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A QUANTITATIVE EVALUATION OF THE SPECIES OF *BOLASPIDELLA* FROM THE MIDDLE CAMBRIAN OF KASHMIR

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ABSTRACT

Populations of the two species *Bolaspidella himalayensis* Shah & Sudan and *Bolaspidella sp.* have been analysed to determine the quantitative basis of speciation and to compare them among themselves and with some American species of the genus. It has been concluded that they constitute quantitatively distinct populations but share several identical dimensional ratios with the American species and can be justifiably grouped in the same genus.

INTRODUCTION

The trilobite genus *Bolaspidella* was known from North America (Resser, 1937; Robison, 1964, 1971; Shaw, 1966) from an important Middle Cambrian zone bearing that name. It is only recently that some new species of the genus have been reported from the Middle Cambrian of Kashmir (Shah & Sudan, 1982). Since this happens to be the first report of *Bolaspidella* from Asia, its occurrence in the Himalayan regions raises some questions as to whether *Bolaspidella* at the generic level can be still considered as a provincial element restricted to the craton of North America (Lochman-Balk, 1971). In this regard some doubts have been expressed as to whether Himalayan species could be referred to *Bolaspidella* at all (Robison in Kumar, 1983). In qualitative terms the Himalayan species correspond in all generic characters to *Bolaspidella* as defined by Robison (1964, 71), a fact which has been discussed in detail by Shah & Sudan (op. cit.) and further emphasized by Shah (1983). In order to remove any shadow of doubt it would be necessary to analyse the Himalayan species quantitatively and to compare them with the American forms to determine, (i) the basis of speciation of the Himalayan forms, (ii) the parameters that differentiate them from the American species and (iii) the justification of including the Himalayan species within the genus. The present study has been undertaken with this end in view.

METHOD OF STUDY

Two species of the genus *Bolaspidella* viz., *B. himalayensis* Shah & Sudan and *Bolaspidella sp.* were chosen for the quantitative studies because both of them were available in sufficient quantity. Thirty eight cranidia of *B. himalayensis* and twelve cranidia of *Bolaspidella sp.* were selected and measurements of different cranidial parameters were made by Vernier Callipers. Paired combinations of measured dimensions based on the descriptive characters were subjected to a statistical treatment which was undertaken first using a scientific calculator and confirmed with the aid of a IBM-360 computer. The data was tabulated and the significance of the coefficent of correlation for the various parameter ratios was determined. Comparisons of regressions and reduced major axis of the two species was made for the various paired dimensions. Graphically, the data was plotted in different scatter diagrams in which the equivalent parameters of some of the American species were also incorporated in order to bring out the comparison and contrast.

SYSTEMATICS OF THE GENUS

Phylum	Arthropoda
Class	Trilobita
Order	Ptychopariida SWINNERTON, 1915
Suborder	Ptychopariina RICHTER, 1933
Super family	Norwoodiacea WALCOTT, 1916
Family	Menomoniidae WALCOTT, 1916
Genus	*Bolaspidella* RESSER, 1937

Bolaspidella : Resser, 1937; Robison, 1964; (for generic synonymy and discussion upto that date), Shaw, 1966; Robison, 1971; Shah & Sudan, 1982.

The main qualitative cranidial characters of the genus can be summarized as follows:—

Cranidium roughly quadrangular, glabella small with bluntly rounded exterior extending approximately two thirds the length of the cranidium. Frontal **area** concave with nearly straight anterior border furrow and prominent, elevated, convex outer rim. Glabellar furrows faint or lacking, if present then three pairs which vary in prominence; the anterior pair is shallow and complete, whereas the two posterior most pairs are short and incomplete. Axial and occipital furrows are shallow and wide; the width of the occipital ring is not uniform, it is wider at centre as compared to sides. Occipital ring may or may not possess spine or a small medial node. Palpebral area of fixigena slightly convex, width slightly less than that of the maximum glabellar width. Eyes prominent and small in size, eye ridges are usually visible. Preglabellar field flat or slightly convex. Facial sutures opisthoparian.

Posterior border furrow shallow and wide. Posterior area of fixigena one to two times wider than that of occipital ring and rounded at sides. Anteriorly facial sutures extend straight forward or converge from palpebral lobe, curve sharply inward at the intersection with border furrow, cross outer rim diagonally for one third width of the frontal area, and become marginal anteriorly. Posterior portion of the facial suture diverges from palpebral lobe, curves around distal end of posterior area of fixigena; at the lateral border it swings inward and backward to posterior margin inside genal angle. Librigena possess genal spines of moderate length. Border furrow poorly defined. Lateral border furrow shallow anteriorly and poorly defined or sometimes absent posteriorly. Intraocular ring elevated above genal field. At the base of genal spine an inward projecting spur is present as a result of the recurved facial suture.

The following are the known species of the genus *Bolaspidella* from North America established on the basis of the description given above:

B. burnetetnsis (Walcott) Robison, 1964
B. contracta Robison, 1964
B. convexa (Howell) Robison, 1964
B. drumensis Robison, 1964
B. housensis (Walcott) Resser, 1937 (Genotype)
B. lucieae Poulsen, 1960
B. macgerriglei (Raymond) Robison, 1964
B. prooculus Palmer, 1954
B. schucherti (Raymond) Robison, 1964
B. wellsvillensis (Lochman and Denson) Robison, 1964

The species of the genus reported from Kashmir are *B. himalayensis* Shah & Sudan, 1982, *B. costatus* Shah & Sudan, 1982, *B. magamensis* Shah & Sudan, 1982 and *Bolaspidella sp.* Shah & Sudan, 1982.

QUANTITATIVE EVALUATION

As mentioned earlier, 38 specimens of *B. himalayensis* and 12 specimens of *Bolaspidella sp.* from Kashmir constituting the holotype, paratypes and topotypes were selected for quantitative statistics. For each individual cranidium, measurements of five dimensions were made. The system of measurements is indicated in Fig. 1 (a, b & c). The terminology and symbols used here for each measured dimension are as suggested by Shaw (1957). Six paired combinations of measured dimensions were made for statistical treatment. The combinations alongwith their symbols are as follows :-

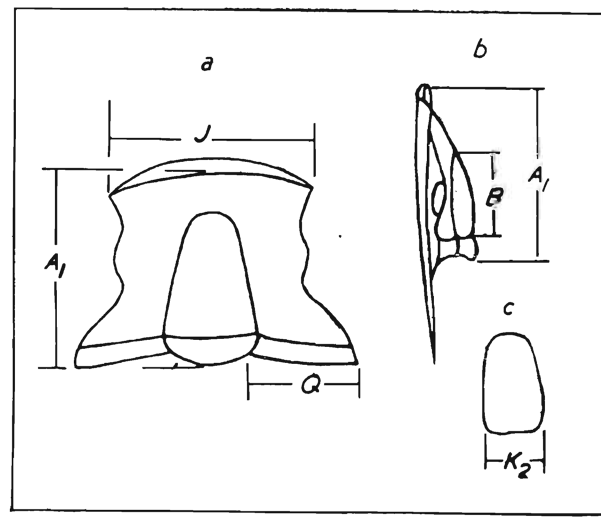

Fig. 1 (a, b and c). Outline drawings showing dimensions measured on cranidia of specimens studied.

A_1 Total cranidial length — B Total glabellar length
J Max. Cranidial width — K_2 Max. glabellar width
Q Max. fixigenal width

1. Max. cranidial width (J) vs Max. glabellar width (K_2)
2. Total cranidial length (A_1) vs Total glabellar length (B)
3. Total cranidial length (A_1) vs Max. glabellar width (K_2)
4. Total cranidial length (A_1) vs Max. cranidial width (J)
5. Total glabellar length (B) vs Max. glabellar width (K_2)
6. Max. glabellar width (K_2) vs Max. fixigenal width (Q)

The computations on these dimensions were carried out as suggested by Burma (1948) and Shaw (1956). The data computed is indicated in Table 1.

From this data it is clear that at 1% and 5% fiducial limits, the coefficent of correlation for all the parameter ratios are highly significant. This would indicate that the population of *B. himalayensis* has also a quantitative basis for being included in a single species. The same holds good for the *Bolaspidella sp.*

From the comparison of regressions between *B. himalayensis* and *Bolaspidella sp.* for six sets of paired dimensions as reproduced in Table 1, it is clear that the difference between the two is significant in case of 3rd pair (K_2-A_1) and 6th pair (Q-K_2) and not significant in others. The data indicates that there is less than a 5% possibility for the 3rd (K_2-A_1) pair and less than a 2% possibility for the 6th (Q-K_2) pair that the difference is due to random distribution. The interpretation that this difference could be due to difference of preservation can be ruled out for there is no distortion in the specimens and many of them occur on the same blocks. Likewise the differences cannot be due to succession in time since all the specimens are from one bed only. This would indicate that these two ratios should constitute the quantitative basis for the differentiation of the two species.

After the comparison of regression, the reduced major axis (also referred to as the unique line of organic correlation) was calculated. This had to be undertaken because in morphological dimensions it is not clear which one of the variates is dependent or independent. The properties and the application of reduced major axis have been worked out and discussed by Kermack and Haldane (1950) and Kruskal (1953) and a detailed discussion with examples is given by Imbrie (1956). For the reduced major axis $y=b+Kx$ the calculations have been undertaken as given by Miller and Kahn (1962).

The comparison of the reduced major axis between *B. himalayensis* and *Bolaspidella sp.* for six sets of paired dimensions is reproduced in Table-2. It is clear from the comparison of slopes that the difference is highly significant in the three sets of paired dimension, that is 2nd (B - A_1), 3rd (K_2-A_1) and 6th (Q-K_1). The rest of the three are not significant. The results obtained by this method tally with the results obtained by the regression method except in case of 2nd (B-A_1) which also shows highly significant results here.

GRAPHIC COMPARISON BETWEEN THE HIMALAYAN SPECIES AND THE AMERICAN SPECIES

Since no quantitative data on the American species was available from the published literature only a graphic comparison could be possible. For this purpose, measurements from the figures in respect of the species viz., *B. housensis* (Genotype) (Robison, 1964), *B. drumensis* (Robison, 1964), *B. wellsvillensis* (Robison, 1964) and *B. contracta* (Robison, 1964) were made and these were plotted along with the scatter diagrams of *B. himalayensis* and *Bolaspidella sp.* (Figs. 2nd and 3). While this approach may not be as illustrative as the comparisons of regression and reduced major axis, it does give an idea of the quantitative similarities and differences. Between *B. himalayensis* and the American species the paired dimension no 6th (K_2 - Q) is the only one, significantly different. This would indicate that this ratio does not only differentiate *B. himalayensis* from *Bolaspidella sp.* but also differentiates it from the American forms. All other pairs are identical. *Bolaspidella sp.* is identical in all ratios with the American forms except for the pair no 6th (K_2 - Q) where it is significantly different from the species *B. wellsvillensis.* It may be mentioned that the latter is different from other American species also in this respect.

CONCLUSIONS

1. There is a similarity in the ratios cranidial width/glabellar width, cranidial length/cranidial width, glabellar length/glabellar width and also to a great extent in the cranidial length/glabellar length in all species of *Bolaspidella* which includes the American and the Himalayan forms. These dimensional ratios should constitute the diagnostic characters of the genus.

2. The species *B. himalayensis* differs from *Bolaspidella sp.* in cranidial length/glabellar width and glabellar width/fixigena width.

3. *B. himalayensis* differs from the American forms *B. housensis B. drumensis, B. wellsvillensis* and *B. contracta* only in the glabellar width/fixigena width and is identical in other ratios.

Bolaspedella sp. is similar to *B. housensis, B. drumensis* and *B. contracta* in all the paired dimensions but differs from *B. wellsvillensis* in glabellar width/fixigena width.

4. There is a quantitative basis for treating the populations constituting what is described as *B. himalayensis* as a single species and *Bolaspidella sp.* also as a single species, each distinct from the other. Both share most of the common dimensional characters with the American forms and can, therefore, justifiably be grouped into a single genus.

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Table 1. Univariate, Bivariate and Comparison of Regression

Name of the species	Paired Dimensions	N	Range	Mean	S.D.	'r'
B. himalayensis	Max. glabellar width K_2	36	2.5— 6.0	3.6944	0.7752	0.7784
	Max. cranidial width J		4.5—12.0	8.5555	1.8921	
Bolaspidella sp.	Max. glabellar width K_2	10	3.0— 6.0	4.1999	0.9539	0.9773
	Max. cranidial width J		7.0—14.0	10.1499	2.0862	
B. himalayensis	Total glabellar length B	38	2.5— 5.5	3.9736	0.7859	0.7697
	Total cranidial length A_1		6.0—13.0	8.7842	1.6848	
Bolaspidella sp.	Total glabellar length B	12	3.0— 6.5	4.5833	0.9753	0.9022
	Total cranidial length A_1		8.0—12.0	9.4583	1.2622	
B. himalayensis	Max. glabellar width K_2	36	2.5— 5.0	3.7222	0.6712	0.7575
	Total cranidial length A_1		6.0—13.0	8.7027	1.5475	
Bolapspidella sp.	Max. glabellar width K_2	12	3.0— 6.0	4.2500	0.9013	0.6579
	Total cranidial length A_1		8.0—12.0	9.4583	1.2822	
B. himalayensis	Max. cranidial width J	36	4.5—12.0	8.5555	1.8921	0.6604
	Total cranidial length A_1		6.0—13.0	8.6478	1.6151	
Bolaspidella sp.	Max. cranidial width J	12	7.0—14.0	10.7083	2.2863	0.6283
	Total cranidial length A_1		8.0—12.0	9.4583	1.2822	
B. himalayensis	Max. glabellar width K_2	38	2.5— 6.0	3.7500	0.7587	0.6840
	Total glaballer length B		2.5— 5.5	3.9736	0.7859	
Bolaspidella sp.	Max. glabellar width K_2	12	3.0— 6.0	4.2500	0.9013	0.6871
	Total glabellar length B		3.0— 6.5	4.5833	0.9753	
B. himalayensis	Max. fixigena area width Q	35	1.0— 4.0	2.0714	0.6340	0.6406
	Max. glabellar width K_2		2.5— 6.0	3.7837	0.7586	
Bolaspidella sp.	Max. fixigena area width Q	12	1.5— 3.0	2.2916	0.4769	0.8965
	Max. glabellar width K_2		3.0— 6.0	4.2500	0.9013	

N stands for Number of specimens
S.D. stands for Standard Deviation
r stands for Coefficient of correlation

Computed for the *Bolaspidella himalayensis* and *Bolaspidella* sp.

Regressions Equations $Y = a + bX$ $X = a' + b'Y$	Standard error of estimate	σdb	t	D.f.	Probability	Remarks
$J = 1.5365 - 1.8998\ K_2$	1.1877	0.4427	0.5364	42	60%	Not significant
$K_2 = 0.9655 - 0.3198\ J$	0.4866					
$J = 1.1730 - 2.1373\ K_2$	0.4419					
$K_2 = -0.3357 + 0.4468\ J$	0.2020					
$A_1 = 2.2270 + 1.6501B$	1.0754	0.3671	1.2639	46	20%	Not significant
$B = 0.8194 + 0.3590A_1$	0.5017					
$A_1 = 4.0218 + 1.1861B$	0.5527					
$B = -1.9036 + 0.6863\ A_1$	0.4205					
$A_1 = 2.2028 + 1.7462\ K_2$	1.0102	0.4229	1.9160	44	5%	Significant
$K_2 = 0.8626 + 0.3285\ A_1$	0.4382					
$A_1 = 5.4807 + 0.9358\ K_2$	0.9656					
$K_2 = -0.1226 + 0.4625\ A_1$	0.6788					
$A_1 = 3.8242 + 0.5637\ J$	1.2128	0.1869	1.1303	44	25%	Not significant
$J = 1.8655 + 0.7736\ A_1$	1.4208					
$A_1 = 5.6849 + 0.3523\ J$	0.9975					
$J = 0.1114 + 1.1203\ A_1$	1.7786					
$B = 1.3165 + 0.7085\ K_2$	0.5733	0.2443	0.1433	46	90%	Not significant
$K_2 = 1.1261 + 0.6603\ B$	0.5534					
$B = 1.4230 + 0.7435\ K_2$	0.7086					
$K_2 = 1.3394 + 0.6350\ B$	0.6548					
$K_2 = 2.1979 + 0.7664\ Q$	0.5824	0.3745	2.4781	43	2%	Significant
$Q = 0.4432 + 0.5354\ K_2$	0.4868					
$K_2 = 0.3664 + 1.6946\ Q$	0.3991					
$Q = 0.2756 + 0.4743\ K_2$	0.2111					

a stands for intercept on Y axis
b stands for coefficient of regression
σdb stands for standard error of estimate of the difference of two coefficients of correlation.
t stands for students t test
D.f. stands for degree of freedom.

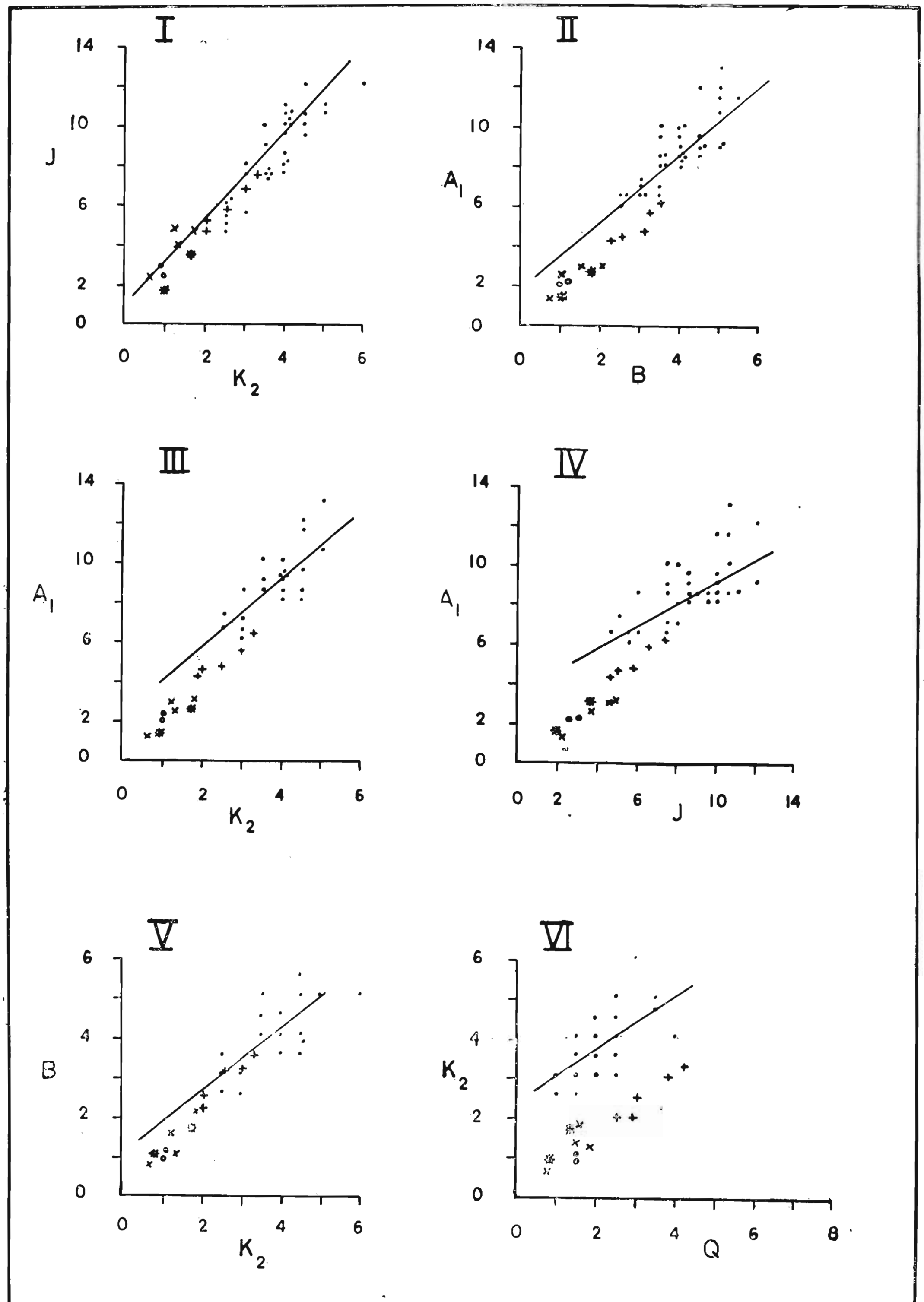

Fig. 2 (I, II, III, IV, V & VI)

Scatter diagrams of *B. himalaynesis* (·), *B. housensis* (o), *B. drumensis* (x), *B. wellsvillensis* (+) and *B. contracta* (*) for the paired dimensiosns:

I Max. cranidial width (J)/Max. glabeller width (K_2)
II Total cranidial length (A_1)/Total glabellar length (B)
III Total cranidial length (A_1)/Max. glabellar width (K_2)
IV Total cranidial length (A_1)/Max. cranidial width (J)
V Total glabellar length (B)/ Max. glabellar width (K_2)
VI Max. glabellar width (K_2)/Max. fixigenal width (Q)

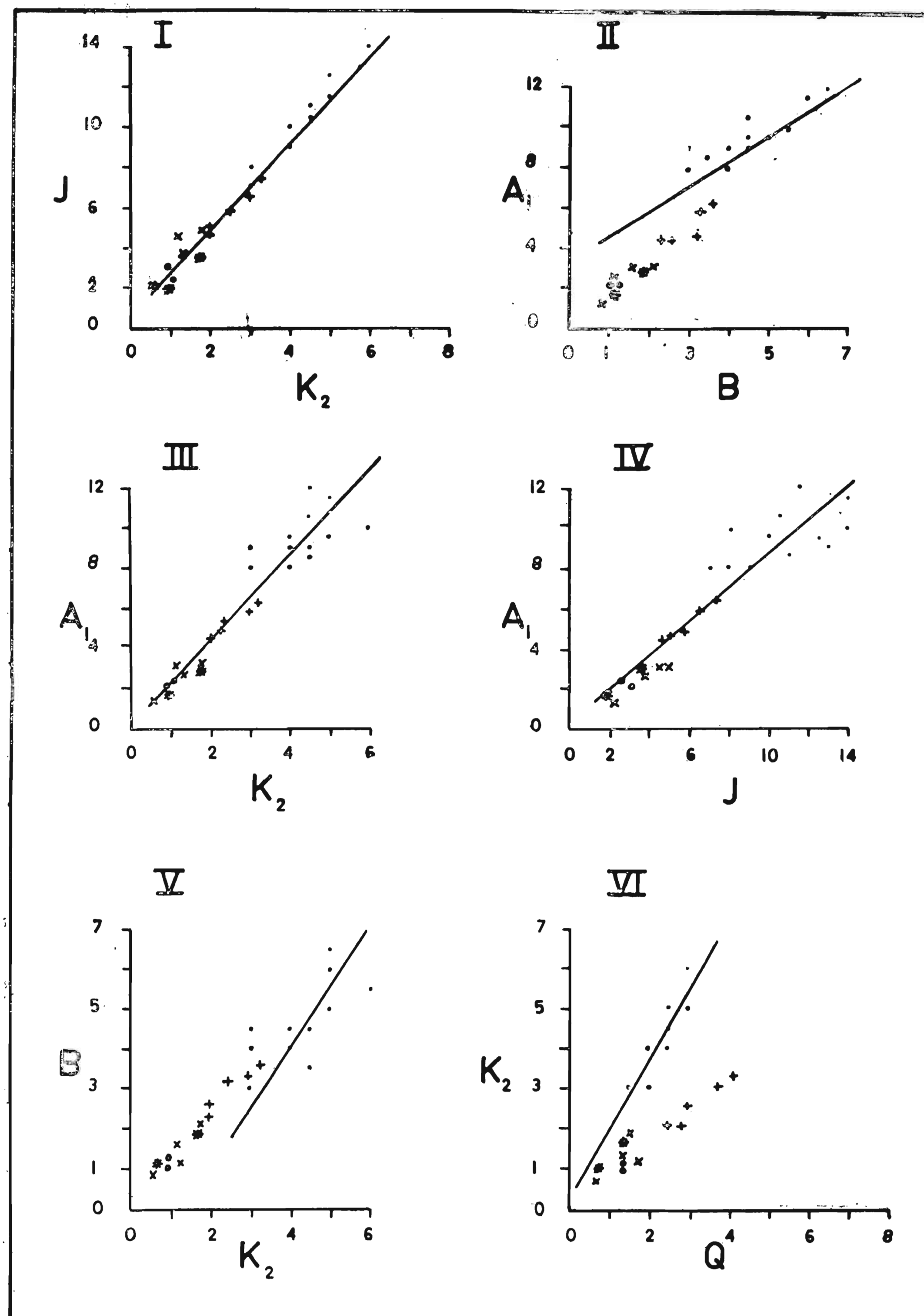

Fig. 3 (I, II, III, IV, V & VI)

Scatter diagrams of *Bolaspidella sp.* (·), *B. housensis* (o) *B. drumensis* (x), *B. wellsvillensis* (+), and *B. contracta* (*) for the paired dimensions:

I Max. cranidial width (J)/Max. glabellar width (K_2)
II Total cranidial length (A_1)/Total glabellar length (B)
III Total cranidial length (A_1)/Max. glabellar width (K_2)
IV Total cranidial length (A_1)/Max. cranidial width (J)
V Total glabellar length (B)/Max. glabellar width (K_2)
VI Max. glabellar width (K_2)/Max. fixigenal width (Q)

Table 2. Reduced major axis calculated for the Bivariate

Name of the Species	Paired Dimensions	N	K	SK	b
B. himalayensis	Max. glabellar width K_2/	36	2.4405	0.2553	—0.4609
Bolaspidella sp.	Max. cranidial width J	10	2.1870	0.1465	0.9646
B. himalayensis	Total glabellar length B/	38	2.1437	0.2220	0.2657
Bolaspidella sp.	Total cranidial length A_1	12	1.3146	0.1636	3.4332
B. himalamayensis	Max. glabellar width K_2/	36	2.3053	0.2508	0.1219
Bolaspidella sp.	Total cranidial length A_1	12	1.4225	0.3092	3.4127
B. himalayensis	Max. crandial width J/	36	0.8536	0.1068	1.3442
Bolaspidella sp.	Total cranidial length A_1	12	0.5608	0.1259	3.4529
B. himalayensis	Max. glabellar width K_2/	38	1.0354	. 0.1226	0.0896
Bolaspidella sp.	Total glabellar length B	12	1.0821	0.2269	—0.0156
B. himalayensis	Max. fixigena area width Q/	35	1.1964	0.1553	1.3074
Bolaspidella sp.	Max. glabellar width K_2	12	1.8901	0.2416	—0.0815

P. S. :

N stands for Number of Specimens
K stands for The Slope
SK stands for The standard error of the slope

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measures of *B. himalayensis* and *Bolaspidella* sp.

Sb	Sd	Reduced Majoraxis $y = b + Kx$	Z	Remarks
0.9638	1.3611	$J = -0.4609 + 2.4405\ K_2$	0.8613	Not significant
0.6310	0.4887	$J = 0.9646 + 2.1870\ K_2$		
0.8992	1.2616	$A = 0.2657 + 2.1437\ B$	3.0068	Significant at less than 1%
0.7666	0.7122	$A_1 = 3.4332 + 1.3146\ B$		
0.9487	1.1747	$A_1 = 0.1219 + 2.3053\ K_2$	2.2171	Significant at less than 3%
1.3435	1.2964	$A_1 = 3.4127 + 1.4225\ K_2$		
0.9361	2.0502	$A_1 = 1.3442 + 0.8536\ J$	1.7728	Not sigificant
1.3790	2.2601	$A = 3.4529 + 0.5608\ J$		
0.4690	0.8684	$B = 0.0896 + 1.0354\ K_2$	—0.1792	Not significant
0.9359	1.0505	$B = -0.0155 + 1.0821\ K_2$		
0.3364	0.8382	$K_2 = 1.3074 + 1.1964\ Q$	—2.4150	Significant at less than 2%
0.5656	0.4638	$K_2 = 0.0815 + 1.8901\ Q$		

b stands for The intercept
Sb stands for The standard error of the intercept
Sd stands for Dispersion around the reduced major axis.
Z stands for Comparison of the slopes of two separate reduced major axis.

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