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The Kabo, Nigeria, meteorite fall

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SUMMARY. At least four stones fell over a distance of about 9 km at the end of a west to east trajectory on 25 April 1971 at about 1630 hours local time. Their approximate location is 11° 51′ N., 8° 13′ E. About 13·4 kg of this xenolithic bronzite chondrite, class H4, were recovered. A bulk chemical analysis with total Fe = 29·4 % (wt), is presented. Olivine is $Fa_{18.9}$ (molec.) in composition. Concentrations of the cosmogenic radionuclides ^{22}Na, ^{26}Al, and ^{54}Mn were 71±6, 56±5 and 84±6 dpm/kg, respectively.

The fall. At about 1630 hours local time (1530 hours GMT) on Sunday, 25 April 1971, various people in Gwarzo[3] administrative area of Kano State heard a thundering noise—some said like the sound of blasting. Four villagers in 4 different places claimed to have seen 4 separate objects fall; some observers were standing less than 16 m from the points of impact. The map, fig. 1, illustrates their location near the large village of Kabo, which provides a specific name for this event. Common to the reports of all observers is that each stone was seen for some time in the air, either 'in flame' or red hot and revolving as it fell and finally making an impact pit the diameter of which was proportional to the size of the individual and the depth of which was related to the hardness of the soil. Fragments become progressively larger from west to east, that is, in the direction of flight as indicated by the sonic phenomena.

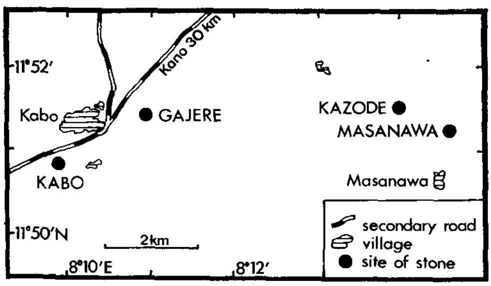

FIG. 1. Location map of Kabo meteorite fall.

Table I summarizes the first measurements made on the stones. One was seen red hot and revolving as it fell before making a slightly asymmetrical impact pit in very loose soil on a cultivated farm in Masanawa village. Mallam Abdulahi Masanawa claimed to have been about 90 m away and to have seen the fragment for a minimum of 3 minutes in the air. Ten minutes after it landed he touched it, found it to be still

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[3] 'Gwarzo' was the name given to this fall when first reported by the Smithsonian Institution, Center for Short-lived Phenomena.

hot and took it to the village head. An observer in Kazode village, Mallam Mohammadu Kazode, saw the largest stone fall and split into two in its crater. Mallam Yakubu in Gajere village saw a red hot revolving fragment descend and land about 16 m away. A few minutes later he touched it, found it to be warm, and removed it. The smallest stone was seen to fall near Kabo by an equally close witness. This stone, too, was warm some time after impact. These eye-witness accounts were not formally recorded till 4 weeks after the event, when one of us (D. E. A.) arrived in the area.

TABLE I

Location	Mass	Sp. gr.	Dimensions	Impact Pit	
				Diam.	Depth
Masanawa	5·071 kg	3·65	22·8×12·8×8·3 cm	56 cm	42·2 cm
Kazode	2·989	3·68	17·1×12·2×8·3	25·5	7·7
	3·0				
Gajere	1·422	3·70	14·8×10·3×6·2	25·5	15·3
Kabo	0·903	3·75	12·5×9·2×5·9	12·8	5·3

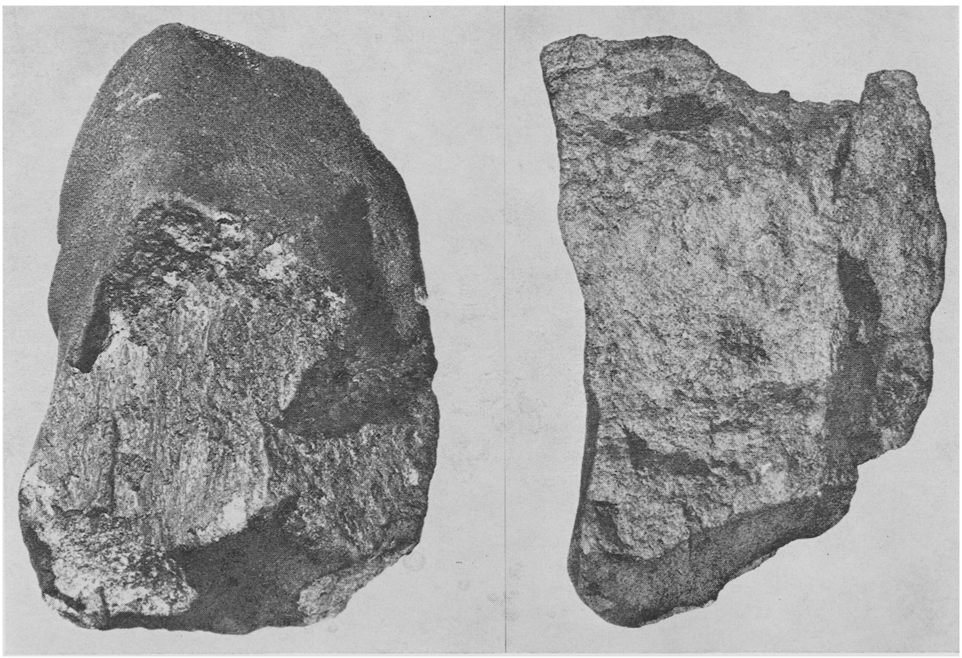
For locations, see fig. 1.

Location of material. Except for the 3 kg fragment of the Kazode stone, the others listed in Table I, which are now in the office of the Military Governor, Kano State, Nigeria, were kindly loaned to the British Museum (Natural History) for about 9 months. Approximately 250 g of the 2·989 kg fragment of the Kazode stone were removed for investigation (see fig. 3), 210 g of which are now in the B.M. (N.H.) Collection, No. 1972, 131. The bulk of this fragment, 2·745 kg, was returned to Kano. From the larger piece of the Kazode stone, specimens are now in the Geological Survey of Nigeria, Kaduna, in the University of Ibadan, and in the U.S. National Museum, Washington.

Surface features. All four individuals are largely covered by a matt black fusion crust about 2 mm thick, through which finely mottled nodules of metal, up to 1 cm long, occasionally project. On a scooped out surface of the Gajere stone (fig. 2), thin, secondary fusion crust has formed. Some uncrusted surfaces are present, for example that on the Kazode stone illustrated in fig. 3. Break-up of the meteoroid therefore took place at early and late stages of ablational flight and for a third time after ablation had ceased. No evidence of preferred in-flight orientation was observed.

Texture and mineralogy. Individual light coloured chondrules can be seen in fig. 3, and a few light coloured xenoliths can be discerned. Xenoliths range to at least 4 cm in length and are composed of light coloured chondrules set in a light coloured matrix. In the host, the matrix is dark. In each type of material, chondrules are numerous, well defined, and up to 5 mm in diameter. Not all are spherical, some being broken and others having their outlines modified by the impingement of round chondrules upon them. Metal is distributed in irregular interstitial patches, which occasionally include or partially enclose small chondrules. Chondrules are generally free from metal, but one of the radiating pyroxene type, of about 3 mm diameter, has small (< 0·02 mm) inclusions of metal dispersed through it.

In the only thin section examined, of surface area 2 cm^2, one xenolith and host material are present. As observed by Binns (1967) in other meteorites, the xenolith is more recrystallized than the darker host, for although the various chondrule types are



FIGS. 2 and 3: FIG. 2 (left). The Gajere stone of the Kabo fall, showing scooped surface with secondary fusion crust. $\times\frac{5}{8}$. FIG. 3 (right). Half of the Kazode stone. The material studied for this work was broken from the bottom right-hand corner. In this area of the figure, light-coloured xenoliths may be distinguished. $\times$0·48

present in both, polysynthetic twinning is rarer among the pyroxene crystals of the xenolith than among those of the host, suggesting that in the host clinobronzite is the predominant Ca-poor pyroxene, whereas the orthorhombic form is more common in the xenolith. Turbid, devitrified glass is present throughout, but in addition, in the xenolith a clear mineral occurs interstitial to olivine in both chondrules and groundmass. The low birefringence and a R.I. less than that of olivine suggest that the mineral is feldspar or phosphate. These differences indicate that the host is petrologic grade 4, and that the xenolith is grade 5 (Van Schmus and Wood, 1967).

Only dark host is present in the polished thin section studied. Microprobe analysis indicates that the olivines may be slightly inhomogeneous from grain to grain, but variation was at the approximate limit of experimental error. The 7 grains analysed have a mean composition of $Fa_{18.9}$, with limits of $Fa_{18.2}$ and $Fa_{20.2}$. SiO_2, FeO, and MgO were determined; totals vary from 97·4 to 101·6 % (wt); molecular Si ranges between 33·0 and 34·2 % (cf. the theoretical value of 33·3 %). The olivine composition indicates that Kabo is a bronzite chondrite (Mason, 1963).

Pyroxenes are significantly inhomogeneous (see Table II) the wollastonite content of 6 grains varying from 0·4 to 3·4 % (molec.) and the ferrosilite content from 14·6 to 18·1 %. This is consistent with the earlier diagnosis that the host material is petrologic grade 4 (Van Schmus and Wood, 1967).

TABLE II. *Microprobe analyses of 6 pyroxene grains* (*Anal. R. Hutchison*)

No. of points analysed	3	2	2	2	3	3
SiO_2	57·5	58·7	57·4	55·9	56·6	56·7
FeO	11·6	9·8	12·0	11·2	9·4	11·3
MgO	31·7	29·8	30·3	30·4	30·9	29·4
CaO	0·2	1·0	1·2	0·4	1·8	1·0
Sum	101·0	99·3	100·9	97·9	98·7	98·4
Wo	0·4	2·1	2·2	0·8	3·4	2·0
Fs	16·8	15·2	17·7	16·9	14·1	17·3
$\frac{Fe \times 100}{Fe+Mg}$	16·9	15·5	18·1	17·0	14·6	17·7

TABLE III. *Chemical analysis and Wahl norm* (*Anal. C. J. Elliott*)

Fe	19·2			*Trace elements*	
Ni	1·8	*Norm*		*in metal and sulphide*	
Co	0·09	Metal	21·09	Cu	40 ppm
FeS	5·84	Troilite	5·84	Cr	8
SiO_2	36·0	Olivine	32·02	Mn	150
TiO_2	0·11	Bronzite	26·39	Zn	8
Al_2O_3	1·98	Diopside	4·21	Ti	110
Cr_2O_3	0·53	Orthoclase	0·77	Ga	2
FeO	8·3	Albite	7·36	Ge	13
MnO	0·27	Anorthite	1·11	*In silicate*	
MgO	23·0	Chromite	0·78	Cu	4
CaO	1·71	Ilmenite	0·21	Sr	7
Na_2O	0·87	Apatite	0·72	V	80
K_2O	0·13				
P_2O_5	0·30	Total Fe = 29·4 %			
Sum	100·13	(FeO+MnO)×100/(MgO+FeO+MnO) = 17·3 (molecular)			

Bulk chemistry. A chemical analysis is presented in Table III. The chlorination technique used was an improved version of the method of Moss *et al.* (1967), details of which can be obtained from C. J. E. on application. There is good agreement between norm and mode, the FeO content of the normative silicates being close to that determined by microprobe. The total Fe figure, 29·4 % (wt), confirms that this meteorite belongs to the high-iron (H) group of chondrites.

Cosmogenic nuclides. The concentrations of ^{40}K and of the cosmogenic nuclides ^{22}Na, ^{26}Al, and ^{54}Mn were determined in the Gajere stone by γ-ray spectrometry. The meteorite was positioned between two 15 cm diameter by 9 cm thick NaI (Tl) detectors, arranged 6·4 cm apart, and the combined output of the two counters was recorded using a multi-channel analyser. The spectrum, after subtraction of counter background, showed peaks attributed to ^{22}Na, ^{26}Al, ^{54}Mn, and ^{40}K (fig. 4). Spectra were obtained from standardized sources of those nuclides distributed throughout plastic models containing iron filings to simulate the geometry and the conditions of self-absorption and scattering of γ-rays obtained with the meteorite. A computer method of least-squares fitting (Salmon, 1965) was used to analyse the spectrum from the meteorite in terms of the standard spectra, i.e. to calculate the proportions of each standard that combined to produce the best fit to the observed spectrum in the energy range 0·4 MeV to 2·4 MeV. The best-fitting curve is shown in fig. 4: the concentrations of ^{22}Na, ^{26}Al, and ^{54}Mn, corrected for radioactive decay to the time of fall of the meteorite, are given in Table IV. The potassium concentration was (0·07±0·01) %. This is close to the average figure for common chondrites, the K_2O figure in the chemical analysis (0·13 %), being abnormally high.

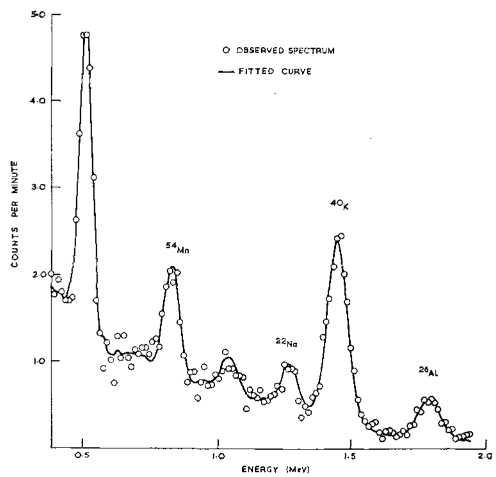


FIG. 4. γ-ray spectrum of the Gajere stone. The large peak at 0·51 MeV is due to annihilation radiation from ^{22}Na and ^{26}Al and the peak at 1·02 MeV is caused by the summation of two 0·51 MeV quanta.

TABLE IV. *Cosmogenic radionuclides in Kabo and Lost City, dpm/kg.*

	Kabo	Lost City		
	1	1	2	3
^{22}Na	71±6	71±2	80±8	84±3
^{26}Al	56±5	62±1	57±6	56±6
^{54}Mn	84±6	85±4	65±6	76±4
$^{22}Na/^{26}Al$	1·27	1·19	1·40	1·50

Lost City 1, Cressy (1971).
Lost City 2, Bogard *et al.* (1971).
Lost City 3, Wrigley (1971).

Concentrations of ^{22}Na, ^{26}Al, and ^{54}Mn are very similar to those in the H5 chondrite Lost City (see Table IV), the orbit of which is known. The ^{26}Al content is within experimental error of the saturation value of 60 dpm/kg calculated from the data of Fuse and Anders (1969) and is close to the measured value of Heimann *et al.* (1971) for chondrites, namely 58 dpm/kg. Thus Kabo has a minimum radiation age of almost 2 Myr. The three nuclides measured are produced by high-energy galactic particles, the flux of which is affected by the solar magnetic field. Increase of solar magnetic activity during the 11-year solar cycle results in a larger proportion of high-energy particles being deflected from the inner solar system. This causes the production rate of ^{22}Na to vary as a sine function with an 11-year period, if the meteoroid has an orbit within the solar magnetic field (Fireman, 1967). Since the 740 000 year half-life of ^{26}Al is much longer than the solar cycle, the abundance of this nuclide is not affected by these variations. The ^{22}Na : ^{26}Al ratio of Kabo, 1·27, lies near the minimum of Fireman's curve (1967, fig. 2), when extrapolated to the year 1971. This indicates that, like Lost City (see Wrigley, 1971), Kabo has spent its most recent period of irradiation within about 2AU of the sun, this being about the maximum distance at which the galactic flux is thought to be affected by the solar cycle.

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