despite the assertion of certain firms to the contrary, the writer has still to find a tar macadam in which the stone can truthfully be said to be impregnated with the tar. Even if this were possible, the most probable aggregate to admit of it would be perhaps the limestone chippings, but with this material the grain is too close for the purpose, whilst the pitch mingled with the tar could not penetrate the pores to any appreciable extent. Should the naturally impregnated limestone be advanced as controverting this statement, it must be remembered that this latter material has been proved to have been impregnated in nearly every instance, whilst in a powdered and not fragmentary condition. Further than this, the tar which first enters the pores of the chippings fills them and so obstructs the passage of any further quantity.

The tar macadam thus made is at first very soft and should be stored for some time—certain firms recommend a period of three months—before use, so as to allow it to mature and to enable the tar, which at first merely lies on the surface of the stone, to sink deeper into it.

The work of laying a tar macadam road or pavement should only be carried out in fine weather. If the operations are attempted in the wet, the rain or dampness appears to form a kind of emulsion with the oils that are contained in the tar with the result that, although the material becomes very pliant and easily spread and rolled, it never dries or becomes hard and pressure resisting, but instead, the emulsion formed, in place of forming a binder between each piece of stone, acts rather as a lubricant, and so assists their movement with the result that the tar macadam is easily displaced by traffic and quickly forms into ugly ruts and holes.

A solid and well-drained foundation, too, is a necessity. In many cases the ordinary macadam surface existing upon the road will prove sufficient, but if this is not suitable, a proper one of hard ballast well rolled must be provided. It is preferable that this be formed to the required gradient of the road, as it is much easier to do this with the foundation than to attempt to taper the tar macadam surface, particularly so when this bevelling means the reducing of the thickness of the tar macadam coat in the gutter, *i.e.*, that portion of the road which should be the most waterproof of the whole, for whilst the main surface is practically a water-shedder merely, the gutters have to act as carriers of the water to the gullies.

Upon this foundation is spread the first layer of the tar macadam. This is usually of 4-in. gauged material laid and rolled, with the interstices filled in with finer tar macadam, when the whole is steam rolled. The second layer should be about $\frac{3}{4}$-in. in thickness, made up of $\frac{5}{8}$-in. tar macadam and left unrolled; on this should then be applied a layer of 2-in. material and rolled into the $\frac{5}{8}$-in. When this is done, $\frac{3}{8}$-in. tar macadam should be swept with a brush into every crevice or open joint. As a final coating, a perfect layer of $1\frac{1}{2}$-in. tar macadam should be applied, and after being rolled once or twice, finished with a further quantity of the $\frac{5}{8}$-in. material being swept over its surface, following which the entire surface is well rolled.

Another method of laying tar macadam is to put the material down in two layers only. For the bottom layer, all the crushed stone which passes through a 2-in. ring but is retained by a $\frac{1}{2}$-in. sieve is used, and the tar macadam made from this is so laid that when compressed it is some $3\frac{1}{2}$-ins. thick. The top layer consists of the tar macadam which has been made from the crushed stone which has passed through the $\frac{1}{2}$-in. sieve after the dust has been extracted from it, and this is spread so as to finish to a thickness of $\frac{3}{4}$-in. when consolidated.

Passing mention may be made, too, of the Gladwell system of laying tar macadam, which is carried out by sandwiching a layer of tar macadam between two other layers of untreated screenings, the idea being that the compression exerted by the roller and the later traffic will extract the excess of tar from the centre layer and press it into the other layers above and below, thus bonding the whole together.

After the proper preparation of the material itself, there is no doubt that the life of the road is dependent upon the care that is taken in properly rolling each layer of the road surface in order to consolidate the macadam and to reduce the number of voids in it as much as possible. Where the material has been prepared upon the soft side and so shows an excess of the binder, there is often a difficulty with the macadam sticking to the roller when the latter is passing over it. This, however, can be prevented quite simply by keeping the surface of the roller wet or coated with dust.

That a tar macadam road when properly made can be extremely durable is seen by a certain highway which was thus surfaced and received a dressing of tar every second or third year and a new facing of fine tar macadam every tenth year. This, although laid over thirty years ago, has proved to be entirely satisfactory, and when broken up in order to allow of the putting down of tramway rails, it was found that the main body of the road was well preserved and it required a considerable amount of labour to raise the tar macadam, so dense had it become.

The principal causes of failure with tar macadam road. may be summarised in the following: the omission to provide a proper drainage of the subsoil underlying the tar macadam surface; the use of moist or dirty stone in the preparation of the material; the choice of unsuitable sizes of material; an insufficient rolling of the respective layers when placed in position; the use of too large or too small a quantity of tar as the binder; the unequal distribution of the binder through the tar macadam; the careless overheating of the binder when being boiled in the cauldron; wet, damp, or frosty weather during the process of laying and compressing. In each of these cases the remedy is apparent.

A suitable prepared tar for use in the preparation of tar macadam has been thus specified: the specific gravity at 15·5° C. should be approximately 1·220, and when distilled to a temperature of 275° C., it should not give off more than 10 per cent. of distillate, which percentage should not exceed 25 per cent. when the temperature is increased to 350° C. When extracted with carbon bisulphide, benzol and alcohol, the residue of free carbon that is left behind should not be more than 15 per cent. by weight.

The idea of making up a road surface with a macadam bound with tar seems to have been first acted upon in Nottingham about the year 1840, though as far back as 1834 Cassel's patent pitch macadam was on the market.

As a palliative of dust upon highways where, owing to financial considerations, the adoption of even tar macadam is impossible, the practice is greatly extending of spraying the surface of the road with hot tar. Whilst naturally temporary in effect, and of not so advantageous a character as tar macadam itself, there is no doubt that the tar spraying of road surfaces, besides alleviating the dust evil —and so receiving the condemnation of the æsthetic soul who mourns for the lost beauty of the white country road, the " crime " being equally placed by that person on tar macadam as well—has a very beneficial effect in preserving the material constituting the macadam road and so prolonging its life. Although it is still possible to see the work carried out by manual labour, that is to say, with one man boiling the tar, a second carrying the hot tar from the cauldron in a bucket and emptying it over the road, where a third brushes it over the surface, the customary method now is to use a spraying apparatus, consisting of a reservoir, in which the tar is heated, which is connected to a spraying pipe at the rear. In order, too, that the tar, by forcibly impinging upon the surface of the road, shall penetrate it to a certain extent, certain types of sprayers have an air compressor attachment, by means of which the hot tar can be ejected at the desired pressure.

For this work, however, two things are absolutely essential for success, the one being fine, dry and warm weather, and the other a bone-dry, dust-free road. Dryness is imperative, as otherwise the tar is unable to obtain a bond with the stone, and dust also forms a very effectual barrier against proper penetration. The necessity for a period of fine weather is seen when it is pointed out that instances have occurred where a road, after being tar sprayed in the orthodox manner, has been practically stripped of its newly-formed surface by a heavy rainfall which has occurred shortly after the completion of the work. The road is usually cleaned from dust as much as possible by suitably brushing it, though at least one writer on this subject has suggested the adoption of a modification of the household " vacuum cleaner " for the work.

A gallon of tar is usually sufficient for 5 to 9 super yards of roadway, but in order to keep the road in a good condition it is necessary to renew this tar surface periodically, so that, although initially low in cost, the continuous renewal of the work causes the price to augment considerably, approaching, if not actually passing, that of a properly prepared bituminous roadway.

The permanent utility of tar as a binder for road-making and, to a minor degree, as a dust preventative is a very questionable point, whether it is used as the tar macadam or merely in tar surfacing. A more suitable material has, therefore, been sought for, and this apparently has been found in the natural bitumens, the use of which will, in time, there is little reason to doubt, entirely replace that of tar except in such instances where initial cost still dominates.

The various types of bitumen from liquid to solid have been pressed into service for this purpose, the first for spraying and surfacing, and the latter as road binders. For this purpose the main characteristics demanded of the material besides durability are adhesiveness and elasticity. The bitumens of paraffin origin show a great lack of the necessary adhesiveness, and this to such an extent as to render its main virtue, *i.e.* that of bonding the mineral aggregate of the road, almost nil. Owing to their non-cohesive character when they are used for road-spraying or surfacing, they usually render the surface of the road smeary and greasy, whilst, when the oils disappear after the inevitable evaporation, instead of leaving behind them the more solid bitumen, they disintegrate entirely, and the dust formed on the roads so treated is accompanied with greasy particles which occasion even more annoyance than the dust itself. It is often found that the instances where the spraying of roads with a liquid bitumen has been brought into discredit, have arisen simply from the use of an unsuitable material of this character.

With a true liquid bitumen, on the other hand, its intense affinity for finely divided mineral matter, which has been remarked upon in earlier chapters, causes it to be quickly absorbed by loose macadam or screenings, and these will not release it later on. Unless, therefore, the liquid bitumen is sprayed in excess, there will be no "bleeding" of the road so treated, but as the more volatile elements evaporate out, the more solid bitumen left behind, being already closely combined with the mineral, still holds it firmly together to form a coherent dustless surface. If a road is consistently treated in this manner, it results in the gradual formation of a bituminous macadam surface of an excellent character. Care, however, must be taken in the operation of spraying that the liquid is spread evenly over the surface, for its peculiar characteristic is that it will not spread over the road but lie where it is applied. Again, the road must be carefully freed from dust, with which the material will incorporate to form lumps, whilst if the bitumen is spread in excess, it will result in the formation of soft spots in the road surface. It is therefore suggested that the liquid bitumen be spread over a good foundation consisting of a thin, loose, but even layer of crushed stone passing through a 1-inch ring, and after this a top course of similar screenings should be rolled in which, by binding with the bitumen thus spread, will result in a surface very similar to the usual bituminous macadam.

Even for road surfaces made of concrete this idea can be adopted with advantage, as by this means the concrete foundation is rendered good for all time, whilst the wearing course serves the purpose of carrying all classes of traffic without rubbing, ravelling or creating a dust. It must be understood, however, that to obtain a satisfactory result, the liquid bitumen must not be sealed up in the body of the road, as in this case it would merely lie dormant, developing no strength, but acting more as a lubricant to the road metal than as a binder. It must be so used that its strength can develop by the evaporating out of it of the lighter oils.

In new roads, however, the principal method of employing bitumen is in the form of a bituminous macadam. This material is formed in much the same way as the tar macadam type, in batch-mixing machines, with the sole difference that a suitable bitumen is substituted for the tar. It is difficult to define the most suitable proportions of bitumen and aggregate, for this material, as so much depends upon the type of the stone that is used and the widely varying qualities of bitumen that are employed. The best results, however, will be obtained by combining such proportions that the entire aggregate will be coated with bitumen in an amount which is equal to that which the material would hold after compaction, without any excess being forced to the surface. Whilst the proportions may be adjusted either by volume or by weight, it is perhaps advisable if only the former were used. To see the reason of this, it is only necessary to call to mind the variations in the specific gravities of both mineral aggregate and bitumen. Thus the maximum variation in road-making rocks is from 2·00 to 3·65, so that if rocks of extreme character were crushed to the same size and mixed with, say, 6 per cent. by weight of a given bitumen, a variation would be obtained in the number of gallons of the latter of 45 to 81 per cent. per cubic yard of rock. If the variation in the bitumens is still further taken into consideration, the proportioning by weight would show even greater differences in the volume proportions. (From a paper by Prevost Hubbard on the bituminous content of bituminous aggregates).

Before laying the bituminous macadam, the surface of the existing road is scarified and upon it is placed a bottom course 4 ins. deep of crushed stone graded between 1¼ to 2½ ins. This is rolled to the standard depth and upon it is then laid the bituminous macadam consisting of crushed stone graded from 1¼ in. to ¼ in., mixed with a suitable bitumen in a hot condition. When this has sufficiently cooled, so that the weight of the roller will not push the material out of its place, it is rolled to a firm surface, free from any irregularities. On this is applied a seal coat of bitumen, which, as soon as spread, is covered with grit of pea size. The whole is now well rolled with the heavy roller until the grit is firmly bonded into the bitumen forming the seal coat.

As an alternative to the mixing method of preparing a bituminous macadam, the material is sometimes made up in what is known as the " penetration " method, though it must be confessed that this latter does not appear to give anything like the satisfactory results obtained with the former. In this case, too, the sub-grade is first scarified and a 2-in. layer of coarse stone applied, rolled and shaped to the camber of the finished road. A further layer of the same stone is now put down 3 ins. thick, into which after being rolled, is sprayed a hot bitumen by means of a pressure sprayer, about $1\frac{1}{2}$ gallons being used per super yard. Immediately after this application, a coating of pea stone is spread upon the hot bitumen and the whole rolled. A second spraying of about $\frac{1}{2}$ gallon per square yard is now applied, following which a sufficient amount of pea stone is put down to form a good wearing surface.

The adoption of this class of work in the United Kingdom is still in its infancy, so that as yet it is impossible to give any definite figures or results of its use. In the United States highways and roads thus formed are giving gratifying results, but as Dr. Sommer, of the Barber organisation, remarked to the writer during a conversation this summer, both weather conditions and subsoil are entirely different here and will necessitate a great modification in the type of bitumen used, in order to successfully combat them.

CHAPTER XV

OTHER USES OF BITUMEN

One of the most important uses of bitumen after the paving industry is that for the impregnation of felts for roofing, waterproofing, insulating and similar purposes. This is in reality the outcome of the gradual perfecting of the older tar impregnated felts, so that a short *resumé* of the entire history of this industry may not be out of place here.

Scandinavia is the birthplace of this material, and it was invented there in the eighteenth century by the Swedish naval adviser, Dr. Faxe. His methods, although brought up to date, as may be expected, are still in use at the present time there.

Naturally the first roofs covered by him with this material proved to be very defective, for the idea of impregnating the felt with a waterproofing compound had not then been thought of. Instead, the method adopted was to lay the unimpregnated felt upon the sarking boards, to which it was fixed with short-headed nails, in shingle fashion, the felt being made at this time in flat sheets some 30 to 40 ins. wide and of varying lengths, not in the long rolls as we have it now. When the roof was completely covered in this way, the felt was then painted with hot wood tar in order to make it watertight. A natural consequence of this was that the tar only partially penetrated the fibres of the felt, and the thin coat of tar thus formed was soon destroyed by the action of the weather. Following this, the felt itself became swollen up with the absorption of rain and was the victim of the first strong gale that came along. For this reason the crude idea found but very little use at that time.

In Germany Dr. Gilly, of the Office of Works, appreciated the value of the method and so he interested himself in its perfection. In his book "The Art of Public Buildings" he strongly recommended its use to the German public, particularly for agricultural buildings. His efforts were frustrated, however, by the intervention of the Napoleonic wars at the commencement of the nineteenth century, as the result of which all trace of roofs covered in this way in Germany seem to have been lost, and it was not until the early forties that we again find any interest taken in them there. About the year 1842, Herr Büsscher, the founder of the firm of Büsscher and Hoffmann, in Eberswalde, came from Sweden, and having asked for and obtained from the Swedish government the necessary instructions for the preparation and laying of roofing felt as carried on in that country, he covered his premises in Eberswalde with this material. He only appears to have made sufficient felt for his personal requirements, for we find that it was only after another firm in the same town, Messrs. Ebert Bros., had prepared it in bulk for sale that their example was followed by Büsscher. It was now that the first improvement in the manufacture of the roofing felt was made, for whereas the Swedish method had been to paint the unimpregnated roofing felt after it had been fixed in position on the roof, the idea suggested itself to the German manufacturers of impregnating the sheet, a process which was at first carried out immediately before the sheets were placed in position on the roof, and then later in the factory itself before the sheets were sent out. With the increasing use and competition between manufacturers came improvements both in the material and in the methods of manufacture, so that, with more and more satisfactory results to offer, this method of roof covering came to be better appreciated by the general public, and so came more and more into vogue.

Instead of the expensive wood tar which was at first used as the impregnating compound, a substitute was found at this juncture in the coal tar which was formed as a by-product in the gas-works. As here this material was looked upon as an extremely troublesome, undesirable and worthless article it was readily and freely sold to the roofing felt manufacturers at nominal prices. As yet, however, the method of manufacture was merely to steep the square of unimpregnated felt into a cauldron of hot tar until it was thoroughly soaked. When this was done, the sheet was taken out of the tank, the superfluous surface tar drained off and the felt allowed to dry in the open air. The idea of extracting this excess of tar by means of press rollers was only thought of at a later date, when it was begun to manufacture the felt in rolls instead of sheets.

No article has been more misconceived, perhaps, than the raw felt, *i.e.*, the unimpregnated article, that is used in the manufacture of roofing felt. By many, even amongst those who should know better, it is spoken of in a disparaging manner as "paper," and its possibilities discounted accordingly. The true raw felt as used by the reputable firms of roofing felt manufacturers is, however, a loosely woven felt prepared from woollen fibres, and though the process through which it goes may in some respects be comparable to that seen in the ordinary paper mill, the resultant material is quite distinct. Like paper, though, it lends itself to an easy adulteration, but the true type is prepared from woollen fibre only. This adulteration is done in two ways: either the quality of the fibre is reduced by intermixing with it a quantity of vegetable fibres, or else, since this material is always sold by weight by the manufacturers to the makers of roofing felts, by the addition of "loadings" of mineral matter such as chalk, gypsum, whiting, alumina, etc. All these methods of cheapening are to the detriment of the finished roofing felt, and as showing how completely in the hands of the makers of this material the manufacturers of roofing felts are, it may be stated that there is only one firm of roofing felt producers in the United Kingdom who prepare their own raw felt.

In order to show how completely dependent upon the quality of the raw felt the prepared product is, it should be remembered that vegetable fibres rapidly decay with constant exposure to all weathers, whilst of the "loadings" chalk in particular forms an additive compound with tar, which, being soluble in water, is dissolved out with heavy rains and leaves behind it open pores in the roofing felt through which damp and rain readily penetrate.

These adulterants are all readily recognisable by certain chemical tests, but as this is too wide a subject to admit of adequate treatment here, the reader who is desirous of going more fully into the matter is referred to a work on "Roofing and Waterproofing Felts," which the writer hopes to produce shortly, and in which the manufacture and use of these articles will be thoroughly dealt with.

In brief, upon the quality of the raw felt is essentially dependent the life of the finished roofing felt, and this quality is itself dependent upon the quantity of vegetable fibre and "loadings" that is used in the process of manufacture.

The different thicknesses of the raw felt are known to the trade under particular numbers, and these numbers relate to the area of the material in a certain fixed weight. The usual varieties range upwards as follows, though any special one can be prepared by the manufacturers if it is specially ordered :—

Number.	Thickness.	Area in 50 kilogrammes.
00 or 50	2·00 mms.	50 square metres.
0 or 60	1·75 ,,	60 ,, ,,
I or 75	1·66 ,,	75 ,, ,,
II or 90	1·40 ,,	90 ,, ,,
III or 120	1·00 ,,	120 ,, ,,
IV or 150	under 1·00 mms.	150 ,, ,,

and so on. These thicknesses and areas are, of course, only approximate, and depend to a very great extent upon the material from which the raw felt is made and the amount of moisture and loadings that it contains.

A first-class raw felt should show an approximate composition somewhat as follows :—

Moisture	5 to 10 %
Ash	0·5 %
Wool fibre	89·5 to 94·5 %

The amount of this last can be ascertained by treating a dried sample with caustic potash in a solution of which the wool fibre dissolves out.

In the early stages of the manufacture of roofing felt, this raw felt, or " fibre " as it is now usually termed by its users, in order to prevent any confusion with the finished impregnated felt, was made in sheets. These were immersed in heated tar, drained and air-dried. The operation was done by filling a suitable tank about three parts full of tar and then heating this to the requisite temperature by means of a fire-box below the tank. Into this hot tar were then laid singly, one on the top of the other, as many sheets of " fibre " as the tank would hold. The tar was kept heated and the sheets were left in it until they were all thoroughly impregnated, a process which usually occupied several hours, during which time care had to be taken that the topmost sheet was always kept covered with the liquid. The sheets were then lifted out by means of iron tweezers and placed upon a draining table preparatory to being hung up to dry, and their place in the tank filled with a further number of unimpregnated sheets after the volume of the tar in the tank had been replenished. After the impregnated felt had been drained of all its superfluous tar it was then hung up to dry, or in fine weather laid out in the open, first one and then the other side being exposed until the whole was thoroughly dry. Following this, the sheets would be made up into piles in the store in readiness for use or for despatch in that form. It was then made only in one thickness, and of this a hundred sheets of about 0·7 metres square weighed 50 kgs. and cost in the early fifties about 16*s*.

As time went on the manufacture of the fibre became more perfected, with the result that instead of the material being made up in sheets, it was manufactured in long rolls.

From this the natural consequence was the alteration of the method of impregnation so as to fit in with this modification. Various means were tried from time to time to bring about a satisfactory result, but all of them with but varying degrees of success. The first difficulty was that the full length of the roll could not be laid out flat in the tank, as this would necessitate the requisition of too large a tank. Then it was also found that as long as the fibre remained in the tar the saturation by the liquid loosened the texture of the material, so that it was very easily torn, and therefore demanded a very careful and skilful handling. Again, it was further discovered that when the raw felt was placed in the tank in its rolled up state as received from the manufacturers, it was not properly impregnated by the tar, which merely soaked through the outer piles and left the inner ones untouched.

At first the rolls of the fibre were cut into shorter lengths of 10 to 15 metres, and these again rolled up loosely, so that a definite air space was left between each ply. As the weight of the roll would cause each ply, even although thus loosely rolled up, to press upon each other, and so prevent a regular impregnation, they were immersed in the tank in an upright position by being first stood upon a perforated board in the centre of which was fixed an upright rod which, by being passed through the centre of the roll of fibre, held the latter in position and at the same time acted as a kind of handle, since by means of it the roll could be raised and lowered into the tank as required. After the fibre had been completely saturated the roll was taken out of the tank and placed upon the draining table, from which the excess of tar ran back again into the tank. Following this the roll was opened out either in the open air or, when the condition of the weather precluded this, in a drying room, and after being thoroughly air-dried, it was finally rolled up again and stood upon its end in the stock room ready for despatch.

The next advance in the manufacture of the tarred felt was to do away with the troublesome and lengthy work entailed with the air-drying of the finished material, and to avoid this, and also to prevent the felt from sticking together when it was finally rolled up, the makers began to scatter sand over its surface. By doing this, it was discovered that further advantages had been unconsciously obtained for the felt, for the weight became appreciably increased, the material became apparently thicker, and hence, to the popular mind, stronger—a fallacy that still holds at the present time among many buyers—whilst the surface offered a much more pleasing aspect when the felt was laid upon a roof than the hitherto monotonous black colour of the older type.

Nor did the progress of the manufacturing methods stop here. The time required for the final operation having been so appreciably reduced in this way, it was then desired to cut down the period taken up by the draining of the felt after impregnation. For this, however, two successive steps are traceable. The first idea was to scrape the felt as it was being extracted from the tank.

By this time the method of upright immersion had been replaced by that of rolling the length of fibre around a reel which was then lowered horizontally into the boiling tar. In this case the difficulty of merely impregnating the surface of the roll, as the result of the adjacent plies pressing upon each other, was again met with and obviated in this instance by the use of a pair of waxed cords which were rolled on the reel together with the fibre in such a way as to separate each ply. In order to form a still greater space between the latter, the cords were knotted at regular intervals of about 3 ins. and a free access to the entire surface of the fibre on both sides was thus secured for the tar.

The scraping operation was effected by fixing two iron rods across the tank, so that an aperture was left between them, and after the fibre had been suitably saturated, the free end of the roll was passed through this slit. As the impregnated fibre was drawn from the tank, each side was thus scraped by these rods and the superfluous tar immediately flowed back again into the tank. By this means, not only was the excess of tar scraped off, but the certain amount of pressure that was necessarily exerted by the rods upon the surface of the felt resulted in the material becoming closer in texture, since the fibres which had been loosened by the liquid were thus firmly compressed together, and the resultant impregnated felt, therefore, became tougher.

At this stage the felt was withdrawn from the tank by hand, and the next idea was to effect such extraction mechanically by means of rollers. Immediately this was done, it was observed that these rollers must also exert pressure upon the felt in order to obtain the requisite grip upon it, and it therefore naturally followed that in place of the scraping rods, the rollers were brought forward immediately above the tank and made to act in the double capacity of drainers and extractors. This method is the one which is still adopted in the different types of impregnating machines used in the modern processes.

Attention was now turned to the impregnating operation itself. The first alteration to be put in hand here was that instead of reeling the fibre before immersion, one end only of the fibre was fixed to the reel, which was then lowered into the hot tar, and only after this had been done was the remainder of the roll of fibre reeled upon it. By this means, of course, the fibre came in contact with the impregnating fluid before being rolled up, and the saturating thus commenced continued during the length of time that the roll was permitted to remain in the tank.

Of late years though, efforts have been made with the greatest success both in Germany and the United States—the process being installed in certain English factories, after the experience of the first two mentioned countries had proved its value—whereby the entire operation of impregnating, draining, sanding, and rolling up can be carried out without a stop. Mechanical power has been most effectively employed to replace the older hand labour, so that in the modern machine capable of turning out as many as 500 to 1,000 rolls of the finished felt, each 15 yds. long by 1 yd. wide, only five workmen are really needed. Two of these attend the beginning of the machine, where a huge reel of the fibre is mounted and runs constantly at a steady rate into the impregnating tank.

When one reel is finished, its end is "stitched" to the beginning of a second reel with metal slips so that no stoppage of the machine is necessary. By suitably placing in the tank a set of immersing rollers, which having a rotary motion of their own exert no tension on the fibre as it passes over them in the impregnating fluid, the material is passed backwards and forwards through the liquid until it has been immersed for such a length of time that previous tests have shown to be requisite for the proper impregnation of the fibre. As, for instance, a heavy fibre will need a much longer time for the impregnating fluid to properly penetrate it than would a lighter one, the speed at which these immersing rollers rotate can be reduced according to the particular class of felt that may be in the process of preparation at the time being.

From this tank the wet fabric automatically passes on to a set of press rollers which, after extracting the excess of the impregnating fluid and suitably compressing the fibre, conveys it, in the case of the more modern types of machines, into a small coating tank in which the impregnated felt, whilst passing through a less fluid mass than is to be found in the impregnating tank, receives a surface coat of a much tougher material which, being deposited in a hot condition at a time when the impregnating compound is also warm, obtains the requisite bond with it, and so prevents the possibility of it peeling off when exposed. From this coating tank the felt proceeds through a further set of press rollers, after which it is drawn below sand "hoppers" in such a way that each side is alternately sanded. Journeying on, the felt thus sanded is passed through a cooling chamber, and from thence it goes through a guillotine arrangement, the cutting edge of which drops mechanically every 12 or 15 yds. as the case may be. Automatic rolling-up arrangements terminate the machine, from which the rolls of impregnated felt pass down an incline which transfers them into the store quite ready for immediate despatch, though it is to the advantage of the felt if it is allowed to mature for not less than a fortnight before being used.

Of the squad of workmen mentioned above, the remaining three are employed, one to watch the progress of the felt through the machine and to regulate the fall of sand from the hoppers—the sand being filled automatically into the hoppers from the sand drier and screen by means of a suitable elevator and conveyor— and the other two to attend the rolling up of the prepared and finished material, to place upon it the different coloured paper bands which denote the particular quality of the felt then being prepared, and to transfer it to the store.

But the mechanical arrangement is not the only portion of the work that can show such a remarkable progress. The impregnating material itself has been greatly modified. At first, as we have already seen, crude tar was the liquid used, but it was found by experience that the felt prepared from this had the very unsatisfactory attribute of becoming brittle with any length of exposure and, therefore, cracked with the warping of the sarking boards upon which it was laid. Inquiry into the cause of this resulted in the discovery that the exposure of the felt to atmospheric conditions caused the volatile light oils of the tar to evaporate out of it, leaving the material both brittle and porous. As a temporary expedient it was then the custom to periodically paint the felt with a fresh supply of tar so as to renew the flexibility of the material, but even this merely masked and did not really correct the weakness. To obviate this, therefore, the crude tar was replaced with distilled tar in which all the light oils had been previously extracted, or with prepared tar in which the light, medium, and some of the heavy oils were first extracted, and then the pitch thus obtained "cut back" or remixed with the medium oils. The reason of this was to obtain the heavy (anthracene) oils which had an extensive employment in other trades, particularly in the manufacture of artificial indigo, and then, by regulating the amount of the oils used in the "cutting back" operation, to obtain an impregnating compound which would have a suitable body for this particular impregnating work. When distilled tar only is used, it is usual to obtain the necessary body, especially for the coating operation, by mixing in with it a sufficient quantity of pitch.

The so-called "sheet asphalts," now so extensively used for both roofing and dampcoursing, are in reality this class of felt in which the impregnating compound is the distilled or the prepared tar.

No matter with what type of impregnating material, however, the tarred felts always have the inherent weakness of gradually losing their flexibility, and so of becoming liable to crack, hence the necessity of periodically tarring or "varnishing" all roofs covered with this material in order to replace the volatile elements which have been lost, and also to fill up the pores in the felt that have been formed by the evaporating out of these oils. The next progressive step, therefore, was to find some alternative impregnating compound which would not develop this weakness upon exposure, and for this purpose are now largely used such materials as stearin pitch, petroleum pitch, cotton seed oil, etc., but by far the best results have been secured by the adoption of bitumen, with the use of which was created that type of roofing felts now so widely known as "ready roofings." Of these, however, only three of the many brands to be found in the United Kingdom are actually manufactured in Great Britain, the remainder, although marketed through English firms, being imported principally from the United States.

The felts prepared from materials other than coal tar and pitch are naturally much more expensive, but this initial expense is more than outbalanced by their durability and the entire absence of any maintaining cost, for with even the "asphalt" roofing felts it is absolutely essential for the well being of the covering to coat it with tar varnish when laid and to renew this protective coat periodically. With the advent of the bituminous felts, the necessity for the coat of sand, too, is done away with, its place being usually taken by powdered French chalk, mica, or even asbestos, so that the same thickness of fibre shows a much thicker roofing felt when made into the sanded material than when used for the "ready roofings." The writer mentions this, as he has found that too much stress is laid upon the gross thickness of the sanded felt and not sufficient upon the net thickness of the impregnated fibre only, which, after all, is the essential part of the roofing. In a like way, too much attention is paid to the keeping up of the weight of the felt, a matter which is easily adjusted by the use of an additional quantity of sand on the surface, and at times it is almost impossible to get the consumer to grasp the fact that the durability and the water tightness of the felt cannot be gauged by weight, unless the weight which is taken into consideration is that of the felt without the sand.

The " ready roofings " are made in two operations, the first the impregnation of the felt, and the second, the coating of the felt thus formed. A similar type of machine to that used for the continuous manufacture of the tarred felts is employed in this case too, so that the entire process of rolling the fibre into the thin impregnating bitumen, saturating the fibre, extracting and compressing the impregnated felt, passing this into the coating tank, extracting and surfacing this with mineral, rolling up, etc. is done on the one machine consecutively. For the impregnating material, a thin flowing consistency is given by means of heat to the fluxed bitumen in order that the fibre shall be thoroughly saturated with it. The coating compound is a much thicker type, for its duty is not to impregnate, but to lay thickly upon the surface of the saturated felt, obtaining the bond requisite to prevent it from peeling off, by adhering to the bitumen saturating the pores. Its purpose is to hermetically seal the fluxed bitumen in the fibre, and by thus preventing any possibility of the latter drying out, it results in the felt permanently retaining its flexibility. As, of course, this coating of bitumen must also possess a certain amount of elasticity, it is customary to use the so-called " rubber " bitumens, usually " cut back " gilsonites, for this purpose, although, for the sake of cheapness blown petroleum residues are often used in the lower grade classes.

The fibres usually employed for these roofings are numbers 100 for the one-ply, 90 for the two-ply, and 60 for the three-ply roofings. The term " plies " as used in this manner is not very happy, since it would imply that the thicker varieties are composed of two or more layers of the thinner one combined together, which, however, is not the case. Immediately the felt has been coated, it is then dusted with either French chalk, mica or asbestos, in order to absorb any small quantities of the fluxing oils that may show upon the surface, and also to prevent the felt from sticking when rolled up. The mica gives a white glistening appearance to the surface, whilst the French chalk leaves a quiet neutral grey finish. The use of the asbestos is to exhibit an absolutely fire-proof surface when laid, though its value is more apparent than real. The British made felt is put up in rolls containing 15 sq. yds., and it is now usual in packing up a roll of this material to also include with it the necessaries for its use—the cement for the joints, and the nails and caps, these being packed up in circular tins or boxes, which fit into the centre of the roll.

The material, as its name implies, is used in the covering of roofs of buildings of all descriptions, whether temporary or permanent, sloping, segmental or flat. Although very suitable for temporary roofs or even for the sloping and segmental roofs of more or less permanent structures, the writer does not agree with its use for flat work, although it is now employed for this purpose in England to a fairly large extent, and his belief is also held by various other gentlemen intimately concerned with the manufacture and use of such felts.

The weak point in work of this description is at the joints. The work is usually carried out with a single layer of felt, an overlapping joint being made at the seams, which are then sealed with a bituminous mastic and nailed. Now with the intense heat of summer this mastic must soften, and, further, the felt itself expands; with the cold evenings comes the corresponding hardening of the one and contraction of the other. This continuous movement, although imperceptible, can only have but one result, the weakening of the joint, which is usually only some two or three inches broad. Again, the felt is left entirely unprotected, and so is easily cut and damaged by traffic, for flat roofs at the present day are nothing if not utilitarian, and the writer has seen them put to the most varied and multitudinous of uses, from a drying lawn to a skating rink. Besides this, too, in wet weather there is always a mass of water lying directly upon them, so that when any weak spots are occasioned by the motion mentioned, or by sharp objects brought in contact with the felt, whether flying slates from adjoining buildings in stormy weather, or hob nails in the boots of the promenaders, this water soon finds them out and works its way below, doing great damage to both the structure and its contents alike. If a flat roof is to be covered in this way, two layers at least of the felt should be put down, but as this would then bring the cost of the work up to approximately that for the more superior methods of flat roof covering, such as rock asphalt, vulcanite, etc., this recommendation will scarcely be carried out, for in the majority of cases this method is adopted only because of the initial economy effected.

When laid on a sloping or segmental roof, there is the option of running the layers either from gable to gable or from eave to eave. Both methods are in use, as the difference in their respective values is more theoretical than real. However, the writer personally much prefers the latter, since by this means the rain draining from the roof has a clear run from ridge to eave, whilst with the first method there is invariably a hollow every three feet where the overlapping of the two adjacent sheets occurs to form the seam, and in which water is trapped.

In either way the method of carrying out the work is the same. The sheets of felt are first unrolled out flat on the roof so as to attain the same temperature as it, and thus prevent any stretching after the covering has been finally placed in position and fixed, as this would cause the sheet to sag and wrinkle. This done, it is then cut into suitable lengths, and these laid on the sarking boards in the places they are to take. At each joint of the felt, whether where two lengths adjoin or where two pieces are joined to form a complete length, an overlap of from 3 to 4½ ins. is made. Whilst this is being put in hand by one workman, another is engaged in melting the cement to a fairly watery consistency, in which state it is painted between the laps with a broad stiff brush, and then the upper lap is firmly pressed down into the lower one. After this the joints are again gone over and nailed with either specially made broad-headed, dome-shaped nails, or, which is more usual, with galvanized broad-headed nails and washers, the nails being spaced about 2 ins. apart. The heads of these are customarily given a coat of cement, so as to prevent them rusting in damp weather. At the eaves the felt is tucked under the edge of the boarding and close nailed there in a similar way. Where any projections occur in the roof, such as chimneys, ventilators, lantern lights, or party walls, a wood angle fillet is fitted at the base of the projection, up which the felt is dressed and close nailed at the apex. To protect the junction of the felt and the wall, a top flashing is used, preferably of metal, which is wedged into a raggle cut into the wall for the purpose and then dressed over the felt.

Despite the manufacturers' assurances to the contrary, it is always advisable to give the surface of the felt a protective coat of asphalt varnish, and to renew this periodically. With the felt which has been finished with French chalk (which it has been omitted to state must be thoroughly brushed away from the felt at the seams before the application of the cement, since, if present, it prevents the proper adhesion of the cement with the felt), a neutral grey roof covering is the result when first laid—if it is not provided with the suggested protective coat—but this gradually changes to a dull black. Many occupants and owners of felt covered structures prefered to see a coloured roof rather than this, and the desired effect is easily obtained by the use of a paint made from a non-fugitive colour, whether mineral or otherwise. The usual solvents used for these paints have a solvent action on bitumen, so that a paint thus applied has a partial bond to the bitumen which coats the felt through the medium of its solvent and so is not washed away. Certain coloured bituminous felts for this purpose are to be met with on the market, but the method just mentioned gives equally satisfactory results, whilst it has the further advantage that the paint coat possesses a similar protective action to the felt as would the layer of asphalt varnish.

Bituminous products allied to the roofing felts are the bituminous sheetings and the bituminous dampcourses. A slight amount of confusion is occasionally found with the use of the first named term, since it is employed by certain manufacturing firms to refer to a material which is practically identical with the bituminous roofing felt, except for the fact that it does not receive the second coat of bitumen, but consists merely of the impregnated fibre. Besides this the term is also seen used to designate a thinner quality of the bituminous dampcourse.

The first type of bituminous sheeting is used principally as an insulator against cold and damp, so that the question of the probable effect of heat upon it is negligible. In any case the method of using it eliminates the possibility of exposure to any outside influence, so that the protective coat given to the roofing felt is unnecessary here. Some American types of this material are to be found which have been sized, but, although this additional operation gives the product a more finished appearance, it cannot be said that any important practical advantage is to be derived from it.

The bitumen dampcourse is, however, quite a distinct material. In fact it may be regarded as a layer of more or less pure bitumen through the middle of which runs a sheet of jute cloth or, as it is now sometimes made, a thin sheet of laminated lead. The advantages of its use as described by "Specification" are that "it is absolutely impervious, apparently indestructible, and yields to settlement without fracture. Perfectly watertight joints can also be made between vertical and horizontal damp proofing." A weakness in this material that is not always understood as much as it might be is the fact that as the mortar used in the wall in which it is placed can only obtain a very slight bond with the bitumen, there is always the tendency to create a movement of the upper portion of the wall resting upon it.

The recent adoption of lead as a core for this material is entirely unnecessary, and from the manufacturers' catalogues it would appear that the strong point in support of its use for this purpose is the longevity of the metal. Be this as it may, the thinness of the laminated lead which is actually used in this article reduces its practical value to a minimum, whilst as regards durability, a reference to the earlier pages of this book, which refer to the ancient uses of bitumen, will show that the use of the latter for waterproofing and dampcoursing, besides being much older than that of lead, can still be found in erections which were built many centuries earlier than the date of the ancient Greek use of lead which is brought forward in support of its use in the bitumen dampcourse.

The jute cloth which is used in the ordinary types of this material is generally a 10-oz. Hessian. Cloths of lighter weights than this are unable to give the requisite support to the heavy coat they have to carry, whilst the heavier and closer woven ones prevent the interbinding of the bitumen on the two sides, with the result that the latter is liable to peel away from the jute backing.

The bitumen which is employed in its manufacture is of very varying types, although the Trinidad epure was originally the only one used, since at that time the more flexible rubbery types were not on the market. Now, however, but few of the possible kinds are not used, including blown petroleum residues and other substitutes. With this bitumen is usually mixed a quantity of mineral matter in a very fine pulverulent condition, very often a low grade French chalk, though lamp black and other non-gritty powders are sometimes used. Like roofing felt, the manufacture was originally carried on by hand, the thickly flowing hot bitumen being brushed over each side of the tautly stretched jute cloth, though now the coating is done by mechanical methods. Some firms add a quantity of rock asphalt powder to the mixture—sometimes up to 33⅓ per cent.—but although this toughens the material considerably, until it is almost like stone, it causes it to entirely lose its flexibility, which is its most necessary feature. Its uses are principally as a dampcourse for buildings and as a lining for reservoirs and liquid containing tanks, though upon occasion it is found, but with doubtful success—since the quality of the bitumen most in use in its preparation differs greatly from that used in the bituminous roofing felts, not to speak of the difference in the process of manufacture itself—acting as a roofing.

The procedure of using this material is slightly modified from that of laying the roofing felt. In this case, the cement for the joints is not required, as the necessary bond between the two overlapping sheets is effected by the bitumen itself. The margin of the material that is to form the seam is carefully cleaned of the French chalk with which it is usual to coat this product also, and of the paper which is used by some firms as a temporary backing for the purpose of preventing the plies from sticking when rolled up. The sheets are then placed in position and the flame of a blow lamp played between the edges so as to fuse the bitumen there. Immediately the bitumen is in a suitable condition, the upper lap is pressed firmly upon the lower one and the joint then dressed with a jointing iron. When used for vertical work, the necessary hold to the vertical structure is obtained by the use of special wall ties. These are made in two parts, one of which is built into the supporting wall in such a way as to leave a screw portion projecting. This is forced through the material and the hole made good by fusing the bitumen around it and pressing upon it an iron washer. When this has been done, the second portion of the wall tie is fixed to the screw and afterwards built into the retaining wall, which it is usual to erect in front of damproofing work of this description.

The fact of bitumen being used largely in the manufacture of black varnishes and japans has been repeatedly referred to in the earlier chapters. For this purpose it is of course necessary that the bitumen shall be perfectly pure, without any mineral matter, and shall be of such a type that it will not soften or become liquid at such extremes of heat to which it may be subjected when in use, or become brittle at the maximum degree of cold with which it may have to contend, but it should always remain elastic and flexible. The particular type that best fulfils these requirements is the American gilsonite when cut back with a suitable flux, though the material obtained from the Dead Sea and in Syria generally is still largely used by the more conservative firms manufacturing these materials.

These bituminous varnishes, enamels and paints are of inestimable value for all kinds of outside work, but especially so for exposed iron and steel work, since their flexibility allows them to stretch and to contract with the corresponding expansion and contraction of the metal work without the protecting film of bitumen becoming weakened in any way. Their success has, as might be expected, caused the creation of cheaper substitutes with coal tar bases, but as these crack, flake and become oxidised with the continuous exposure to the atmosphere, the results of their adoption are, to say the least, unsatisfactory. The bituminous paints are specially valuable for the protection of steel work on ships or similar marine structures which are subjected to the action of salt sea spray for lengthy periods, whilst, since bitumen is proof against most acids and alkalies, it is extremely useful to protect metal work that may be exposed to atmospheres in which these active agents are found. Although these bituminous paints are usually black in colour, at least one firm has recently placed upon the market a coloured bituminous paint which, the makers affirm, does not contain more than 5 per cent. of colouring matter.

Bitumen for varnish making should be practically entirely soluble in carbon bisulphide, chloroform, and oil of turpentine. It should have a conchoidal fracture showing a bright resinous lustre. It should not flow into a modified shape when left upon a sloping surface as does coal tar pitch, but should retain its sharpness of angle even when immersed in boiling water. If the bitumen has been adulterated with coal tar pitch, it has a much less brilliant fracture, and shows a metallic rather than a resinous lustre. Whilst pure bitumen has a smooth and homogeneous appearance and feel, the adulterated specimen shows up granular and pasty, nor will the latter allow itself to be drawn out into even threads like the pure variety.

Another very extensive use to which this material is now put is the insulation of electric cables. For the origin of this idea in the United Kingdom, the credit must be given to the late W. O. Callender, the founder of the celebrated firm of Callenders' Cable and Construction Co., Ltd., and who, during his business career, was intimately interested in certain of the continental rock asphalt companies. For this work a long fibred flexible bitumen is desirable, and particular attention should be taken in the choice of a suitable type so as to prevent all possibility of the troublesome and expensive task of tracing and repairing an underground fracture or weakness at a later date. It is with regret that the writer has noticed at times, particularly when the work of conduit insulation has been in the hands of smaller firms, the adoption of adulterated bitumens, if not actually artificial ones. Such material can only have the one result of occasioning the development of weaknesses in the work at a later date, and this does not tend to enhance the reputation of the firm who has carried it out. It must be confessed, too, that the adoption of such material is often the result of an insufficient knowledge of the material being handled, the question of price playing a very important part in its choice.

With the ever increasing use of reinforced concrete for constructional purposes, efforts have been, and are still being, made to overcome the inherent capacity of this material to absorb moisture. Two distinct methods have been adopted, the one being to coat the surface of the concrete structure when erected with a damp resisting compound, and the other to blend into the concrete itself a compound which, by filling up its pores and any minute voids that may be in it, will thus prevent the entry of water. Both methods are claimed to have special advantages and their drawbacks, and, whilst the use of an external coat of a bituminous paint is used by some firms for the facing method, it is of interest to note that attempts have been successfully made to blend into the concrete during the operation of mixing, a quantity of asphaltic oil which, whilst, so it is affirmed, not affecting the strength of the concrete in any way, is able to thoroughly waterproof it. A few years ago a British patent was granted for a method of waterproofing concrete with a compound having as its base the heavy tar oils, but the writer has not been able to ascertain whether the idea has been used to any great extent, whilst, having in mind the quality possessed by coal tar products of gradually oxidising, he is inclined to doubt the lasting nature of such a method.

Owing to the fact that its flexible nature enables it to withstand vibration, use has been made of bitumen in the foundations of such pieces of machinery as steam hammers or high speed engines, where it is desirable to reduce the amount of vibration otherwise transmitted to their immediate surroundings. This is usually done by making up the foundation with a bituminous concrete, using just sufficient bitumen to coat the aggregate and to fill the voids, without making the material too soft to withstand the pressure that will later be brought to bear upon it. On the continent it is the custom to include in this material a quantity of the naturally impregnated asphalt rock, as this materially assists in the absorption of both pressure and vibration. After the material has been placed in position, it is then bricked in, or else walled in with concrete, and covered over with a layer of the last named, so as to protect the bitumen from any droppings of oil or grease which, as will be understood from earlier chapters, have a solvent effect upon it.

In a similar way bitumen is also used for insulating purposes in ice chambers, cold storage rooms and the like, owing to the fact that it is able to retain its flexibility under intense cold. For this purpose, the aggregate which is bound together by the bitumen is composed of crushed cork, and slabs of the bitumen bound cork are thus made under the influence of heat and pressure, in varying thicknesses.

The foregoing is but a brief mention of a few of the many uses to which bitumen is now put, and it shows how limit-less are the possibilities of this material if its properties are carefully considered. That its use other than as a paving material is not new, is seen by the fact that over fifty years ago, " bituminised paper pipes " were made and used for the purpose of gas mains in the north of England. As, however, illuminating gas has a certain amount of action upon bitumen—as is found even in the modern asphalt pavements when a leakage of gas occurs below such a surface—it must be concluded that the experiment then made could not have been a lasting success, especially so as the writer, despite careful inquiries in the district, has not been able to find any trace of their present existence in the towns in which they were originally laid down, so that the suggestion then thrown out by the local newspaper that " there is every probability that they will speedily come into general use " was apparently not realised.

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BRADBURY, AGNEW, & CO. LD., PRINTERS, LONDON AND TONBRIDGE.