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青藏高原下大武地区炭屑浓度所反映的环境演变与人类活动

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摘　要：青藏高原主体海拔在 4000 m 以上，4000 m 以上的人类活动与环境演变之间的关系研究很薄弱。本文通过对下大武遗址各粒级炭屑浓度的分析，试探讨其与人类活动和环境的关系。研究发现：（1）全新世大暖期时，气候温暖湿润，适宜生存。在对应的历史文化层中各粒级炭屑浓度出现高值区，说明此时下大武地区人类活动频繁，地方火和区域火频繁出现。（2）全新世中期，季风减弱，气候向冷干转变，植被退化，炭屑浓度普遍处于稳定的低值区，反映当时下大武地区人类活动的强度与范围缩小。（3）全新世晚期以来，3700—1800 cal.a BP 炭屑浓度出现明显高值区，指示高原区域火的发生；1800 cal.a BP 以来各粒级炭屑浓度波动频繁，粗粒炭屑浓度的波幅最大，指示下大武地区人类活动增强。

关键词：炭屑；环境；人类活动；下大武；青藏高原

Charcoal concentration reflect of environment change and human activities in Xiadawu Relic, Qinghai-Tibet Plateau

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Abstract: ***Background, aim, and scope*** Fire as an unique and important ecological factor, both in past and present, has a significant impact on the environment. Charcoal is the direct product of fire and vegetation, it's related to both climatic changes and human activities. Therefore, charcoal not only can be used to reconstruct ancient fire event, but also indicate the strength of human activities. Xiadawu site which is located on Tibetan Plateau with 4000 meters elevation has been excavated in 2007. However, the research on the relationship between the ancient climate and human activities is rarely. In this paper, we analyzed the concentration of each granular level of charcoal in Xiadawu site, and attempted to explore its relationship with human activities and the environment changes. ***Materials and methods*** Soil samples were collected for determination of charcoal. Heavy liquid flotation was used to isolate the charcoal, and pollen circuit method was used to count the charcoal which was separated from soil samples. According to the long axis of charcoal, charcoal samples were separated for grading: <50 μm (fines), 50—125 μm (medium grain) and >125 μm (coarse). Coarse-grained

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charcoal indicated local fire events, and fine-grained charcoal indicated region fire events with large area. Charcoal concentration reflected the intensity and frequency of the fire. Four charcoal samples were collected for radiocarbon dating. ***Results*** The results showed that: (1) The average concentration values of each grade showed obvious peak value during the Holocene Optimum Period and the Medieval Warm Period, fluctuated frequently. (2) The average concentration of fine-grained charcoal took a great proportion in the total concentration of charcoal, and the average concentration of coarse-grained charcoal was lowest. (3) In the whole profile, the average concentration of fine-grained charcoal reached maximum during 2200 cal.a BP. ***Discussion*** (1) During the Holocene Optimum Period, the climate was warm and wet, it was suitable for survival. The high concentration of each granular level of charcoal occured in the corresponding historical cultural layer, which indicated that human activity was frequent in Xiadawu at that moment, local and regional fire happened frequently. (2) During the mid-holocene, the climate conditions changed drier and colder, and vegetation began to degenerate with the weaking summer monsoon, and the concentration of charcoal was generally lay in the stable low-value zone, indicating that human activity intensity and range have greatly shrunk in Xiadawu at that moment. (3) Since late Holocene, human had relatively continuous and stable activities at the high elevation region above 4000 m a.s.l. The peak concentrations of charcoal were more closely related to human activities. ***Conclusions*** Changes in the average concentration of charcoal in Xiadawu region not only related to the natural environment, but also closely related to human activities. The average concentration values of each grade showed obvious peak value during the Holocene Optimum Period and the Medieval Warm Period, fluctuated frequently. (1) During the Holocene Optimum Period (7400—6200 cal.a BP), the climate was warm and wet, it was suitable for survival. The high concentration of each granular level of charcoal occured in the corresponding historical cultural layer, which indicated that human activity was frequent in Xiadawu at that moment, and local and regional fire event happened frequently. (2) During the mid-Holocene (6200—3700 cal.a BP), the climate conditions changed drier and colder, and vegetation began to degenerate with the weaking summer monsoon, and the concentration of charcoal was generally lay in the stable low-value zone, indicating that human activity intensity and range had greatly shrunk in Xiadawu at that moment. (3) Since late Holocene: 3700 cal.a BP—), this period can be divided into two stages: 3700—1800 cal.a BP and 1800 cal.a BP—. The average concentration of charcoal was gradually increasing, reached a peak in 2600 cal.a BP. The average concentration of fine-grained charcoal reached an unprecedented high value, indicating that the trend of the regional fire event enhanced. Meanwhile the average concentration of medium-grained and coarse-grained only reached a small peak, implying that during this period the regional in large scale area fire activity was obvious, but low occurring probability of the local fire. During 3000—1800 cal.a BP, relatively continuous and stable human activities at the high elevation region above 4000 m a.s.l implied permanent colony on high elevation. The peak concentrations of charcoal were more closely related to human activities. During 1800—750 cal.a BP, the average concentration of medium-grained and coarse-grained charcoal fell to 0 grain·g^{-1}, and the average concentration of fine-grained was still relatively high, indicating that during this period there was little local fire while the regional fire happened frequently. Near 630 cal.a BP, the average concentration of each grade of charcoal reached another peak, which maybe associated with human activity intensity. ***Recommendations and perspectives*** Changes in concentration index of charcoal during Holocene have a good correspondence with previous studies on the surrounding area. It indicates that charcoal concentration of different grain-size is a sensitive proxy to reconstruct the plaeocliamte change and human history of fire using. However, in this paper, we only use charcoal concentration without any other environmental index, which can not support our story strongly. Thus, it is necessary to use other environmental indicators for further verification.

Key words: charcoal; environment evolution; human activities; Xiadawu; Qinghai-Tibet Plateau

火作为一种独特且重要的生态环境因子，无论在过去还是现在，都对环境产生着重要影响。火演化记录不仅是研究植被与生态的重要依据，也是反映气候变化的重要指标之一（李小强等，2006）。炭屑是植物有机体不完全燃烧的产物，常被风和流水从产生地带到沉积地保存下来（曹艳峰等，2007），作为火与植被作用的直接产物，是重建古森林火灾历史与古植被的首要证据之一（Patterson et al，1987；MacDonald et al，1991；Millspaugh and Whitlock，1995）。炭屑的产生不仅与自然火的发生有关，还与人类活动密切相关。炭屑含量的变化不仅可以指示气候变化，而且可以反映研究区人口数量和人类活动强度的变化（Figueiral and Mosbrugger，2000），因此，炭屑不仅可以用来恢复古火灾，还可以指示人类活动的强弱（郭小丽等，2011），炭屑研究对探讨古野火、气候与人类活动之间相互作用机制具有重要意义。目前对古环境中炭屑的研究主要集中在以下几个方面：（1）炭屑的提取过程；（2）炭屑的种属鉴定，通过对炭屑最大长度（L）和最大宽度（W）比值的分析，能够初步分析草本植物和木本植物的差别：草本的 L/W 最大，灌木和乔木次之，阔叶类植物叶片炭屑的 L/W 最小（张健平和吕厚远，2006）；（3）炭屑统计：炭屑浓度法（曹艳峰等，2007）、面积浓度法（李小强等，2006；吴立等，2008）和沉积通量法（储国强，2001；黄翡，2002；罗运利等，2006）；（4）炭屑在古环境和人类活动研究中的应用（储国强，2001；李宜垠等，2009；李冰等，2012；谭志海等，2014）。干旱 - 半干旱区火事件时空分布特征易受气候变化和人类土地利用方式变化的影响（Huber et al，2004），在干旱的气候条件下，人类活动更能加速火的发生频率和强度（姜莹莹等，2015）。虽然下大武遗址早在 2007 年就已经被发掘，但关于下大武地区的古气候及其人类活动研究还很少，本文通过分析下大武 3 号（XDW3）剖面各粒级炭屑平均浓度的变化，试探讨炭屑颗粒大小与人类活动和气候环境变化的关系。

1　研究地点和土壤剖面

下大武 3 号（图 1）（35°0′6.9″N，99°15′37.7″E）位于果洛州下大武乡，海拔 3988 m，典型的高原亚寒带半湿润气候，年平均气温在 −3.8℃以下，年降水量在 420—560 mm，降水多集中在春夏季节，年日照时数在 2300—2500 h，无绝对的霜期，光、水资源丰富。XDW3 号剖面位于清水河西岸的台地上，台地高约 10 m，台地上目前仅保留长 55 步、宽 15 步的土堆，上置一个水泥碑——小清水细石器遗址，其他均已破坏，土堆上分布有较多的石片，崖壁上也出现较多的石片、石块。XDW3# 剖面（图 2）属于自然断面层，呈东西向，高约 1.6 m，右侧有一文革时期挖的大洞。0—40 cm 深度为松软的表土层，富含高等植物的根茎；40—100 cm 处为文化层，其中 40—90 cm 为粘土质浅色文化层，90—100 cm 处为深色文化层，土壤颜色黑；100 cm 以下为黄土层，本文取土样至 130 cm 处。

2　研究方法和断代依据

清理剖面 0—20 cm 处的地表土，从 20 cm 处开始每 2 cm 取一个样品，共采集样品 55 个，将采集的样品在室内自然风干后，进行炭屑的测定。炭屑测定采用重液浮选法将炭屑分离出来，并采用花粉流程法对分离出的炭屑进行统计。分析流程如下：1）称重：从采集的样品中取土样 10 g，置于 250 mL 的烧杯中，然后在每个样品中加入一粒石松孢子；2）加盐酸：取浓度为 10% 的盐酸 150—200 mL 入烧杯中；3）加水中和：向加入盐酸的样品中加水，静置 7 个小时以上，此步骤至少重复 4 遍；4）抽取上清液，离心，直到玻璃杯中的样品全部冲洗干净为止；5）重液配置及离心；6）制片；7）上机。

炭屑颗粒大小可以反映火源的远近，区分不同粒级的炭屑，并对其进行统计分析，有助于判断炭屑来源，进而探讨火发生的特征和地区（Clark，1988；Ohlson and Tryterud，2000）。根据炭屑最长轴将其分为 3 个等级：<50 μm（细粒）、50—125 μm（中粒）和 >125 μm（粗颗粒）。粗粒炭屑（>125 μm）代表地方性火活动事件，细粒炭屑则主要反映区域性火活动事件（李小强等，2006）。利用粗粒炭屑、中粒炭屑和细粒炭屑的比值同样可以表达炭屑沉积地与火灾源区的距离远近，比值越大，火灾源区越近，反之，火灾源区越远（孙湘君等，2000）。根据 Ward 和 Hardy 的研究知道，随着火灾频率的增加，炭屑颗粒也会相应增大（Ward and Hardy，1991）。炭屑浓度变化指示历史野火强度和频率变化（Huang et al，2006）。炭屑浓度高指示火活动强烈，反之火活动

微弱。气候越干旱，火灾发生的可能性越大，频率越高。另外，在对全新世和近 2000 年的研究中发现，火的发生往往与人类活动密切相关（郭小丽等，2011）。

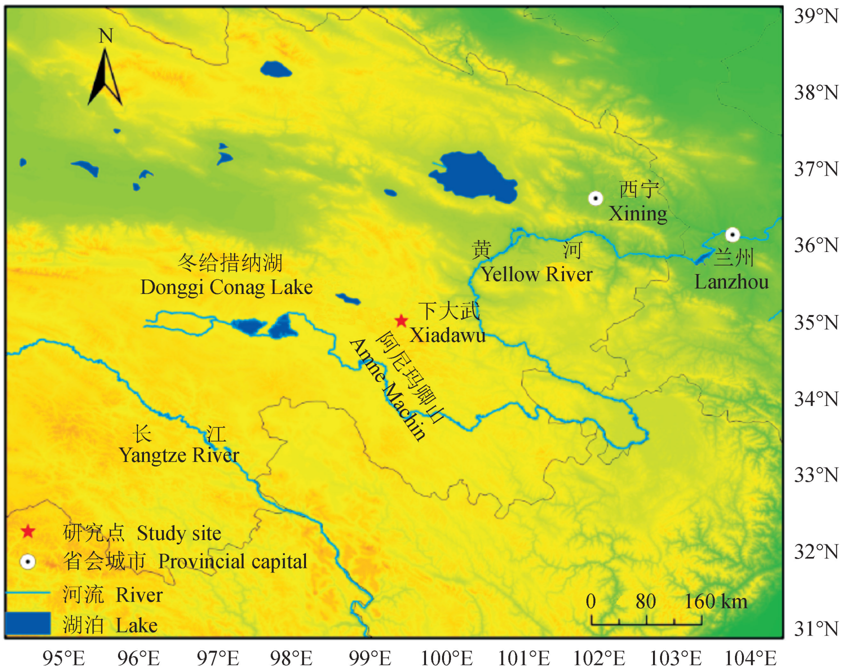

图 1　下大武（XDW）地理位置
Fig.1　The location of XDW

炭屑浓度换算方法为：

$$W=A/B\times C/G \tag{1}$$

其中：W 为炭屑浓度（粒 / 克），A 为统计的炭屑粒数（粒），B 为统计的外加石松孢子数（粒），C 为样品中的外加石松孢子数（27600 粒），G 为所取土样的重量（10 g）。

选取剖面不同深度采集的 4 个炭屑样品送交北京大学第四纪年代实验室进行 ^{14}C 年代测定，并建立年代—深度关系（图 2）（相关年代有专文论述）。不同深度采用不同年代—深度计算方法：0—58 cm 深度采用 $Y=14.93X$；57—85 cm 深度采用 $Y=191.96X-1009$；85—126 cm 深度采用 $Y=4284e^{0.0043X}$。

3　结果与分析

3.1　炭屑总浓度变化特征

从整个剖面炭屑总浓度的变化特征（图 3）来看，炭屑浓度平均值为 21756 粒 / 克，其中最小值出现在 750 cal.a BP 时，为 1813 粒 / 克，平均浓度最大值出现在 2200 cal.a BP 时，为 76594 粒 / 克。炭屑平均浓度变化出现三个峰值区，一级峰值区出现在 2200 cal.a BP，在 2600 cal.a BP 呈现逐渐增加趋势，到 2200 cal.a BP 达到最大值，期间炭屑平均浓度变化范围为 13887—76594 粒 / 克，波动幅度为 62307 粒 / 克，次一级的两个峰值区分别出现在 6500 cal.a BP 和 630 cal.a BP，6200—2600 cal.a BP 炭屑平均浓度波动平稳，保持在 11817 粒 / 克 左右。

3.2　<50 μm 炭屑平均浓度变化特征

从整个剖面 <50 μm 炭屑平均浓度的变化特征（图 3）来看，炭屑浓度平均值为 10673 粒 / 克，最小值出现在 750 cal.a BP，约为 1633 粒 / 克，最大值出现在 2600 cal.a BP，为 75936 粒 / 克。与炭屑总浓度变化曲线大致相同，<50 μm 的炭屑浓度变化亦出现三个峰值区，在 7300—6200 cal.a BP 期间炭屑平均浓度值波动剧烈，但波幅不大；2600—1800 cal.a BP 炭屑平均浓度值总体波动幅度较大，约为 62871 粒 / 克；750 cal.a BP 炭屑平均浓度波动频繁。6200—2600 cal.a BP 波动平稳，保持在 11657 粒 / 克左右；1800—750 cal.a BP 炭屑平均浓度值平稳下滑。

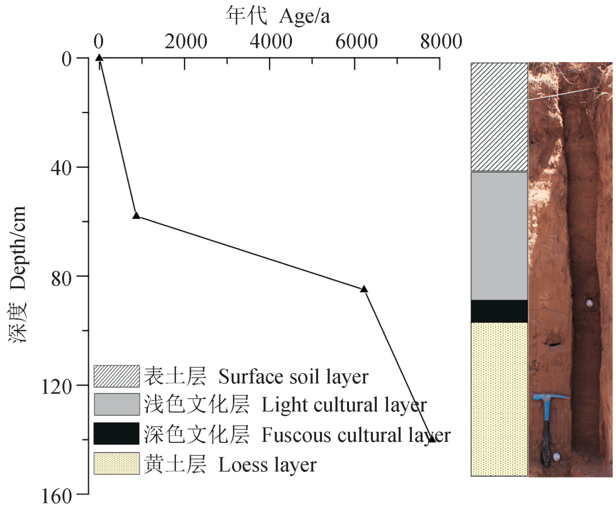

图 2　土壤剖面及深度—年代关系图

Fig.2　The profile of XDW3 and strata depth-age relation of XDW3

3.3　50—125 μm 炭屑平均浓度变化特征

从整个剖面 50—125 μm 的炭屑浓度值变化特征（图 3）来看，其炭屑浓度平均值明显低于＜50 μm 的炭屑浓度平均值，为 316 粒 / 克，炭屑平均浓度最大值出现在 6500 cal.a BP，最小值降至 0 粒 / 克，多次出现。6590—6530 cal.a BP 炭屑平均浓度变幅较大，由 69 粒 / 克 迅速上升为 1866 粒 / 克，波动幅度为 1796 粒 / 克。与＜50 μm 的炭屑平均浓度相比，50—125 μm 的炭屑平均浓度在 2600 cal.a BP 左右仅出现一个小峰值。

3.4　>125 μm 的炭屑平均浓度变化特征

从整个剖面炭屑平均浓度的变化特征（图 3）来看，>125 μm 炭屑平均浓度值最低，波动幅度最小。其炭屑浓度平均值为 97.13 粒 / 克，最小值降至为 0 粒 / 克，在剖面中多次出现。炭屑平均浓度出现三个峰值区，630 cal.a BP 出现最大峰值，炭屑平均浓度值为 622 粒 / 克 ，6500 cal.a BP 为次级峰值区，2200 cal.a BP 左右为三级峰值区，炭屑平均浓度值在 7300—6200 cal.a BP 期间和 750 cal.a BP 至今波动频繁。

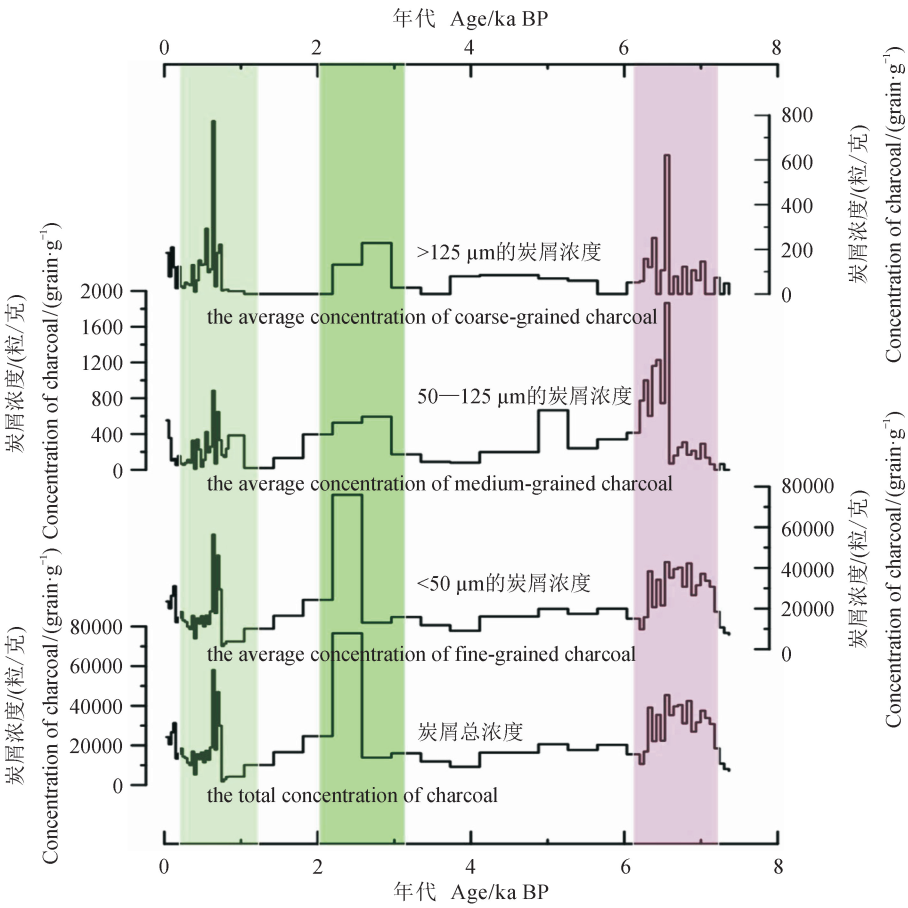

图 3　XDW3 剖面不同粒级的炭屑浓度变化

Fig.3　Change of concentration in different sizefraction of charcoal in XDW3

4 讨论

分析整个剖面炭屑浓度变化特征曲线，可以发现：<50 μm 的炭屑浓度平均值在整个剖面炭屑总浓度中所占比重最大，平均值为 106733 粒 / 克，而 50—125 μm 和 >125 μm 粒级的炭屑平均浓度所占比重较小；>125 μm 的炭屑浓度波动较大，出现多次峰值，<50 μm 的炭屑平均浓度也有明显峰值，50—125 μm 的炭屑浓度波动较为稳定；全新世大暖期和中世纪暖期，各粒级炭屑浓度波动频繁，出现峰值。分析结果表明：

（1）7400—6200 cal.a BP：处于全新世最为温湿的阶段，炭屑浓度比较高，中、粗粒级炭屑平均浓度值波动较细粒级的炭屑明显，在 6500 cal.a BP 炭屑浓度值均达到此阶段的最大值，明显高出平均值，在深度上对应土壤剖面中 90—100 cm 处的文化层，说明当时下大武地区受人类活动的影响发生地方性火灾。同时，<50 μm 炭屑平均浓度值所占比重高，说明火灾不是局部性的而是区域性的，推断当时下大武及其周边地区都有火灾的发生。

（2）6200—3700 cal.a BP：在距今 5700 年左右中国西部地区进入冰进期（水涛，2001），在 6200 cal.a BP 和 4000 cal.a BP 都有冷事件发生，其中 4000 cal.a BP 降温事件规模较大（侯光良和方修琦，2012），鄂崇毅等在对中亚则克台黄土剖面研究中发现，中全新世的 6 ka 和 4 ka 分别出现粘粒组分突然减少事件（鄂崇毅等，2014），季风开始衰弱，气候表现出冷暖波动并向冷干转变，植被退化，区域火发生的概率降低，炭屑浓度普遍处在低值区。仅 50—125 μm 炭屑浓度值在 4800 cal.a BP 出现一个小的峰值，此时下大武地区可能有短时间的地方性火灾发生。

（3）3700—1800 cal.a BP：全新世晚期是又一相对干旱的阶段，炭屑平均浓度值呈逐渐增大趋势，各粒级炭屑浓度值在 2600 cal.a BP 均出现峰值，其中 <50 μm 的炭屑平均浓度达到了前所未有的高值，炭屑平均浓度值达到 75936 粒 / 克，区域火的趋势增强；而 50—125 μm 和 >125 μm 的炭屑浓度仅为小峰值区，表明此时下大武地区的区域火明显，而地方火的概率较低。在 3000 cal.a BP 左右人类已经能在 4000 m 以上的高海拔地区长期生存（候光良等，2013），此时炭屑浓度的峰值可能与该时期高原人类的火活动有关。

（4）1800 cal.a BP—：1800—750 cal.a BP 期间，50—125 μm 和 >125 μm 粒级炭屑平均浓度一度降至 0 粒 / 克，<50 μm 的炭屑浓度仍然比较高，说明此时鲜有地方性火灾发生，而有区域火的发生。中世纪暖期以来，炭屑浓度值高于前一时期，且波动频繁，>125 μm 的炭屑浓度的波动最为剧烈，在 630 cal.a BP 时各级炭屑平均浓度均达到峰值，可能与人类活动强度加大有关。

5 结论

（1）全新世大暖期时，气候温暖湿润，适宜生存。古文化兴盛时期各粒级炭屑的平均浓度出现高值区，说明此时下大武地区人类活动频繁，地方火和区域火频繁出现。

（2）全新世中期，气候向冷干转变，植被退化，炭屑浓度普遍处于稳定的低值区，仅有部分小的峰值区，指示地方火或区域火的发生，反映当时下大武地区人类活动的强度与范围缩小。

（3）全新世晚期以来，3700—1800 cal.a BP 细粒炭屑浓度出现明显高值区，指示高原区域火的发生；1800 cal.a BP 以来各粒级炭屑浓度波动频繁，粗粒炭屑浓度的波幅最大，指示下大武地区人类活动增强。

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