SECTION II.

DESCRIPTION OF INSTRUMENTS.

The perfection of the results of geodetical operations, and the degree of importance to be attached to them, must be proportioned to the excellence of the individual observations, or to the mean error of an observation, which depends not only on the skill and carefulness of the observer, but on the perfection of his instruments. It is therefore desirable in a collection of such results to have descriptions of the instruments with which the observations were made; but, inasmuch as minute descriptions of all the chief instruments that have been used on the Ordnance Survey have been already published in the previous volumes of the Survey, it will not be necessary here to give more than a general description of each.

Description of Theodolites.

(1.) The Principal Triangulation for the Ordnance Survey of Great Britain and Ireland has been effected with four large theodolites, namely, two of 3 feet in diameter, one of 2 feet in diameter, and a fourth of 18 inches diameter. Besides these, however, subsidiary use has been made in a few cases, and for short distances only, of smaller instruments, having diameters of 12, 9, and 7 inches. The two first-mentioned instruments, measuring 3 feet in diameter, were constructed by the celebrated Ramsden, at the close of the last century. One belongs to the Honourable Board of Ordnance, the other is the property of the Royal Society. The only difference between these instruments is, that the horizontal circle of the former is divided to ten minutes, and read by three microscopes; while in the latter the circle is divided to quarter degrees, or parts of fifteen minutes, and is read by five microscopes: the respective advantage in each case being counterbalanced by the corresponding comparative disadvantage. Each instrument has an extra microscope not generally used, being one of the original pair at 180° from one another. They have, therefore, respectively four and six microscopes. The following general description, written with reference to the Ordnance theodolite, of which an engraving will be found in Plate 1, is applicable, with the exceptions just mentioned, to the other instrument.

(2.) *The Great Theodolite.*—The instrument consists of three distinct principal parts, not including its stand, which is a strong circular four-legged mahogany table, firmly braced.

The lower part consists of, and connects rigidly, the feet of the instrument, the vertical axis, and the microscopes for reading the horizontal circle.

The next part above consists of, and connects rigidly, the horizontal circle, the hollow vertical axis fitting on to the axis before mentioned, and the Y's for carrying the telescope.

The third part consists of the telescope, its axis, and the vertical circles attached.

The instrument rests on three feet, provided with levelling screws, which are firmly united at the place where they branch off by a strong cylindrical plate, or cylinder of bell-metal, about eight inches high and seven in diameter, co-axial with the instrument. From this cylinder, and very strongly connected with it, rises the axis of the instrument, which is of steel, conical in form, and about two feet high, having a bell-metal base, and terminating in a cast-steel pivot with sloping cheeks. From the upper part of the cylinder project three arms, carrying at their extremities the micrometer microscopes for reading the horizontal circle; each microscope is over one of the feet of the instrument. These arms are strongly braced to one another and to the feet of the instrument, so that the connection between the microscope, the feet of the instrument, and its axis, is as nearly as possible rigid and unalterable. Besides these three equidistant microscopes, there is a fourth bisecting the angle of 120° made by one pair. This microscope, with that one which is 180° distant from it, were the original pair of microscopes, the other two having been subsequently applied. One revolution of the micrometer, when in perfect adjustment, is equal to a minute, ten revolutions carrying the moveable wire over the space between two dots. The micrometer head is divided into 60 parts, so that single seconds are indicated, and tenths of seconds can be estimated by dividing mentally the space, about a twentieth of an inch, between two divisions of the micrometer head.

The horizontal circle, of brass, is 3 feet in diameter, divided by dots into spaces of ten minutes, and connected very firmly to the lower part of the hollow brass exterior axis by ten hollow conical radii. The exterior axis is 24 inches high, 5·5 inches in diameter at base, and 2·5 inches in diameter at the top. Within the base of this hollow axis a collar of cast steel is strongly driven, fitting exactly the bell-metal base of the steel axis: the upper end is terminated interiorly in a thick bell-metal plate, with sloping cheeks fitting accurately on to the extremity of the steel axis. Thus the exterior axis and circle, when placed upon the interior axis, revolve with the greatest possible smoothness, and without any shake. By means of an arrangement of screws on the top of the axis it is easy to regulate the pressure of the outer axis upon the inner, and consequently the ease of revolution. When the instrument is travelling, the outer axis and circle are let down completely upon the inner axis. In this state it could not be used for observing, as it would require force to move the circle; nor, on the other hand, could the instrument be used for observing if the pressure were made too light, as in that case there would arise a shake at the centre from want of sufficient contact. The degree of pressure or ease of revolution must therefore be regulated by the observer, but the limits are not wide. This excellent method of centering is one of the best points of the instrument, and has been much admired. Probably no other could have stood the immense wear and tear to which these instruments have been subjected, not only from constant use, but from travelling, necessarily in the roughest manner, and exposure to weather on the summits of the wildest mountains.

A horizontal flat bar 2 feet long, and projecting 1 foot on each side of the centre of the instrument, extends across the top of the outer axis. On its extremities are raised the Y's for the support of the pivots of the telescope. It is supported and made perfectly rigid by two ladder-formed braces springing from the lower part of the outer axis. The Y's are of such a height as to permit a circle of 6 inches radius attached to the axis of the transit to pass freely, and consequently the telescope to be directed to the stars at high elevation, not including of course the zenith.

The focal length of the telescope is 36 inches, aperture 2·5 inches, and the generally used magnifying power 54. In the focus of the eye-piece are the cross wires, with the usual apparatus for adjustment in collimation. Two of the wires intersect in an acute vertical angle; the third is horizontal. By means of a small screw, this horizontal wire has a vertical motion, and is intended for measuring small vertical angles, the amount being indicated by the revolutions and parts of revolutions of the screw. In astronomical observations the wires are illuminated as in ordinary transit instruments, and a reflecting eye-piece used. Concentric with the hollow axis of the telescope, are two vertical circles, similarly placed on each side of the telescope, their planes about 2 inches and a half apart. The diameter of each divided circle is 10·5 inches. They are read by two long horizontal micrometer microscopes passing through the short vertical arms carrying the Y's, each division of the micrometer head being equal to 3 seconds.

The perfect adjustment of the micrometers as to distinct vision and runs is very tedious, and can only be effected after much practice. The runs of the micrometer are easily altered, particularly by travelling. In this adjustment, however, as is also the case with others, if the precise amount of error is known, it is all that is necessary; for if $10+n$ revolutions of the micrometer go to 10 minutes, or the space between two dots, then n being known by observation, the values of a revolution and division become known.

The instrument has two long levels; one of them, 21 inches long, hangs by brackets at the extremities of the horizontal arm, when required in that position, and is also used for levelling the telescope. The other is the striding level, 24 inches long, for levelling the pivots of the telescope in astronomical observations: one division of this level is assumed as equal to one second, which is true only for moderate temperatures.

The whole body of the instrument admits of a small horizontal motion in any direction on its table, which is perforated in the centre. This motion, which is communicated by horizontal screws acting on the raised edge of the mahogany table or stand, is used only for the final adjustment of the centre of the instrument vertically over the centre-mark of the station.

The weight of the whole instrument is about 200 lbs.; it is carried, when travelling, in a four-wheeled spring-van.

(3.) *The Eighteen-inch Theodolite* was also made by Ramsden. It is of precisely the same general construction as the two large theodolites.

The circle is attached by eight conical radii to the base of the exterior hollow axis. This conical axis is 12 inches high, 2 inches in diameter at the base, and 1 inch at the top, across which is fixed the horizontal bar which supports at its extremities the Y's for receiving the telescope pivots. The bar is 12·5 inches long, and is braced to the lower part of the axis.

The focal length of the telescope is 19·5 inches, the aperture of the object glass 2 inches, and the ordinary observing power 30. To the hollow axis of the telescope is connected the vertical circle; it is placed about 4 inches from the centre of the telescope and 2 inches from one extremity of the axis, having a counterpoise at the other extremity. The diameter of this circle is 8 inches; it is read to 10 seconds by three verniers. The horizontal circle, which is divided by lines to every five minutes, is read by three micrometer microscopes in the same manner as in the large instruments.

The whole instrument rests upon a thick hexagonal plate of mahogany, being firmly connected with it as its base. The instrument is levelled by three screws passing through this plate and acting in grooves cut in metal bosses in the upper surface of the three-legged stool forming the stand of the instrument. As in the 3-foot instruments, the same level, 12 inches long, is used for levelling either the telescope or the horizontal arm carrying the Y's, hanging in each case by brackets. A striding level is also used for astronomical observation; the value of one division of this level, as in the large instruments, is a second.

(4.) *The Two-foot Theodolite* was made by Messrs. Troughton and Simms at the commencement of the Irish survey. It is of a different construction from Ramsden's theodolites, and more strictly an altitude and azimuth instrument, with a repeating table, which has been seldom used.

The horizontal circle is 2 feet in diameter and connected with six conical radii to the vertical hollow internal axis of the instrument. This axis is conical and of steel, about 2·5 inches in diameter, but is not so long in proportion as the axes of Ramsden's instruments.

A cylindrical drum of metal, about 8 inches in diameter, having six vertical microscopes attached by conical radii or arms, and an interior hollow axis, is placed upon the vertical interior axis just mentioned, and revolves smoothly round it; the pressure is regulated as in Ramsden's theodolites. From a metal plate on the upper surface of the drum rise two pillars supporting the Y's for the pivots of the telescope. The pillars are of sufficient height to allow the telescope to revolve freely on its axis in a vertical plane, without coming in contact with the upper surface of the drum.

The focal length of the telescope is 27 inches, and the aperture 2·125 inches. It is placed between two vertical circles of 15 inches diameter, firmly secured together by connecting bars, and concentric with the axis of rotation of the telescope. The horizontal and both vertical circles are divided by lines, on silver inlaid into brass, to every 5 minutes; the former is read by the vertical microscopes attached to the radii proceeding from the drum, and the latter by horizontal microscopes passing through the pillars supporting the telescope. As in the Royal Society's theodolite, five of the microscopes are equidistant, or 72° apart, while the sixth bisects one of these spaces.

It will be seen that this instrument differs entirely from Ramsden's, in this respect, that the microscopes for reading the horizontal circle move round with the telescope, while the circle itself remains clamped; in Ramsden's theodolites, on the contrary, the horizontal circle moves round with the telescope, while the microscopes are fixed to the lower part of the instrument. A full description of the instrument will be found in the "Account of the Measurement of the Lough Foyle Base," pp. 108 and 109.

(5.) The stores generally accompanying an observing party are as follows:—

1 Waggon for Instrument.	15 Brass rings for heliostats.
1 Observatory.	7 Pocket telescopes.
2 Wooden houses.	1 Chronometer.
11 Five-inch theodolites.	1 Mountain barometer.
13 Large heliostats.	11 Pocket compasses.
11 Portable heliostats.	10 Measuring tapes.

&c. &c. &c.

with all the necessaries for camp life, and full supplies of stationery, carpenters' tools, mathematical instruments, and any books that may be of use to the observer.

The strength of the party varies from 6 to 10 men.

(6.) The portable observatories used for the theodolites are hexagonal in plan, with a pyramidal skeleton roof, canvas covered. The wooden sides or panels are 5 feet high (4 feet for the 18-inch theodolite), a space of 2 feet, canvas covered, being left between their upper edge and the horizontal rafters of the roof, for the unobstructed use of the telescope. The six iron rods supporting the roof and resting on the tops of the six uprights at the corners of the hexagon, are so formed, being double, that by revolving round a vertical axis, any one of them can be twisted out of the line of sight of the telescope, should it be necessary. Framed wooden huts, having canvas covers to their tops, have now been many years in general use for the parties employed on the Ordnance Survey with the large theodolites and with the zenith sector. The experiment was first tried in 1840, on the recommendation of Major Robinson, R.E., who was then in charge of the Ordnance 3-foot theodolite, in the north of Scotland, and they have been found to be not only much more comfortable for the officers and men employed on this arduous and, at times, disagreeable duty, but also more economical than marquees and tents. They vary in size from 8 feet square to 9 feet by 12, and being constructed in parts they are easily packed or carried by pieces to the tops of mountains.

(7.) Heliostats are used for reflecting the sun's rays to distant stations. The smallest size is 5 inches in diameter, being merely a plane mirror set in brass, with a stand or handle terminated in a spike for sticking in the ground. The next size is 12 inches in diameter. The larger heliostats are rectangular; the largest measures 20 inches by 16. The surface of the mirror, in each case, can be moved with ease to follow the sun. The exact position of its surface is determined by throwing its light through a ring placed in the line between the heliostat, or the reflecting station, and the station reflected to. The ring, which lies in a vertical plane perpendicular to the line joining the two stations, and at a convenient distance from the heliostat, is placed in its true position by means of a small theodolite.

Method of placing the Instrument in Position.

(8.) In placing the theodolite over a station to be observed from, the first point to be attended to, and which has always been considered of the greatest importance, is that it shall rest upon a perfectly solid foundation. The method of obtaining this desideratum must in each case depend entirely on the nature of the ground. While at some stations the instrument has rested almost upon the solid rock; at others some difficulty has been experienced in getting a steady foundation, as for instance at the station on Holme Moss, where it was found that the bog extended to a depth of 9 feet, and below it was a layer of sand 6 feet thick, all of which had to be removed to a total depth of 15 feet before a solid foundation could be obtained, from which to build a strong scaffolding up to the ordinary surface of the ground. Even on the tops of mountains some trouble has occasionally been found in obtaining a firm foundation for the instrument to rest upon. In one or two instances the instrument has been sunk in the ground, so that the telescope only grazed the top of the hill; the excavation also served as a protection against storms. This method would of course be very objectionable if the surface of the hill were flat and of considerable extent.

The following description from the observation-book of the station on Ben Hutig, in Sutherlandshire, will serve to give a general idea of the method of preparing the station when the foundation is rocky:—Four holes were jumped in the rock, about 6 inches deep and 5 inches by 3 in length and breadth, at equal distances of 1·75 feet from the centre mark of the station, to receive four pieces of wood scantling, upon the heads of which the feet of the table for the instrument were to be screwed. These holes were run with lead, the tops of the scantling cut off and levelled accurately, and further secured against shaking by four horizontal braces nailed near the tops, and also two diagonal ones. Their tops were cut off at the level of the highest piece of the rock on which a corner of the observatory rested, and were thus also on a level with the lower edges of the six panels forming the sides of the observatory. The panels were supported by piling up stones so as to form a level all round with that of the top of the rock. A space of about 4 feet square was left in the centre of the flooring, by which the instrument and its stand were insulated, and not liable to be shaken by any motion above or around it. The flooring was laid upon joists, 6 inches above the level of the top of the posts. A batten of wood was nailed upon the extremity of the flooring round the centre space, to keep the feet of the observer from touching the legs of the table of the theodolite.

When the station is on ground of a soft and boggy nature, a hole of a sufficient diameter is sunk until a bed of gravelly earth is reached, which is levelled and firmly rammed. A strongly braced framework of wood of sufficient height, is then placed in the excavation, which is afterwards filled up with stones. Thus the instrument being also isolated from the flooring of the observatory, is rendered as nearly as possible perfectly free from any source of unsteadiness. In order also that the centre of the station may not be lost, four pickets are driven into the ground previous to the commencement of the excavation, in such positions that the intersection of diagonal lines joining them shall coincide exactly with the centre-mark of the station.

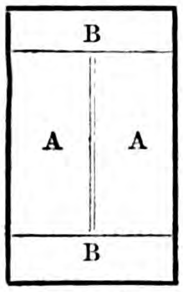
In exposed situations on the tops of mountains a wall of stone is generally built close round the lower part of the observatory, a precaution which at the station on Fashven saved the great instrument from certain destruction, as on the 11th of October 1838 a storm levelled all the marquees and tents, and moved the observatory from its true position, although thus protected by a wall 2 feet thick.

In some cases it has been necessary to raise the instrument above the surface, in order to obtain observations of distant points, not visible from the ground. The high stage used for the great instruments is 32 feet high, but has been only used in cases of absolute necessity. At the south end of the Base-line on Salisbury Plain this stage only barely sufficed to make the two extremities of the line mutually visible. Many instances of high scaffolding occurred in the triangulation of the Eastern Counties, where, the country being flat, the stations were over church-towers. One of the most remarkable was the station on Thaxted Church. The tower of this edifice is 79 feet high, and is surmounted by a spire of 93 feet, making a total height of 172 feet from the ground to the top of the spire. The scaffold for the observatory was carried from the base to the top of the spire; the scaffold for the supporting the instrument, which was interior to the other, was raised from a point of the spire 139 feet above the ground, having its bearing upon timbers passing through the spire at that height. Thus the instrument, at the height of 178 feet above ground, was insulated, and not affected by the movements of the observer, or the action of the wind upon the observatory. This was the 18-inch theodolite. The station, as will be seen on reference to the diagram, was indispensable to the connexion of the triangulation.

In placing the framework for receiving the feet of the instrument, every care has always been taken to have it as nearly concentric with the station as possible: the legs of the table of the instrument are then screwed to the framework. The circular mahogany tray upon which the instrument immediately rests, is then placed on the table, and accurately brought over the centre mark by means of a plumb line suspended from the orifice in its centre, and the motion communicated by horizontal screws acting on the edge of the table, as before explained.

(9.) *The Referring Object.*—The next step after the placing of the instrument in position is to select a spot for the referring-object; an object which from its position should be visible under all circumstances, and to which all other objects are to be referred as to their bearings.

The referring-object, or, as it is usually written in abbreviation, the R.O., generally used on mountain stations, consists of two similar and equal rectangular plates of metal, A A,



in the same vertical plane, and with parallel edges, sliding upon horizontal cross-pieces B B. This being placed against the sky, a fine vertical line of light of any required breadth is obtained. When the opening cannot be backed by the sky, the same effect is easily produced by a plane mirror placed behind the opening, and inclined at an angle of 45°. The angular breadth of the opening generally adopted, and found most convenient for perfect bisection, is about 10″.

In the placing of the referring-object, two points have to be attended to; namely, that it must be as nearly as possible on the same level as the observer, and that it must not be either too close or too distant. If too close, it will not be visible to perfection without altering the focus of the telescope, which is to be avoided; and if too far off, it may be hidden, when required, by mist. The ordinary distance is between one and two miles; but upon the top of a mountain it is obvious that a selection cannot always be made, and the best position that offers must be taken. In some cases the distance has been as small as half a mile, and the effect of the proximity of the referring-object then tells with disadvantage upon the observations of the elongations of circumpolar stars for absolute azimuth. In these observations a lamp is placed behind the referring-object.

Method of Observing with the Theodolite.

(10.) All the adjustments of the theodolite are more or less liable to be deranged by travelling, and consequently the first operation at a station is to correct any deficiencies of this nature. In general, however, the mode of observing is calculated to eliminate as much as possible the effects of slight errors of adjustment.

The general adjustment consists in this: that the line of collimation of the telescope should be perpendicular to its axis of rotation, this axis perpendicular to the revolving axis of the instrument, and the latter perpendicular to the plane of the horizon. The runs of the micrometers should also agree with the divisions on the limb.

The observations then proceed as follows: the instrument being perfectly levelled, and the lower part or body firmly clamped to the table, the observer directs his telescope upon the referring-object, and having carefully clamped the upper limb, brings the intersection of the crosshairs, by the motion of the tangent screw, to bisect the vertical line of light in the referring-object. He then reads the degrees, minutes, and seconds given by the divided circle and each of the micrometer microscopes. The upper limb is then unclamped, and the telescope directed on the next point to be observed, which is bisected, and the readings recorded. Similarly, all the other points to be observed, and then finally the referring-object is bisected and read again. The agreement of this last reading with that at the commencement of the series is some test of the care of the observer and the steadiness of the instrument. Each such series is called an "arc," and they are numbered consecutively from the commencement to the close of the station.

The first arc being completed, the telescope is reversed in its Y's, the horizontal circle turned through 180°, and the levels adjusted, if necessary: the second arc is then proceeded with, precisely in the same manner as the first, closing as well as commencing with the referring-object.

The second arc being completed, the lower limb of the instrument is moved through a small angle, 20° or 30°, and clamped, so as to get readings on another part of the circle; and in this position the third arc is taken.

The third arc being completed, the telescope and horizontal circle are reversed as in the second arc; and so on.

It has generally been the custom to read both horizontal and vertical circles for each bisection of a point, but the vertical angles have not, perhaps, been measured with such care as the horizontal; and the readings of the vertical circles for the true level position of the telescope have not generally been observed at the close of each arc, although its variation during the time of observation of a complete arc is liable to be larger than the change in the readings of the referring-object.

All observations, when received in the office, are considered of equal weight, unless a remark of the observer against any observation condemns it as to be rejected. Observations under favourable circumstances are doubtless more valuable than observations under less favourable circumstances; but how to assign their relative numerical value is a question that admits of no general solution. Observations are seldom taken under decidedly unfavourable circumstances, if it can be avoided. "It appears that the longer time one is compelled to bestow, and does bestow, upon observations, under less favourable circumstances, in a great measure compensates external disadvantages, and that causes of errors of observation of which the observer himself has not been conscious often influence him no less than those which obtrude themselves upon him."—(*Bessel: Gradmessung in Ostpreussen.*) It has indeed been often noticed, that an observation to which the observer has attached a remark to the effect that the bisection was unsatisfactory, or that the light was bad, or any other expression of doubt, has been found to agree with singular precision with the general mean or probable truth.

The mode of observing described above does not strictly apply to the observations from the commencement of the survey until the year 1839, for the referring-object was first instituted in 1840 by Lieutenant-Colonel (then Captain) Yolland, both for the sake of convenience and of accuracy. Otherwise the method followed was much the same as that described above. The method of "arcs" has been always followed; though in the earlier operations an arc contained a smaller number of points. It has never been the practice to observe single and independent *angles*, as in the Indian and other geodetical operations.

(11.) As the readings of the microscopes at each observation are read out by the observer, they are recorded by the booker—invariably in ink—in the observation book. The following is the form:—

Royal Society's Theodolite. BEN NEVIS. 11th November 1846.

		Degrees and Minutes.		Seconds of Microscopes.					Means.
Arc 141.	Bar^{r} 25^{in}·466 Ther^{r} att^{d} 40°. Readings of Vert. Circles corresponding to Telescope Level, A 0° 0′ 2″ B 0° 0′ 0″.			A	B	C	D	E	
		°	′	″	″	″	″	″	″
Corp^{l} Winzer, R.S.M., Observer.	R. O.	121	22	21	19	15	21½	20½	19·40
	Pile Scournalapich . . .	164	54	24	25	19	18	23½	21·90
P^{rte} Bate, R.S.M., Booker,	G^{d} dep. A 359° 35′ 42″ B 359° 35′ 39″								
	Pile Ben Wyvis	182	23	57	53	46	48	50	50·80
Time 7½ A.M.	G^{d} dep. A 359° 28′ 51″ B 359° 28′ 49″								
	Pile Ben Macdui	56	50	54½	55½	47	47	54½	51·70
Clear in direction of Ben Lomond, Ben Wyvis, and Glashmeal; misty in direction of Ben Tuirc, Ben Tartevil, Ben More South Uist, and Storr, and on all low hills.	G^{d} dep. A 359° 39′ 14″ B 359° 39′ 14″								
	Pile 50 miles	49	24	16	16½	7½	10	14	12·80
	G dep. A 359° 23′ 7″ B 359° 23′ 5″								
	Pile Ben Amhlair	74	26	45	43	35	35	41	39·80
	G^{d} dep. A 359° 32′ 25″ B 359° 32′ 21″								
	Pile Ben Lawers	107	56	44	43	35	35	39½	39·30
	G^{d} dep. A 359° 39′ 57″ B 359° 39′ 54″								
	Pile Ben Dornish	161	2	45	41	35	32	38	38·20
	G^{d} dep. A 359° 21′ 5″ B 359° 21′ 2″								
	Pile Ben More in Cowal (v.h.)* .	169	38	35	35½	26	26	32	30·90
	G^{d} dep. A 359° 18′ 6″ B 359° 18′ 0″								
	Pile Ben More in Mull (v.h.) .	44	38	65	65	62	65	65½	64·50
	G^{d} dep. A 359° 28′ 16″ B 359° 28 13″								
	Pile Creachbheinn	50	43	22	24	24½	23½	24½	23·70
	G^{d} dep. A 359° 1′ 30″ B 359° 1′ 27″								
	R. O. for Elongations . . .	69	49	56	58	55	55	56½	56·10
	G^{d} dep. A 357° 26′ 32″ B 357° 26′ 28″								
	R. O.	121	22	21	20	16	21	20	19·60

The column of means is not supplied by the observer; it is filled in in the calculation rooms, and each mean corrected if necessary for the runs of the microscopes, the values of which are occasionally observed and recorded. The original record of the observations is retained by the observer until the book is filled. A copy of the day's work is made every

* This, together with some other similar abbreviations, as (m.m.) (f.) are used to denote any atmospheric circumstance peculiar to the observation, as *very hazy*, *much motion*, *faint*.