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岩浆岩砾石磨圆度地质意义的研究^①

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摘要 定量地质学的兴起促进了地球科学的快速发展,但是国内外对砾石磨圆度与搬运距离之间定量关系的研究长期以来没有明显的进展。本次研究通过对永定河、碓臼峪、滦河和大石河四条河流进行系统的野外考察,从河流的出山口开始向下游设定考察点,详细描述各考察点砾石的磨圆度、粒度特征并进行统计分析,对岩浆岩砾石磨圆度与搬运距离的定量关系以及磨圆度的影响因素进行了研究。研究发现,岩浆岩砾石的磨圆度随着搬运距离的增大而变好,在搬运的初期变化最快,而后逐渐缓慢下来,最终磨圆度趋于稳定。岩浆岩砾石由棱角状变为次棱角状一般需要搬运3~6 km,由次棱角状变为次圆状一般要搬运12~21 km,圆状砾石大量出现至少要搬运22~31 km。砾石的磨圆度受搬运距离、母岩成分、粒度和破碎作用的影响。棱角状、次棱角状砾石容易被磨蚀,在搬运初期转化为次圆状、圆状,而圆状砾石不易磨蚀达到极圆状;岩浆岩砾石磨圆速度比石英快,比石灰岩慢;相同母岩成分的砾石,粗粒砾石比细粒砾石磨圆快;破碎作用则会降低砾石的磨圆度,使部分砾石呈现出与搬运距离不协调的磨圆特征。

关键词 磨圆度 搬运距离 定量关系 砾石 影响因素

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0 引言

圆度反映碎屑颗粒原始棱角被磨圆的程度,是碎屑颗粒的重要结构特征^[1]。Wentworth^[2]首次给圆度下了明确的定义,指出圆度是最尖的角边曲率半径与最长对径一半的比值。Wadell^[3]曾指出圆度是颗粒中所有角或边的平均曲率半径与最大内接球的半径比。目前普遍使用的圆度定义是指碎屑颗粒最大投影面上每个角的平均曲率半径与最大内接球半径的比值^[4]。

砾石的磨圆度包含了大量的颗粒沉积的信息。Pettijohn^[4]指出砾石和砂砾的形状与圆度很早就被用来作为一种沉积历史的译码。国内外学者都做了大量的研究工作,探索磨圆度的地质意义^[5-9]。Kuenen^[10]利用环形水槽实验模拟砾石的搬运过程,发现石灰岩、辉长岩以及脉石英分别在大约50 km、140 km以及300 km的搬运距离后变得极圆。Krumbein^[11]首次用数学术语将磨圆度和搬运距离的关系公式化,指出磨圆度的变化速度是某一点上的磨圆度与确定的极限圆度差值的函数。Plumey^[12]发现黑山区两条河流中的石灰岩砾石分别搬运18 km和37 km后变得极圆。David^[13]利用美国圣克鲁兹河和温德

河砾石岩性和磨圆度统计结果,进行砾石物源分析。国内学者对砾石磨圆度的研究大多以定性描述为主,定量研究比较少^[14-19]。

砾石磨圆度研究虽然取得了一些成果,但是偏重于砾石达到极圆所需搬运距离的研究,对磨圆度变化规律的认识还远远不足,限制了磨圆度在恢复沉积历史中的作用。砾石磨圆规律及磨圆度影响因素的研究,对于研究地质历史时期的沉积环境、物源分析、古地理恢复具有重要的意义。本文通过对永定河、碓臼峪、滦河和大石河四条河流进行野外考察、取样分析,建立了岩浆岩砾石磨圆度与搬运距离的定量关系。

1 研究区概况

永定河发源于内蒙、山西的山区,由桑干河、洋河两条支流汇合而成,流经北京西郊,经海河注入渤海。永定河是北京地区最大的河流,由西北流向东南,年平均径流量为 $3.4 \times 10^9 \text{ m}^3$,市内全长189 km(图1),河床宽度一般为200~800 m,局部超过1 km,平均坡降为1.2‰~3‰。河流域地层主要为太古界、二叠系、侏罗系和第四系。永定河的沉积物包括砾石、砂以及粉砂质黏土,砾石主要分布在河流上游地区,砾石成分以岩浆岩为主。

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碓臼峪位于北京市昌平区境内,流向为由西北向东南(图 1),全长 10 km。研究区内河床宽度一般为 20~40 m,坡降一般为 3.5‰~4‰,河流中发育大量的砾石沉积,砾石成分主要为岩浆岩。

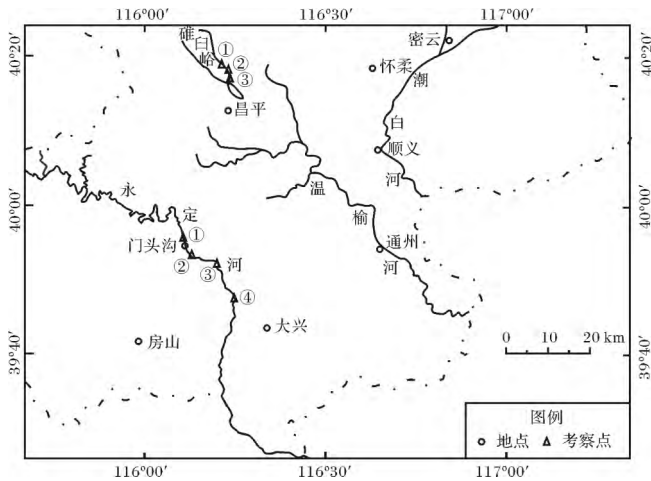


图 1 永定河、碓臼峪位置及考察点分布图

Fig.1 Location and investigation points of Yongding River and Duijiuyu River

滦河发源于河北北部山区,由西北流向东南,流经迁西、迁安、滦县、乐亭,最终注入渤海,沿途有多条支流注入,全长 877 km(图 2),年平均径流量 $1.5 \times 10^{10} \text{ m}^3$ 。滦河从出山口向下游,依次呈现辫状河、曲流河河型,乐亭以下进入三角洲沉积。研究区位于河流的辫状河段,宽度一般为几百到上千米,坡降平均为 1.2‰~2.5‰,河流中发育有大量的砂砾质沉积物,砾石成分主要为岩浆岩。

大石河发源于燕山,自西北流向东南,在山海关西侧注入渤海,全长 22 km(图 2),年平均径流量为 $4.8 \times 10^7 \text{ m}^3$ 。大石河为一近物源的高能河流,流程短、入海快,研究区内河床宽度一般为 100~600 m,坡降平均为 2‰~3‰,发育砾石沉积,砾石成分主要为岩浆岩。

四条河流都位于华北地台东部,其地质背景基本一致,且都在渤海湾周围,气候也大概相同,河流的汛期等也基本相似,且母岩成分都主要为岩浆岩,这些因素决定了磨圆度的变化规律具有相似性。对这四条河流岩浆岩砾石磨圆度进行研究,对于相同地质背景下的古地理恢复具有重要的指导意义。

2 研究方法

本次研究选取了北京的永定河、碓臼峪以及河北

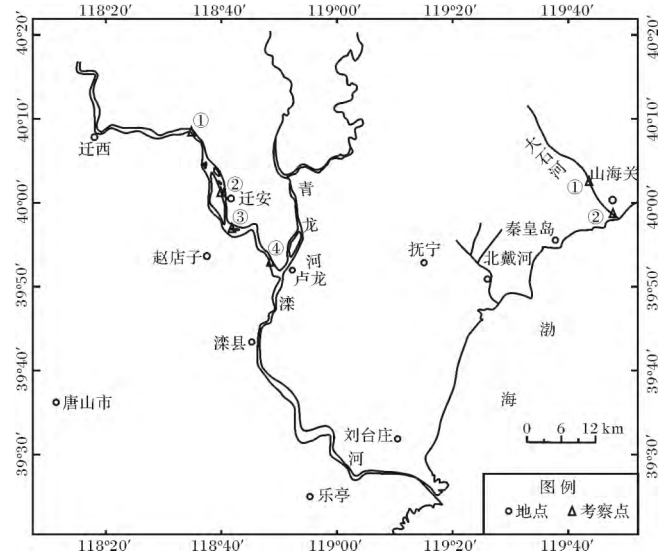


图 2 滦河、大石河位置及考察点分布图

Fig.2 Location and investigation points of Luanhe River and Dashi River

的滦河、大石河四条河流,其中对永定河、碓臼峪进行了重点研究。研究工作都是以河流的出山口为起点,沿河流向下游观察,每隔一定距离设定考察点,并在每个考察点均采集 100 个样品进行详细描述并统计分析。

对永定河的研究,以河流出山口为第一个考察点,向下游方向共设置了四个考察点,其中考察点 1 与考察点 2 之间相距 5 km,考察点 2 与考察点 3 相距 7 km,考察点 3 与考察点 4 相距 10 km(图 1)。从碓臼峪河流出山口开始,向下游方向依次设立了三个考察点,分别为考察点 1、考察点 2 和考察点 3,间距均为 2 km(图 1)。在滦河河流出山口开始,向下游方向设置了四个考察点,间距分别为 15 km、6 km 和 10 km(图 2)。以大石河出山口为起点,设置两个考察点,间距为 7 km(图 2)。

本次研究主要采用目测法确定砾石的磨圆度,依据的标准是 Powers 提出的圆度级别的划分标准以及曾做的圆度的形状和分级图^[20](图 3),将砾石的磨圆度划分为尖棱角状、棱角状、次棱角状、次圆状、圆状和滚圆状六个等级。

为了减小人为的主观误差,由 5 个人组成小组进行试验检查,每人统计 4 个不同的样品,然后对比这 20 个结果,样品的磨圆度都在允许的范围内。反复进行试验三次,都达到允许的精度,然后进行样品磨圆度分析。5 个人分别对每个样品划分圆度级别,圆度分析时采用参考样,当磨圆度分析结果达到 4 个



图 3 Powers 的圆度的形状和分级^[20](同一列的圆度相似,但球度不同)

Fig.3 Roundness shapes and classes from Powers^[20](the same column with similar roundness, but different sphericity)

表 1 永定河、碓臼峪野外考察统计数据表

Table 1 Statistics of field survey of Yongding River and Duijiuyu River

考察点	磨圆度百分比(%)						粒度					
	尖棱角状	棱角状	次棱角状	次圆状	圆状	滚圆状	大粒径 /cm	大粒径百分比 /%	中等粒径 /cm	中等粒径百分比 /%	小粒径 /cm	小粒径百分比 /%
永定河	1	0	14	67	19	0	65~70	2	25~65	79	8~12	19
	2	0	8	71	27	0	50~55	5	20~50	64	6~9	31
	3	0	2	18	44	36	35~45	2	15~35	64	4~7	34
	4	0	2	26	28	44	25~32	4	10~25	66	2~5	30
碓臼峪	1	10	34	44	10	2	7~8	4	4~7	64	2.5~4	32
	2	0	18	54	22	6	6~7	4	3~6	78	2~3	18
	3	0	6	54	32	8	4~5	12	2~4	72	1~2	6

及 4 个以上相同时,该结果达到精度要求,可以使用。当磨圆度分析结果小于 4 个相同时,进行重新分析,直到达到要求的精度为止。这种方法能够有效消除人为因素的影响,确保分析结果的真实、可靠。在对每个砾石进行磨圆度分析的基础上,统计每个采样点不同等级磨圆度的百分含量,统计结果如表 1。

3 砾石磨圆度特征

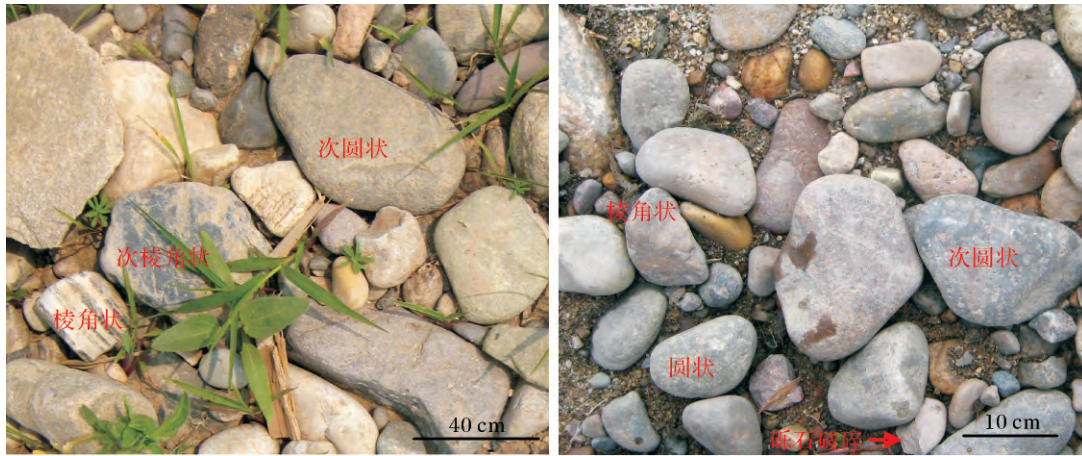
3.1 永定河砾石磨圆度特征

对永定河进行现场考察取样分析,发现砾石磨圆度随搬运距离的增大而明显变好(图 4)。河流出口处(考察点 1)砾石的磨圆度最差,呈现棱角状、次棱角状、次圆状三种圆度级别,并以次棱角状为主,其含量占总数的 67%。考察点 2 砾石的磨圆度变好,棱角状砾石含量降低,次圆状砾石含量升高。考察点 3 开始出现圆状砾石,其含量可达 36%,次棱角状砾石含量明显降低,仅占总数的 18%。考察点 4 的磨圆度进一步变好,圆状砾石可达 44%,次圆状砾石占 28%(图 5)。

每个考察点都由不同圆度级别的砾石混杂堆积在一起,我们利用圆度中值来表征每一考察点圆度的总体特征。规定以 1、2、3、4、5、6 分别作为尖棱角状、棱角状、次棱角状、次圆状、圆状和滚圆状的圆度基数。圆度中值为各等级所占的百分数与该级圆度基数的乘积。圆度中值的范围落在 1 和 6 之间,数值越大代表磨圆越好,数值为 1 表示样品中的所有砾石都呈尖棱角状,数值为 6 表示样品中所有砾石都呈滚圆状。

永定河砾石磨圆度随着搬运距离的增大而变好,在搬运的初期变化最快,而后逐渐缓慢下来,最终磨圆度趋于稳定。砾石在最初搬运的 12 km 内磨圆最快,圆度中值与搬运距离关系曲线斜率高,圆度中值由 3.05 上升到 4.14。在 12~22 km 之间砾石磨圆缓慢,圆度中值与搬运距离关系曲线平缓,圆度中值保持在 4.14 左右(图 6)。

砾石在搬运过程中不仅磨圆度逐渐变好,还由于机械分异作用粒度逐渐变小。永定河出口处砾石的平均粒径为 38.85 cm,距出口 5 km、12 km、



a. 考察点 1 砾石磨圆度特征 b. 考察点 4 砾石磨圆度特征

图 4 永定河不同考察点砾石磨圆度照片

Fig.4 Gravel roundness photos of different investigation points in Yongding River

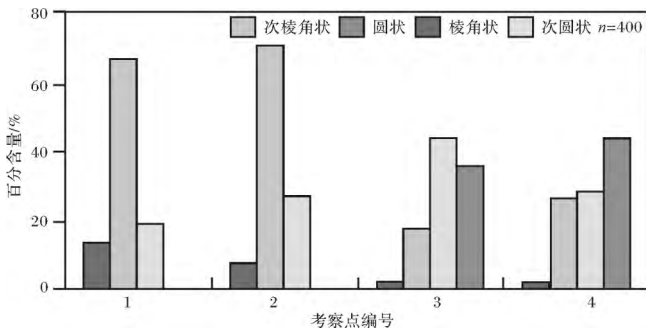


图 5 永定河各圆度级别砾石含量频率图

Fig.5 Gravel content frequency of different roundness classes in Yongding River

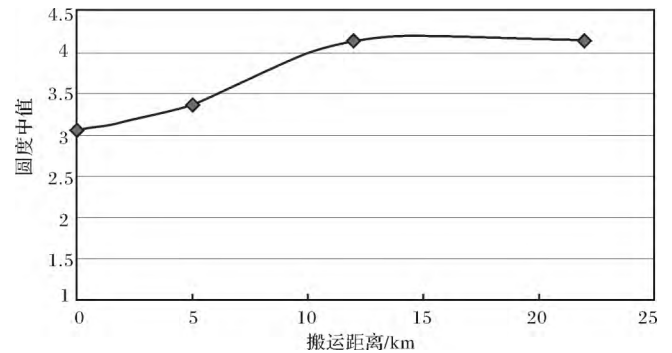


图 6 永定河砾石磨圆度与搬运距离关系图

Fig.6 Relation of gravel roundness vs. transport distance in Yongding River

22 km 处 砾石的平均粒径分别为 27.07 cm、18.6 cm 和 13.4 cm(图 7)。河流出口处砾石的最大粒径为 70 cm,距河流出口 22 km 处砾石的最大粒径仅为 32 cm。河流上游水流流速快,河流的搬运能力强,能够搬运粒度较大的颗粒,向下游方向水流流速降低,搬运能力下降,只能搬运粒度较小的颗粒。

3.2 碓臼峪地区砾石磨圆度特征

碓臼峪地区砾石的主要成分为岩浆岩,由河流出口(考察点 1)到考察点 2,再到考察点 3 砾石的磨圆度迅速变好。河流出口处砾石磨圆很差,10%的砾石呈尖棱角状,棱角状砾石占 34%。考察点 2 磨圆度变好,尖棱角状砾石消失,棱角状砾石所占的比例下降为 18%。考察点 3 棱角状砾石含量进一步下降,仅占 6%,次圆、圆状砾石含量升高(图 8)。

考察点 1、考察点 2、考察点 3 都处于河流的初期搬运阶段,不仅磨圆快(图 9),砾石的平均粒径也明

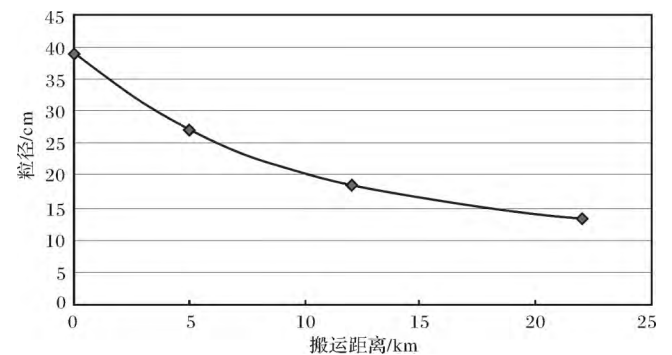


图 7 永定河砾石平均粒径与搬运距离关系图

Fig.7 Relation of average size of gravel vs. transport distance in Yongding River

显降低。河流出口处砾石的平均粒径为 4.88 cm,距出口 2 km 处砾石的平均粒径为 4.24 cm,距出口 4 km 处砾石的平均粒径为 3.35 cm(图 10)。

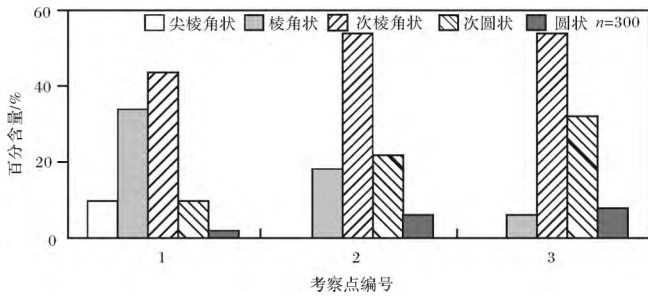


图 8 碓臼峪各圆度级别砾石含量频率图

Fig.8 Gravel content frequency of different roundness classes in Duijiuyu River

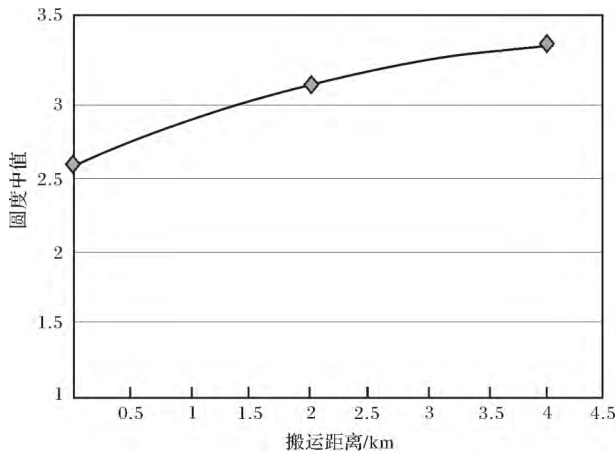


图 9 碓臼峪砾石磨圆度与搬运距离关系图

Fig.9 Relation of gravel roundness vs. transport distance in Duijiuyu River

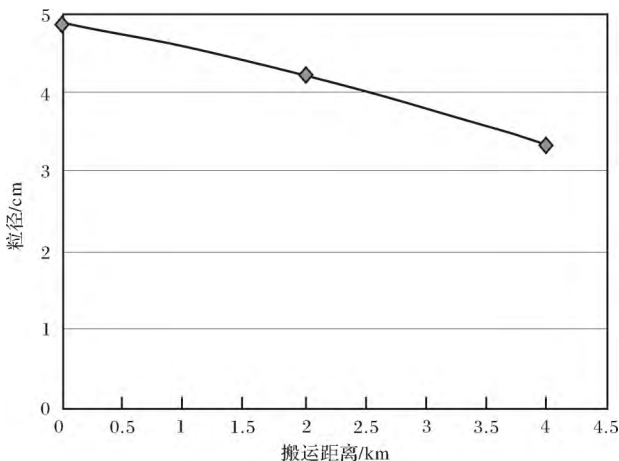


图 10 碓臼峪砾石平均粒径与搬运距离关系图

Fig.10 Relation of average gravel size vs. transport distance in Duijiuyu River

3.3 砾石磨圆度与搬运距离定量关系

磨圆度众数是含量最多的砾石磨圆度,对于研究

磨圆度混杂堆积的砾石非常有效。对永定河、碓臼峪、滦河、大石河,利用磨圆度众数建立磨圆度与搬运距离的定量关系(表 2)。由砾石磨圆度与搬运距离之间的定量关系(表 2、图 11)可以看出,研究区岩浆岩砾石由棱角状变为次棱角状一般需要搬运 3~6 km,由次棱角状变为次圆状一般要搬运 12~21 km,圆状砾石大量出现至少要搬运 22~31 km。

在地质背景相同的条件下,磨圆度与搬运距离存在着定量关系,这个定量关系随着区域的改变而改变,但是在区域内具有普遍的适用性。磨圆度随搬运距离的变化规律及定量关系,在古环境分析中可以用来判断物源方向,确定沉积物的搬运距离以及物源的远近。垂向上砾石磨圆度的变化,可以用来分析河流的演化历史,判断盆地的大小变化。

4 磨圆度影响因素分析

4.1 搬运距离

搬运距离是影响砾石磨圆度的重要因素,上述的分析已表明研究区岩浆岩砾石的磨圆度与搬运距离之间存在明显的定量关系。砾石之所以呈现随搬运距离增大磨圆度变好的规律,是由于砾石的搬运过程是不断遭受磨蚀的过程。研究区岩浆岩砾石主要来源于母岩的机械破碎,最初形成的砾石棱角较尖锐,圆度很低,这些棱角状、次棱角状的砾石容易被磨蚀,在搬运的初期阶段被快速磨圆向次圆状、圆状转化,而圆状砾石不易磨蚀达到极圆状。永定河砾石的磨圆度在最初搬运的 12 km 内变化最快,棱角状砾石含量降低,次棱角状砾石迅速磨圆,含量快速下降,同时伴随着次圆状砾石的快速增加,圆状砾石开始出现并不断增加(图 12)。搬运 12 km 以后,砾石的磨圆缓慢,棱角状、次棱角状、次圆状、圆状砾石的含量随搬运距离的增加变化缓慢,并逐渐趋于稳定。因此,磨圆度随搬运距离的增加而变好,搬运的初期阶段磨圆快,而后逐渐缓慢下来,最终磨圆度趋于稳定。

砾石在河流中的搬运方式以滚动搬运为主,滚动磨蚀是造成砾石圆度变好的一个重要因素。将棱角状砾石简化为正方体来分析其在搬运过程中所受的磨蚀作用,随着磨蚀作用的进行,棱边数逐渐增加,最终趋向于球。在滚动搬运过程中,砾石受到重力 G 、支撑力 N 、浮力 $F_{浮}$ 、滚动摩擦力 f 、流水对砾石的拖拽力 F 的共同作用,砾石滚动需要克服滚动阻力矩 $(G - F_{浮}) \times e$ 的阻碍作用(图 13)。随着砾石磨圆度增加,棱数增加,力臂 e 减小,搬运所需的拖拽力减小,磨蚀

表 2 岩浆岩砾石磨圆度与搬运距离定量关系表

Table 2 Quantitative relation of magmatic gravel roundness with transport distance

永定河	搬运距离/km	0	5	12	22
	磨圆度级别	次棱角状	次棱角状	次圆状	次圆—圆状
碓臼峪	搬运距离/km	0	3	5	
	磨圆度级别	棱角状—次棱角状	次棱角状	次棱角状—次圆状	
滦河	搬运距离/km	0	15	21	31
	磨圆度级别	次棱角状	次棱角—次圆状	次圆状	次圆—圆状
大石河	搬运距离/km	0	7		
	磨圆度级别	次棱角状—次圆状	次圆状		

作用减弱,磨圆速度降低。因此 棱角状、次棱角状砾石容易被磨蚀,在搬运的初期阶段被快速磨圆向次圆状、圆状转化,而圆状砾石不易磨蚀达到极圆状。

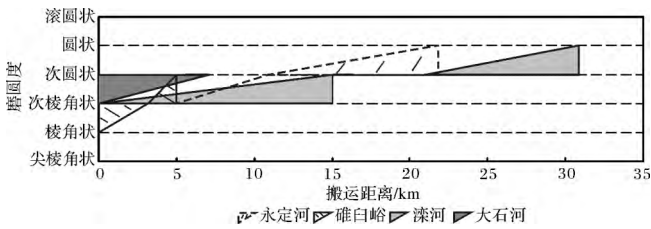


图 11 砾石圆度众数与搬运距离关系图

Fig.11 Relation of gravel roundness mode with transport distance

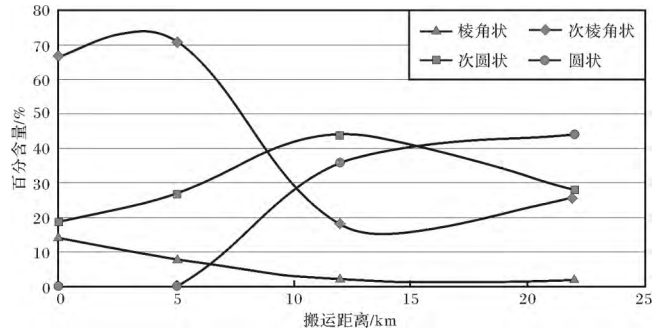
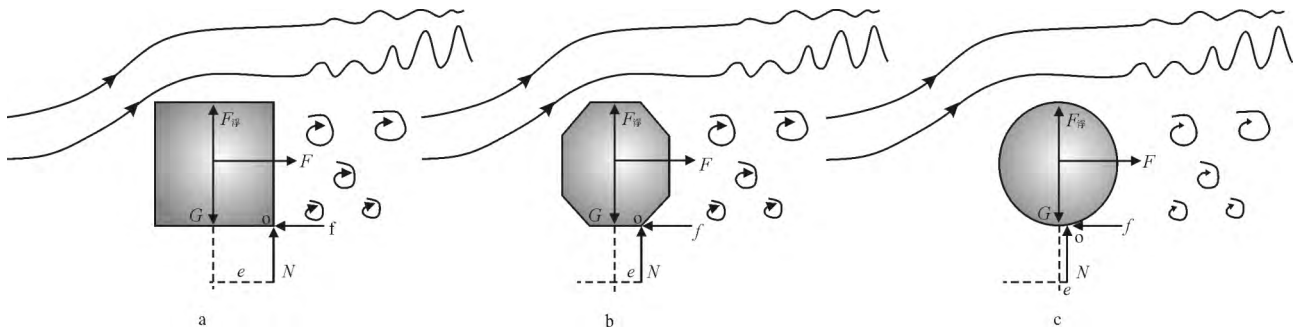


图 12 永定河各圆度级别砾石含量与搬运距离关系图

Fig.12 Relation of gravel content of different roundness classes with transport distance in Yongding River



O 为滚动时的瞬时心 e 为 G 和 $F_{浮}$ 的力臂,由 a 到 b 到 c,力臂依次减小

图 13 砾石磨圆过程示意图

Fig.13 The schematic diagram of gravel rounding process

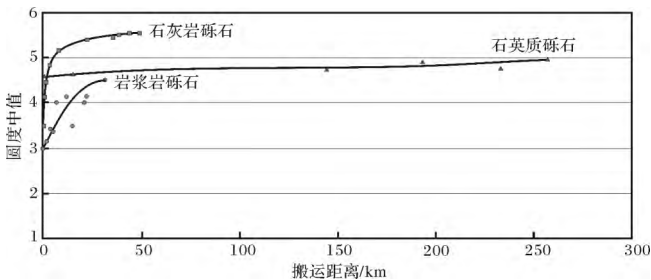


图 14 不同母岩成分砾石磨圆度与搬运距离关系图

(据 Edmund D. Sneed (1958) Plumley (1948) 修改)

Fig.14 Relation of roundness of gravel with different original compositions with transport distance

4.2 母岩成分

母岩成分决定了其形成砾石的硬度、耐磨性的大小,不同母岩成分的砾石磨圆速度差别很大。对研究区四条河流砾石的磨圆特征分析表明,四条河流的岩浆岩砾石均在最初搬运的 30 km 内迅速圆化,圆度中值曲线斜率中等(图 14)。石英质砾石磨圆速度非常缓慢,科罗拉多河石英质砾石在搬运 250 km 的距离内,磨圆度变化不大^[21]。石灰岩砾石磨圆速度快,南达科他州石灰岩砾石在最初搬运的 10 km 内迅速磨圆^[12],圆度中值曲线斜率最大。因此,母岩成分对砾石磨圆特征具有重要影响,岩浆岩的耐磨性介于石英

和石灰岩之间,磨圆速度比石英快,比石灰岩慢。

4.3 粒度

砾石磨圆快慢受粒度大小的影响显著,相同母岩成分的砾石搬运相同的距离时,粗粒砾石比细粒砾石磨圆快。研究区永定河、滦河的砾石成分都主要为岩浆岩,河流出口处砾石的磨圆度非常相近,圆度中值分别为3.05和3,但是在最初搬运的22 km范围内,永定河砾石磨圆度明显比滦河高,磨圆速度快(图15)。这种磨圆速度的差异主要是受粒度大小影响产生的。永定河在出山口(考察点1)、考察点2、考察点3、考察点4砾石的平均粒径分别为38.85 cm、27.07 cm、18.6 cm和13.4 cm,滦河在考察点1、考察点2、考察点3、考察点4砾石的平均粒径分别为9.5 cm、7 cm、4 cm和2.5 cm,永定河砾石粒度明显大于滦河。砾石所受的摩擦力与正应力呈正比,粗粒砾石所受的磨擦大,搬运相同的距离时,粗粒砾石磨蚀严重,磨圆速度快。

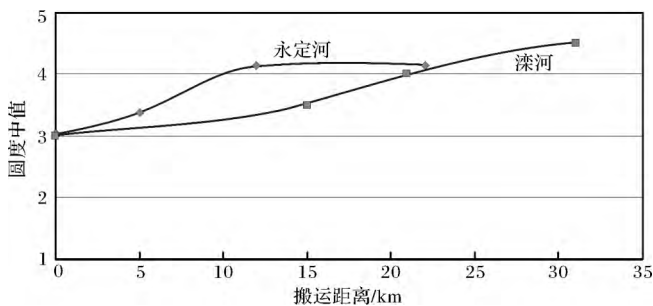


图15 不同粒度砾石磨圆度与搬运距离关系图

Fig.15 Relation of roundness of gravel with different sizes with transport distance

4.4 破碎

砾石在搬运过程中除因磨蚀作用磨圆度不断升高外,还由于破碎作用降低磨圆度,使部分砾石呈现与搬运距离不协调的磨圆度。野外考察发现永定河在距出山口22 km处(考察点4),可见发生机械破碎的砾石,砾石具有明显的破裂面(图4b)。破碎作用使砾石的磨圆度明显变差,与周围砾石的磨圆度差异明显。颗粒之间的碰撞是造成砾石发生破碎的重要原因,脆性大以及发育溶蚀裂隙的砾石受颗粒碰撞时容易发生破碎。

5 结论

(1) 对研究区四条河流砾石的磨圆特征研究表明,岩浆岩砾石的磨圆度随着搬运距离的增大而变好,在搬运的初期变化最快,而后逐渐缓慢下来,最终

磨圆度趋于稳定。磨圆度变化的同时伴随着机械分异作用,砾石的粒度逐渐减小。

(2) 研究区岩浆岩砾石磨圆度与搬运距离的定量关系研究表明,岩浆岩砾石由棱角状变为次棱角状一般需要搬运3~6 km,由次棱角状变为次圆状一般要搬运12~21 km,圆状砾石大量出现至少要搬运22~31 km。

(3) 砾石的磨圆度受搬运距离、母岩成分、粒度和破碎作用的影响。砾石的搬运过程是不断遭受磨蚀的过程,棱角状、次棱角状砾石容易被磨蚀,在搬运的初期阶段被快速磨圆向次圆状、圆状转化,而圆状砾石不易磨蚀达到极圆状。岩浆岩砾石磨圆速度比石英快,比石灰岩慢;相同母岩成分的砾石搬运相同的距离时,粗粒砾石比细粒砾石磨圆快。破碎作用则会降低砾石的磨圆度,使部分砾石呈现出与搬运距离不协调的磨圆特征。

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Geological Significance of Magmatic Gravel Roundness

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Abstract: The rise of quantitative geology promotes the rapid development of earth science, while the study on the quantitative relation between gravel roundness and transport distance has not made obvious progress at home and abroad for a long time. The study on rounding laws and influencing factors of gravels has very important significance to the research of sedimentary environment, provenance analysis and paleogeography recovery in geological history.

Four rivers were investigated in this study including Yongding River, Duijiuyu River, Luanhe River and Dashi River. Luanhe River and Dashi River are in Hebei province. Yongding River and Duijiuyu River that are in Beijing are studied in detail. The four rivers all lie on the east of North China platform around the Bohai bay. They have the similar geological backgrounds, climate conditions, and flood seasons. And their parent rocks are all magmatic rocks. All those factors cause the similar change law of roundness.

Field investigation is the base of this study. Field investigation starts from the mountain-pass of each river where river flows out of the mountain. Investigation points were set from the mountain-pass to the downstream in each river. And 100 samples were taken at each point, described and statistically analyzed in detail. Based on the above study, the relation between roundness and transport distance is established, and influencing factors of gravel roundness are defined.

Roundness class is defined by visual observation, according to the roundness classification standard and the figure of roundness shapes and classes from Powers. The roundness of gravel is divided into sharply angular, angular, subangular, subrounded, rounded, and well rounded. To minish the subjective errors from person, five people are needed to classify the roundness of every sample. When four or five people have the same result, then the result is eligible. This method can avoid the subjective errors, and make the results authentic and credible.

Roundness of magmatic gravel becomes better with the increase of transport distance. It varies fast at the early stage of transport, then slower, and stable at the final. The particle size decreases gradually with the increase of the transport distance. In the upstream the flow is of high capability of transportation and can carry coarse grain because of the high flow velocity. To the downstream the flow is of low capability of transportation and can only carry fine grain because of the low flow velocity.

Roundness mode is the highest proportion roundness class in each investigation point. It is a very useful parameter in the study of mixed accumulated gravels that are of different roundnesses. In this study the quantitative relation of roundness and transport distance is established based on the study of Yongding River, Duijiuyu River, Luanhe River and Dashi River. Magmatic gravels usually need to be carried 3~6 km from angular to subangular. They need to be carried 12~21 km from subangular to subrounded, and most of rounded gravels need to be carried at least 22~31 km. The roundness of gravel has a quantitative relation with the transport distance, which is universally applicable in the same geological background. The rounding law and the quantitative relation are significant in the source direction analysis and transport distance prediction. The change law of gravel roundness in the vertical profile can be used to analyze the evolution history of river and the size of basin.

Gravel roundness is affected by transport distance, original composition, particle size and breaking. Magmatic gravels come from the mechanical disruption of source rock. The gravels are mainly sharply angular or angular without being rounded when they first form. They are subject to abrasion in the whole process of transport. Angular and subangular gravels are fast rounded to subrounded or rounded in the early stage of transport because of poor abrasion resistance, while it is very difficult from rounded to well rounded. The component of source rock affects the hardness and the abrasive resistance of gravel. The rounding rate of gravel with different original component is greatly different. The abrasion resistance of magmatic rocks is much higher than limestone, and is much lower than quartz. Based on the study of the four rivers, we find that the magmatic gravels are fast rounded within 30 km in the early stage of transport. The slope of the middle roundness curve is medium. The rounding of quartzose gravel is very slow. It has no great change after being carried for 250 km in Colorado River. The rounding of limestone gravel is the fastest. They are fast rounded after being carried 10 km in South Dakota. And the slope of the middle roundness curve of limestone gravel is the highest. So the rounding speed of magmatic gravel is faster than quartz and is slower than limestone. When the gravels have the same original composition and transport distance, coarse gravel is rounded faster than fine-grained gravel. The breaking lowers roundness, and makes the roundness of a few gravels inconsistent with the distance of transport. Gravels are subject to mechanical breaking in the process of transport. The collision between the gravels is the main reason causing the breaking. And the gravels which are of high brittleness or have dissolved fractures are easy to break in the process of transport.

Key words: roundness; transport distance; quantitative relation; gravel; influencing factors