Again, if a discharge of this type takes place in a smoky atmosphere, the electric wind assists in carrying the charged smoke particles towards the surrounding surfaces, where the particles stick on impact. In other words, it acts as a smoke precipitator.

To sum up, it may therefore be said that the subject of atmospheric ions has a bearing on at least two important problems at the present time. First, there is the problem of the mode and mechanism of attachment of molecules and ions, linking up with allied problems in the structure of bodies in general; and secondly, there is the wide field of meteorology and the problem of atmospheric electricity in particular.

Natural Steam Power in California.

By Dr. E. T. ALLEN and ARTHUR L. DAY,
Geophysical Laboratory, Carnegie Institution of Washington.

OF Prince Ginori Conti's remarkable experiments in utilising the potential power in natural steam, the readers of NATURE have been kept informed (**121,** 59–62; Jan. 14, 1928). The novelty of his conception and the patience and ingenuity with which it has been pursued to full realisation have attracted much attention among engineers and the public, and people have already begun to consider the possibility of similar projects elsewhere.

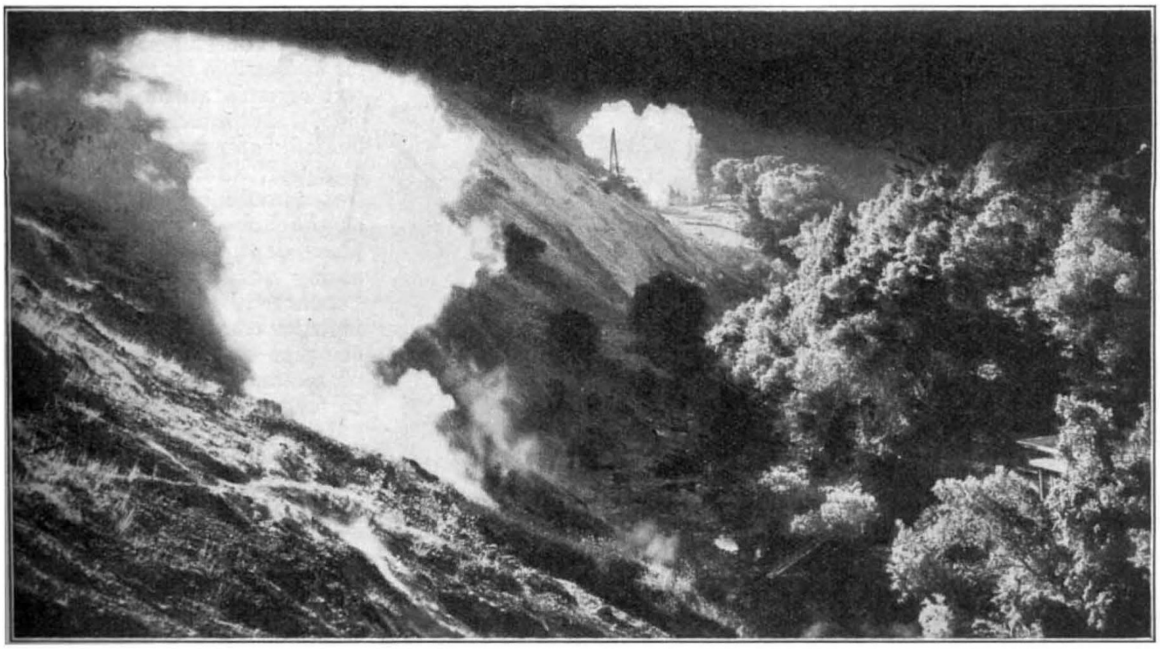

FIG. 1.—Sulphur Creek canyon looking east.

The locality in Tuscany which is the scene of these experiments has long been known as a centre of the boric acid industry, but few have had any definite conception of its character. It is, or rather was before industrial exploitation had modified its appearance, a barren tract covered here and there with very hot steaming springs and vents from which natural steam gushed out in jets of varying size—not infrequently with impressive noise and velocity. Exploration has since brought to light similar regions in other parts of the world, but the Tuscan field still appears to be unusual in the high proportion of its steam output.

Preliminary prospecting for natural steam with the drill in Bolivia and in Oregon has proved unpromising; the flow of steam was too feeble. In the Dutch East Indies one well, bored to a depth of 66 m., showed a pressure (closed) of $4\frac{1}{2}$ atmospheres and a potential power development of 900 kw. Other borings are contemplated in a number of fumarole areas in Java and Sumatra. The Valley of Ten Thousand Smokes, which has been mentioned in this connexion, is much too remote to claim consideration from a commercial viewpoint; besides, the most recent exploration in that region (1923) has proved that a great drop in the surface temperatures has occurred there in less than five years. The Italians have considered, and are perhaps still considering, the sinking of steam wells at Pozzuoli, near Naples, though we have not learned that actual borings have been made there. Recent advices from California inform us that a test hole drilled in Imperial Valley to a depth of 725 feet yielded steam at 175 lb. pressure; but the only development known to us that approaches the achievement in Tuscany has been carried out at The Geysers, a place 75 miles north of San Francisco and about 30 miles from the Pacific coast. It lies near the bottom of a deep V-shaped valley enclosed by steep mountain slopes, and reveals its presence to the approaching traveller as a barren stretch of ground from which on cold or damp days great columns and clouds of steam are seen rising.

The hot ground which has been actually explored covers an area of only 35 acres. Where the surface is hottest the ground is absolutely barren, its desolate appearance being intensified in dry summer weather by salt encrustations—chiefly sulphates of magnesium and ammonium—which partially cover it. In less active spots a very sparse growth of grass and weeds may be seen, and in a few cooler places taller bushes and trees. Shallow hot springs, usually only a foot or two in diameter, yielding turbid water close to boiling temperature (which at this elevation is near 98° C.), are scattered over the surface, along the bottom and east side of the ravine. There are natural vents, never more than an inch or two in diameter, to be found here and there, but the steam that escapes from them, though frequently audible, is scarcely visible in the hot dry summers of California, save at morning and evening, when the observer finds to his surprise that it is not only pouring from the vents but is also seeping through the porous ground and enshrouding the mountain slope. A little below the surface the ground quickly reaches the temperature of boiling water, and in the two most active vents a surface temperature of 102° C. was measured.

FIG. 2.—Geyser Creek canyon looking north at midday.

The Geysers has been known to the white man for about seventy-five years—a considerable period of time for that locality—but until recently it had attracted attention only as an unusual manifestation of Nature or for the reputed medicinal virtues of its hot-spring waters. About six years ago Mr. J. D. Grant, who has had considerable mining and prospecting experience, became interested in the constant escape of hot steam from the ground and, without any knowledge of the successful boring in Tuscany, conceived the idea of utilising it. Beginning in a small way with the help of a few men and an ordinary churn drill, he succeeded in drilling through the surface clay and into the underlying sandstone, keeping the steam condensed so far as possible by running in cold water from a tank on the mountain side. At intervals the rapidly heated water would shoot out like a geyser, after which more cold water would be let in. As soon as the hole had reached a suitable depth, an 8-inch steel casing was lowered into it and 'anchored' to the rock by the ingenious device of pouring around the pipe several hundred pounds of molten zinc, which congealed to form a tight joint.

It was about this time (midsummer of 1922) that we first visited the spot. Mr. Grant demonstrated the force of the steam by shutting off the cold condensing water and lowering the drill and tackle—representing a combined weight of about a ton—so as to cover the top of the pipe, when the whole mass was lifted several inches and the hot steam rushed out with a deafening roar. When the well had reached a depth of 200 feet the top was closed by a heavy gate valve. A second well was afterward drilled to a depth of 300 feet with power derived from the steam of the first well. Each of these two wells, when closed, developed a pressure of about 60 lb. per square inch. The practicability of utilising the steam was demonstrated by piping it to a small turbine and dynamo used for lighting the inn and cottages, the only buildings nearby.

Experimenting with the wells, Mr. Grant discovered that they would discharge continuously for a month, apparently without the least abatement of vigour, and, when closed again, would return to

(*Continued on p.* 27.)

the same pressure as at first. With the aid of outside capital the work was continued under a competent engineer, Mr. J. D. Galloway, of San Francisco, who completed five new wells ranging from about 400 to 650 feet in depth and developing pressures (when closed) from 95 lb. to 276 lb. per square inch. Further measurements showed a steam output for the individual wells of 7500 to 52,000 lb. per hour (average above 30,000 lb.), corresponding to a switch-board delivery (average) of about 1000 kilowatts per well at a pressure of 75 lb. The wells are separated by distances varying from 50 feet to 175 feet, and none of them appeared to show any diminution in pressure or flow of steam due to the output of its neighbours.

The figures show that the steam wells here are fully equal to those in Tuscany in point of power developed, and that they contain a somewhat smaller percentage of fixed gases to diminish the effectiveness of the application of the steam to power development. On the other hand, the chances for extension of the power development appear much more limited. While the hot ground in Tuscany is said to cover an area of about 100 square miles, thermal activity in the Californian locality is confined to a narrow belt less than a quarter of a mile in width and not more than six miles in length, and even within this area hot water and steam appear at the surface only in places. In Tuscany, too, there is an added commercial advantage in the boric acid supply; in California the percentage of boric acid in the gas is small. But the industrial outlook is not unpromising; the operating company has under consideration at the present moment a plan for the appropriate utilisation of the power. Of the scientific interest of what has already been accomplished there can be no doubt whatever.

In the summers of 1924 and 1925 we were permitted to make quite a large number of tests on five of the seven wells—all that were completed at the time. Analyses showed that the steam was accompanied by other gases varying in amount from three-quarters of one per cent to a maximum of two per cent by volume. These gases are mixtures of carbon dioxide—always the chief constituent—and smaller amounts of hydrogen, methane, hydrogen sulphide, nitrogen, argon, and traces of boric acid and ammonia (about 0·03 per cent). A series of temperature and corresponding pressure measurements in the closed wells showed that the former ranged from about 154° C. to 190° C. at the top, while pressures varied from 62 lb. to 180 lb. per square inch. The most powerful well, as a matter of safety, was kept partially open during the time of these experiments, discharging at a pressure of about 120 lb. per square inch. Without taking time to analyse the figures,[1] it may be said that they prove conclusively the superheated character of the steam. Nasini had already reached the same conclusion regarding the natural steam of Tuscany. A wider experience has proved that this is not a sporadic occurrence in thermally active ground; we have found vents in the Yellowstone Park, in the Lassen National Park, and many in Alaska, where the temperature of the escaping steam was so high as to leave no doubt of superheat.

The facts would probably convince any competent observer that the source of the steam in the wells under discussion could not be derived from a reservoir of water, either above or below ground. The high temperature, high pressure, enormous output, and superheated character of the steam point to hot magma below the surface, of such extent that the steam may be drawn off in quantity for an indefinite time without materially diminishing its pressure. Only a hot magma, probably still near its crystallisation temperature, could answer these requirements. We know that water is an invariable constituent of all types of igneous rocks and that there is more of it in the glassy rocks which approach in character nearer to the liquid state. We know also that the gases associated with the steam both in the wells and in natural vents correspond in character to those found in igneous rocks, varying only in their relative proportions from place to place as other rock constituents do.

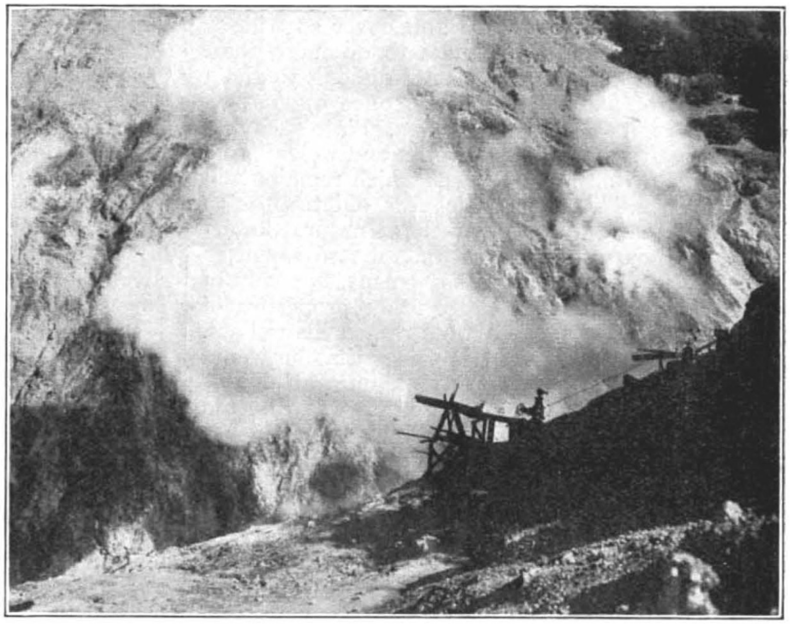

FIG. 3.—Wells No. 1 and No. 2 discharging into the atmosphere, 1924.

The area where these steam wells are located is superficially covered with sediments and meta-

[1] For details see "Steam Wells and Other Thermal Activity at 'The Geysers,' California." E. T. Allen and Arthur L. Day, Carnegie Institution Publication No. 378 (Washington, D.C.: Carnegie Institution), pp. 55 seq.

morphics, but a core of gabbro was brought up from a depth of 230 feet in drilling one of the wells, while andesite outcrops on the higher peaks of the mountain range. With the incomplete evidence at hand it would appear that the rock from which the steam issues is not recent, for the sediments are apparently of Cretaceous or Jurassic age. The view here presented concerning the source of the steam assumes the existence of a fault—a means of egress for the imprisoned steam. Of that we have interesting evidence in the fact that within a narrow belt, more than 25 miles in length, many quicksilver mines as well as all the hot areas are found. However, every theory of hot springs assumes the existence of faults to account for their appearance at the surface, and the association has been proved to be true in so many instances as to inspire some degree of confidence in its general validity.

Obituary.

PROF. T. W. RICHARDS, FOR. MEM. R.S.

THE death of Prof. T. W. Richards on April 2, at the comparatively early age of sixty years, is a grave loss to science. His contributions to knowledge were so valuable and cover so wide a field that it is impossible here to do more than indicate their scope: yet it is not difficult to grasp the secret of his greatness. He once quoted, as an expression of his own views, Plato's saying that "if arithmetic, mensuration, and weighing be taken away from any art, that which remains will not be much." All that Richards did testifies to his belief that the development of natural knowledge is primarily dependent upon measurement.

It was in precision of measurement, not only of atomic weights but of many other properties of matter, that Richards far outstripped his fellows. To read any of his papers is to see that he would spare no effort to ensure the maximum attainable accuracy in his data. His attention was directed to work on atomic weights through the influence of J. P. Cooke (himself a pupil of Regnault), who worked on the ratio of oxygen to hydrogen and undoubtedly did much to inspire Richards' interest in chemistry. Shortly after graduating at Harvard in 1886, Richards began work on the atomic weight of copper, and in the next few years he developed the essential features of the new technique for the determination of halide ratios upon which many of his subsequent researches depended. Successively assistant, instructor, and assistant professor in the Department of Chemistry at Harvard, he was appointed professor of chemistry in 1901, and chairman of the Department in 1903.

During this period, with the frequent collaboration of his colleague, Prof. G. P. Baxter, he was actively at work, and when, in 1912, he became director of the Gibbs Memorial Laboratory at Harvard, he had already redetermined the atomic weights of more than thirty important elements. By a critical survey of the researches of Stas, and especially by the continual criticism and development of his own methods, Richards, at tremendous cost in thought and labour, achieved that essential simplicity which is the mark of genius. The obvious importance and interest of his work attracted many able research students, by whom his methods and ideas have been widely disseminated; and, more significant still, it inspired and guided not a few who had never seen him.

Richards investigated the balance and developed improved methods of weighing; he invented the nephelometer and ascertained the conditions in which it can be used to determine precisely traces of dissolved salts and to indicate the end-point of a silver titration. He demonstrated the insidious effect of occluded moisture and gases in solids, to avoid which he invented the so-called 'Harvard bottling apparatus,' with which it is possible to fuse and resolidify a salt in any desired atmosphere and then transfer it in a dry, inert gas to the closed vessel in which it can be weighed. It was Richards who first applied the centrifuge to facilitate the purification of salts by fractional crystallisation, and he showed how Stas' results had been vitiated by the solubility of oxygen in silver and developed a procedure by which really pure silver could be prepared.

Richards' methods are well exemplified in his monumental work with Willard on the ratios of silver and silver chloride to lithium chloride and perchlorate. By taking advantage of the high proportion of oxygen in the perchlorate of a metal of low atomic weight, a very accurate ratio of silver to oxygen was obtained, and this served to establish, in relation to the fundamental value $O=16{\cdot}000$, really precise and trustworthy values for the atomic weights of silver and chlorine, and the best available value for the atomic weight of lithium.

In later years Richards played his part in the development of modern views of the atom, and we owe to him some of the most accurate determinations of the atomic weight of lead from radio-active sources, and also the only precise evidence yet available that the molecular volumes and the molecular solubilities of isotopes are identical.

Though it is by his work on atomic weights that Richards is best known to chemists, he made many other valuable contributions to knowledge. A study of atomic and molecular volumes led him to formulate the theory of the compressible atom. He observed that the same atom might occupy different volumes according to its state of combination, and concluded that atoms were compressible, and that in compounds they were, in fact, compressed by the forces of chemical affinity. Though this conception seems to us to-day to be simple, natural, and readily intelligible, it was, when propounded, a revolutionary notion which was quite generally discredited. By it, however, Richards was led to carry out a most valuable series of measurements of compressibilities of